SHAPE EVOLUTION

An Algorithmic Method for Conceptual Architectural Design Combining Shape Grammars and Genetic Algorithms

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This project attempts to develop a generic method for supporting the initial (concept design) stages of architectural design by inspiring the architect towards more innovative solutions to design problems. In order to be useful, this tool should embrace the binary nature of architectural design by producing designs that both respond to the designer's stylistic agenda and satisfy the functional requirements of the brief. In Shape Evolution the primary vehicle for aesthetics and style is a shape grammar, created by the designer. Designs generated by the shape grammar are then optimized in terms of their functional performance by a genetic algorithm.

Since their inception in the seventies, shape grammars have been used repeatedly as a tool for historical analysis, showing themselves to be successful descriptors of style (Knight, 1994). More importantly, they are increasingly being used for design generation, defining novel languages of designs. In that capacity, they allow the creation of significantly complicated and elaborate designs with only a limited vocabulary of shapes and few rules. Furthermore, a look at shape grammar applications attests to the great diversity of design languages that they are capable of defining. These characteristics of shape grammars make them ideal for use in a generic design tool geared towards innovation.

Genetic algorithms have been shown to be successful in searching and optimisation problems (Mitchell, 1996); design has often been viewed as either. A particular characteristic of genetic algorithms which makes them appropriate for a generic tool is that they do not require an explicit solution strategy but merely a way to evaluate solutions. A further advantage is that designs can be evaluated for their performance in several areas at once.

The critical interface between the shape grammar and the genetic algorithm is the use of a design's *shape code* (Koutamanis, 2000) as the genotype that the genetic algorithm operates on. In this context, the shape code is a string that encodes the sequence of rule application during the shape grammar driven generation process. Using the shape code directly as the genotype ensures that all the designs produced during the evolutionary process are valid in the language. It also means that the genetic algorithm's operations on the genotype, such as crossover and mutation, alter the selection and sequence of shape grammar rules used for the generation of a design. These can potentially be very meaningful alterations. In addition, the process of embryogenesis is simply a process of parsing the sequence contained in the shape code to produce geometry. Then the designs can be evaluated with respect to their physical attributes.

The example of an apartment building has been chosen to test this method and a simple shape grammar has been developed:

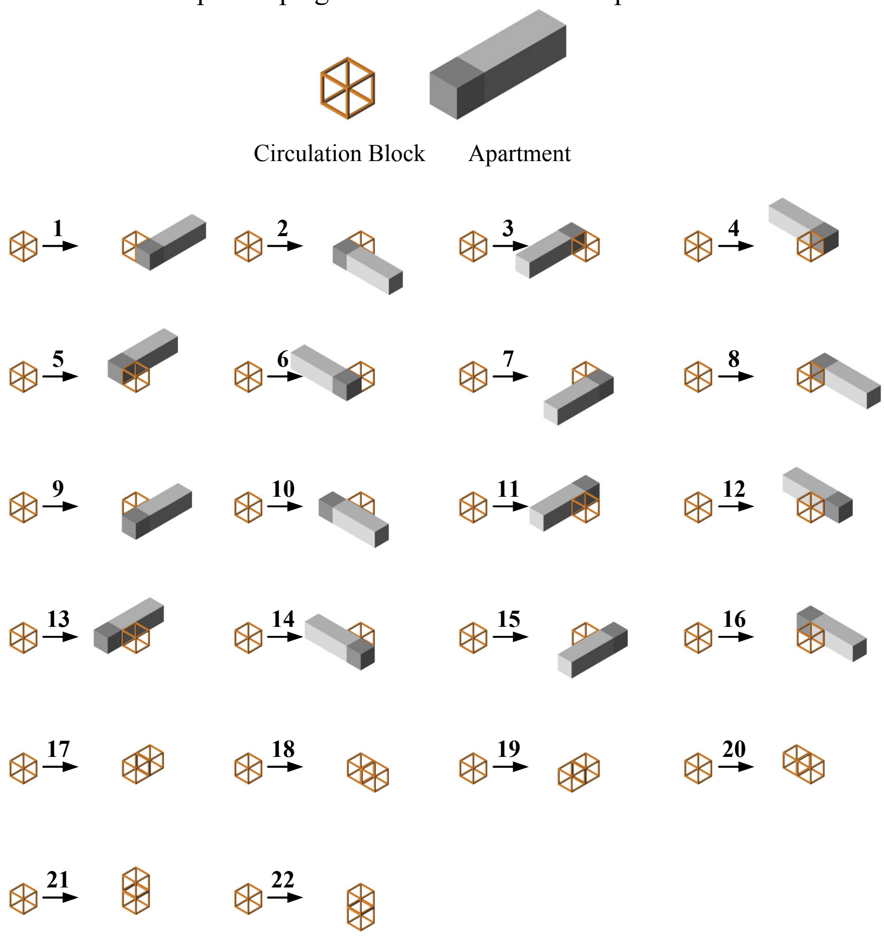

Figure 1. Vocabulary and rules for the apartment building shape grammar

The design language is defined by a minimal shape grammar, consisting of a vocabulary of two shapes (a vertical or horizontal circulation block measuring 4m × 4m × 4m and an apartment measuring 16m × 4m × 4m) and only three basic rules (and their Euclidean transformations).

All rules are addition rules which add shapes to the circulation block, thus ensuring that all circulation is contiguous and that each apartment is adjacent to a circulation block. This is an example design produced using this grammar (the generation process specifically disallows ground floor apartments):

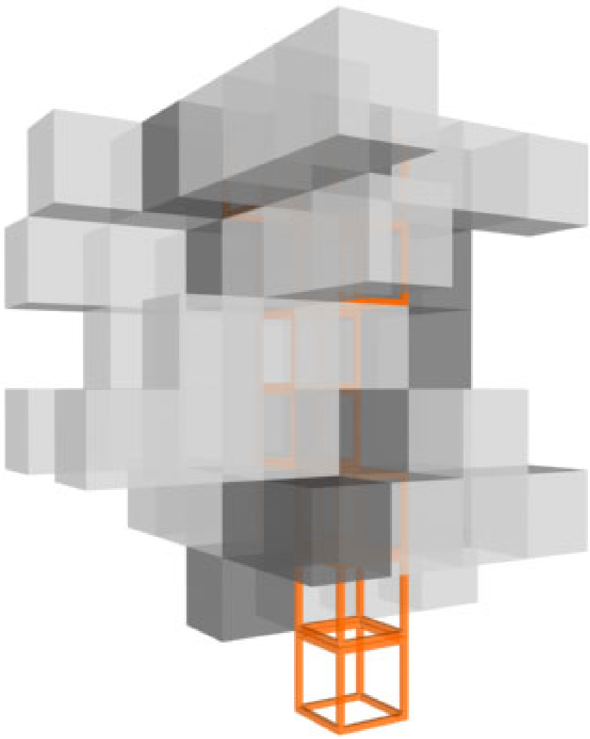

Figure 2. Design with shape code representation
11 21 15 4 6 20 21 5 10 1 21 9 13 21 5 8 14 18 21 15 6 5 17 8

These designs can then be evaluated with respect to volume, height, footprint, density, number of apartments, number of circulation blocks, apartment area to circulation area ratio, apartment aspect, blocked frontages, number of balconies, cost, and any other quantifiable traits which can be calculated from the geometric configuration of the design. Different weightings can shift the focus to a particular trait. The genetic algorithm then proceeds to favour the highest-scoring designs, thus improving the design's fitness over many iterations.

The use of shape evolution as a tool during early design stages is expected to have a number of advantages:

- The high level of separation between input and output means that resulting designs may have unanticipated properties. This has the potential to inspire the users/designers towards innovative solutions.
- The genetic algorithm “weeds out” solutions which are not relevant to the design’s context, defined through the genetic algorithm’s evaluation criteria. This frees up the designer to focus on the more creative tasks.
- Generated designs already conform to the designer’s aesthetic requirements to a large degree, thanks to the use of shape grammars for their generation.
- A large number of designs can be quickly evaluated and the most successful ones presented to the designer.

References

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