Aesthetic-Oriented Generation of Architectonic Objects with the Use of Evolutionary Programming

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Abstract

This aim of this paper is to present an aesthetic oriented evolutionary approach to design. The paper deals with creative design process which is characterized by the variability of design structure. Genotypes of architectonic objects are represented by graphs. Aesthetic evaluation of the objects is based on Biederman’s visual perception model. Phenotypes represent configurations of Biederman’s basic components essential for visual perception. The approach is illustrated by examples of phenotypes preferred by the fitness function with encoded aesthetic evaluation mechanism.

1. Introduction

The process of architecture design involves self-expression of the architect, which results in artistic values added to the designed object. Author's creativity corelates with viewer's aesthetic experiences and it seems necessary to put some dose of human imagination into the project to obtain emotional response. An architectonic object, as any other piece of art, takes part in the dialogue with other artifacts and refers to cultural and historical context. Therefore, the task put before automatic design of architecture is very difficult. At the moment, it is not possible for artificial intelligence to imitate human way of thinking during the design process, and none computer program is equipped with the knowledge about the world that is available for even the least talented architect. However, there is plenty of evidence that objects created by people are not the only ones appreciated by them for high functional and aesthetic values. Products of evolution – living organisms – disregard human culture and do not fit into definition of art, still they are perceived as beautiful and harmonic by people, who themselves are a product of evolution as well. Evolutionary programming gives a chance to imitate to some degree the biological processes in order to obtain optimal solutions.

This paper aims to present a method of aesthetic-oriented generation of architectonic objects prototypes with the use of evolutionary programming. The proposed method is based on Biederman's visual perception model, in which object recognition is assumed to be performed by investigation of components' shape and relation between them. Because aesthetic evaluation of architectonic objects is associated with visual perception, it seems a suitable solution to use human perception model for the purpose of automatic design and automatic assessment of generated models. In our approach, architectonic objects prototypes are generated as configurations of some basic solids. Each prototype has its structural representation in the form of graph, where nodes denote components, while edges describe spatial relations between them. In genetic algorithms considered in this paper all prototypes are represented in two forms: in an encoded form of genotypes and in the decoded form of phenotypes. During the process of evolution, the prototype graphs – genotypes – are modified in the result of mutation and crossover. After each step of evolution a new generation of 3D models (phenotypes) is rendered.

The paper is organized as follows: First, the Recognition-by-Components perception model is explained and phenotypes of architectonic objects are presented as configurations of elementary shapes. Then, the structural representation of objects is proposed in the form of graph, which constitutes genotype for the evolutionary algorithm. Further sections contain the mutation and crossover operators, as well as the selection function, which is supposed to prefer objects with higher aesthetic value. Evaluation is performed by the fitness function basing on Birkhoff's aesthetic measure for polygons adapted for 3D solids. Symmetrical, harmonic forms with optimal equilibrium are preferred, however some elements of chaos, that make the shape more interesting, may occur. Such selection imitates natural environment and therefore enables to generate objects related to organic forms appreciated by people. The next section presents examples of the algorithm's performance, and, finally, some conclusion is made.

2. Phenotype

Aesthetic value of an architectonic object is not easy to represent for the purpose of computational design. We do not know how exactly aesthetic evaluation is performed by a human brain and whether it is possible to imitate this process by a computer. Because aesthetic evaluation is related to perception, it seems a promising solution to use a visual perception model in order to assess quality of a phenotype in an evolutionary algorithm focused on aesthetic values. One of two main perception theories – the view-independent model – appears to be more appropriate for this task. It assumes that object recognition is performed by division of a perceived figure into basic components and investigation of their shape and relations between each other. Contrary, the view-dependent model concentrates on recognition based on memorized views of an object – identification occurs when the most similar view is found. Although probably both models take part in human perception, the first one seems more useful for the purpose of computational design. We have decided to use an alphabet of elementary shapes to construct phenotypes of architectonic objects. This will enable the fitness function to analyse their properties and relations to other components, which may be a step forward finding computational analogues of hard-to-define elements of beauty – order, harmony, rhythm, coherence, etc.

2.1 Recognition-By-Components

The view-independent perception model was proposed by Marr [1] and further developed by Biederman [2] in his Recognition-By-Components theory (RBC), who described a set of elementary shapes that most objects are divided into during the recognition process. These elements – so called geons – are characterized by lack of sharp concavities and can be described by some non-accidental properties, i.e., properties that are easy to recognize independently on the point of view. The most important of them are: cross section edges, which can be straight or curved, cross section symmetry (none, vertical, or vertical and rotational), cross section size change (constant, contract, or expand and contract), and axis type, which is straight or curved. These attributes are perceived by us with high accuracy even when a shape is partially covered or laid at an angle. Non-accidental properties define a type of geon – e.g. a prism or a cone – while exact parameters of a solid, like size or curvature of an axis, are specified by metric attributes. Metric properties take longer time to process and perception of them is prone to errors. For instance, it is quite easy to say that a solid's cross section is symmetrical and round, but its diameter length is difficult to assess. Combining possible values of non-accidental attributes results in 36 geon types. Exemplary geons are presented in Figure 1. Shapes in a), b), c) and d) are characterized by straight axis type, while the axis of e) and f) is curved. Cross section edges are curved in case of c), d) and e), and straight in a), b), f). Cross section symmetry of a), c), d) and e) is both vertical and rotational, b) is vertically symmetrical and f) can be characterized by lack of symmetry. The cross section contracts in c), expands and contracts in d), while in the rest of solids its size remains constant.

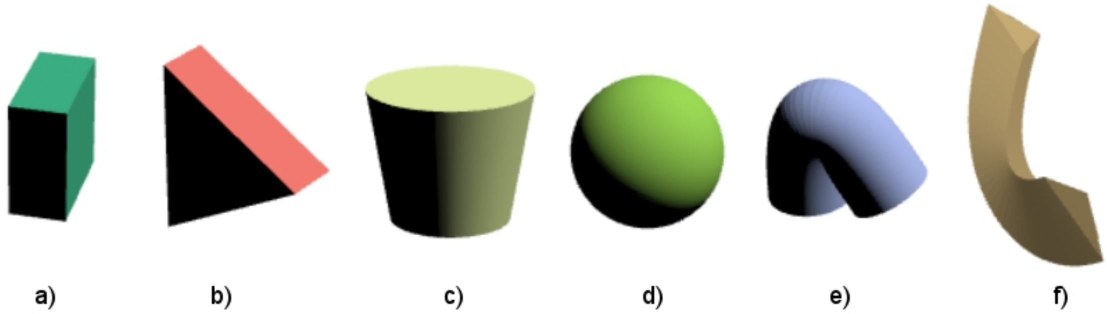

Figure 1. Geons

RBC theory describes also relations between geons. Again, the relation type can be recognized independently on the point of view. Biederman distinguished two main non-accidental relations: an end-to-end relation presented in Figure 2., and an end-to-side relation shown in Figure 3. The end-to-end relation takes place when two neighbouring geons contain a common surface, while the end-to-side relation occurs when a surface of one solid is attached to the larger surface of the second one. For the purpose of architecture design we propose also an overlap relation, illustrated in Figure 4. The overlap relation enables construction of complex objects with the use of few geons and is based on assumption that human eye can identify a geon even when it is partially covered by another solid. In case of lack of the overlap relation, the object from Figure 4. must have been divided into five geons. Assumption that the components may overlap reduces the number of geons to two.

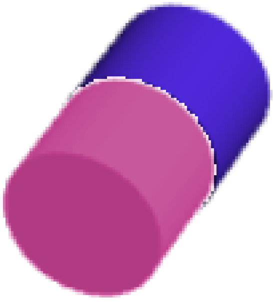

Figure 2. End-to-end

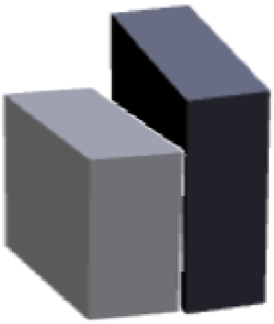

Figure 3. End-to-side

The proposed evolutionary algorithm builds phenotypes of architectonic objects from geons. Our approach assumes that in most cases aesthetic evaluation is based on non-accidental properties, i.e., only geon types are taken into account, disregarding metric information. Therefore, the most important part of the phenotype description are non-accidental attributes and relation types, although metric parameters are of course necessary to visualize a designed object.

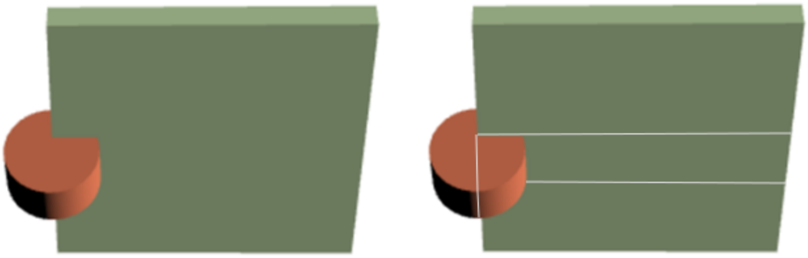

Figure 4. Overlap

3. Genotype

Figure 5. Phenotype

Evolutionary algorithm acts on the basis of genotypes - representations of phenotypes - to reproduce, mutate and select individuals [5] [7]. The proposed approach uses composite graphs [4] for structural representation of phenotypes introduced in the previous section. Composite graphs are directed graphs with nodes containing a set of bonds. Graph edges are attached to bonds. The presented genotype graphs contain nodes representing geons. Each node is described by two groups of attributes: non-accidental properties and metric parameters. Node bonds represent types of geon's surfaces and their number varies depending on the cross section shape. Figure 6. presents a graph structure of a phenotype in Figure 5. The phenotype consists of two overlapping geons. In the graph each of them is represented by two nodes connected by an edge labeled “overlap”. Each node contains a set of attributes (for clarity, only the non-accidental ones are listed), and a set of numbered bonds: no. 1 representing a top basis of a solid, no. 2 - a bottom basis, and no. 3 – a side surface.

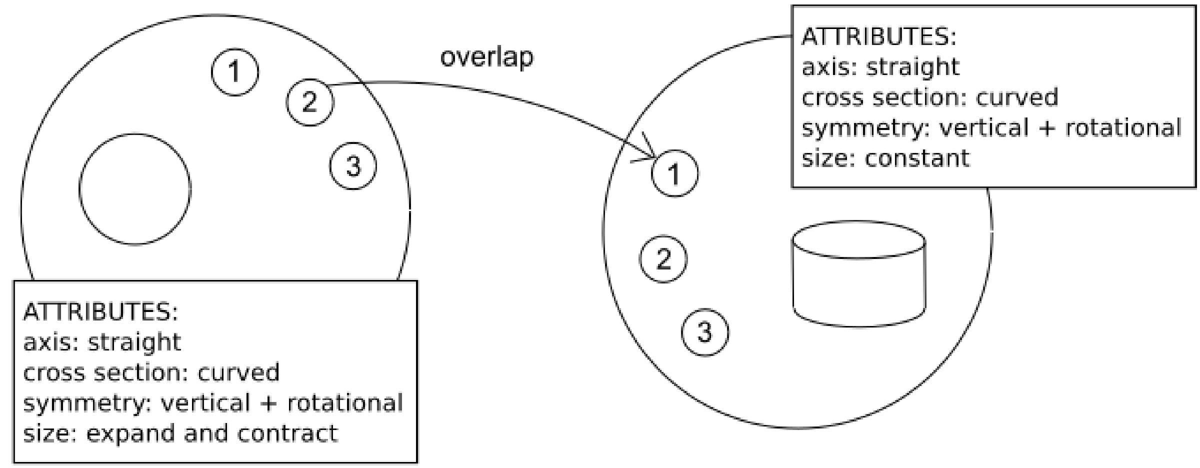

Figure 6. Genotype

4. Genetic operators

Genotypes are modified by means of two genetic operators: crossover and mutation. The way in which these genetic operators are defined strongly depends on the type of genotypes used in a given application. In this paper structures of architectonic objects are represented by means of graphs as genotypes. This representation of genotypes forces new interesting extensions of genetic operators.

4.1 Crossover

The crossover operator is called the major computational engine of genetic algorithms [6]. This operator enables reproduction. Selected individuals are randomly paired and on the basis of their genotypes new individuals are created. Crossover operator for binary strings divides parental genotypes at a given position and exchanges corresponding sub-strings. Applying the crossover operator to the nonstandard pair of genotypes in the form of graphs requires establishing, firstly, their sub-graphs that would be exchanged, and secondly, rules of embedding each of these sub-graphs in another parental genotype.

The presented alghoritm tries to divide a genotype graph into two subgraphs, each of them containing at least one node representing a geon located on the ground (a ground geon), which is indicated by a metric attribute defining location of its bottom basis. In case of only one ground geon in the structure, the second subgraph is a null graph containing no nodes. All the edges between obtained subgraphs are removed. All the other edges remain the same, unless there is a node connected to two ground geon nodes from different subgraphs. In that case, it is randomly allocated to one of the subgraph. After division, the first subgraph of the first graph is merged with the second subgraph of the second graph and the second subgraph of the first graph is merged with the first subgraph of the second graph. An edge representing an end-to-side relation is added between the ground geon nodes in order to provide a consistent object. Phenotype sketches in Figure [nr] illustrate the process of reproduction: in a) the selected individuals are divided into two parts each, in b) two new individuals are created by merging the obtained parts.

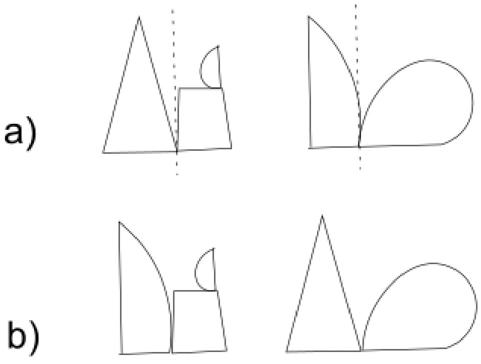

Figure 7. Crossover

4.2 Mutation

In order to introduce new features to the population, the evolutionary alghoritm uses a mutation operator.The mutation operator for a binary string allows flipping bit at a given location of the string. The two following types of this second genetic operator can be applied to graphs: structural mutation which allows to modify graph structures (deleting and adding nodes), and attribute mutation for modifying values of attributes. In this paper the both types of mutation are proposed, extended by modification of a relation type.

Genotypes of random individuals are slightly modified by changing a value of a random attribute or a random relation type, or by adding a random node. Beneficial mutations have a chance to be copied into the next generations. Sketches in Figure 8 present examples of mutation: a) – modification of a non-accidental attribute value, b) – modification of a metric attribute, and c) – modification of a relation type.

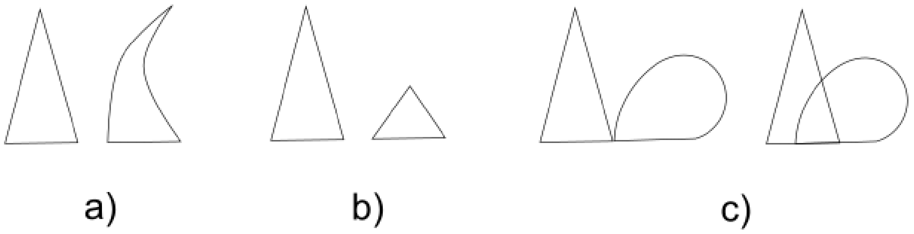

Figure 8. Mutation

5. Selection

During the process of selection the most adequate individuals are chosen for reproduction. Fitness function evaluates to what degree each phenotype fulfills aesthetic criteria of an architectonic object. The evaluation is performed on the basis of Birkhoff aesthetic measure for polygons adapted for 3D solids [3]. Human sense of aesthetics correlates with our urge for gathering information about environment, which is an evolutionary formed strategy that helps to survive. New information is valued provided that it is comprehensible. Therefore, presence of some kind of order increases aesthetic quality of an object, however highly ordered structure may not deliver enough information, as it can be too predictable. It is essential then to ensure optimal balance between the new and the ordered. Our attempt to obtain this goal is to construct a fitness function that rewards the following:

1. every relation of order, i.e., symmetry and alignment to the same plane,
2. every geon in a relation of order,
3. every geon type, provided that the number of geon types does not exceed a critical value,
4. equillibrium.

In result of the first condition, objects with more different relations of order are preferred, which enables novelty, as not every geon of the solid is arranged in the same way as the others. The second condition values relations containing high number of geons, which decreases chaos. The third condition ensures diversity of components and at the same time prevents confusion, inevitable when an object consists of too many different elements. Finally, the fourth condition concerns both aesthetic and functional requirement of architectonic object and enables to obtain a prototype that is possible to be built. Sketches in Figure 9 present individuals preffered by the fitness function according to the described rules, respectively a) – the first rule, b) – the second one, c) – the third one, and d) – the fourth rule.

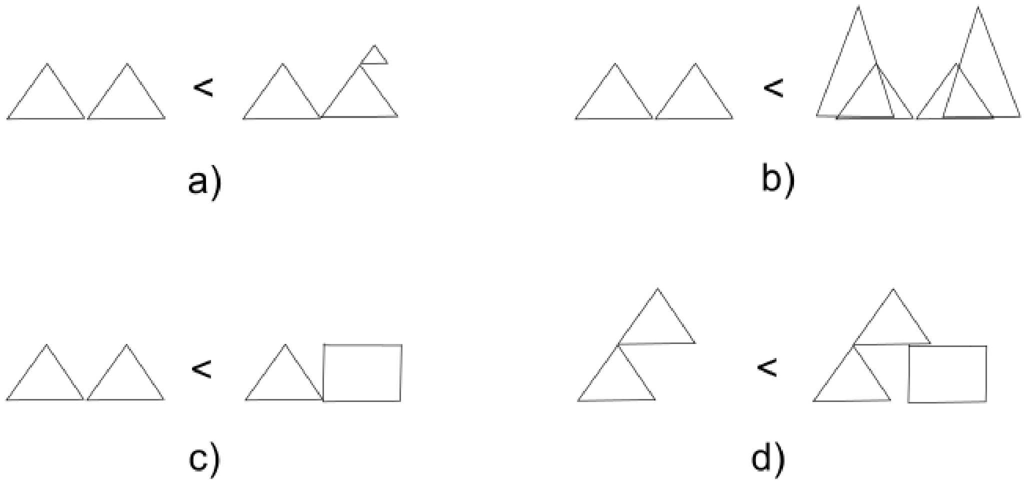

Figure 9. Selection

6. Examples

The proposed alghoritm starts with generating random population of individuals, each of them consisting of no more than three geons. After that, the evaluation is performed by the fitness function and individuals with highest scores are chosen for reproduction, while the rest of them is destroyed. The chosen individuals are randomly paired. Each pair produces two children with the use of the crossover operator. In random cases the mutation operator modifies the child. The new population is created from the reproducing pairs and their children, and the whole process starts again. The number of iterations, the size of initial population and the number of selected individuals are defined by the user.

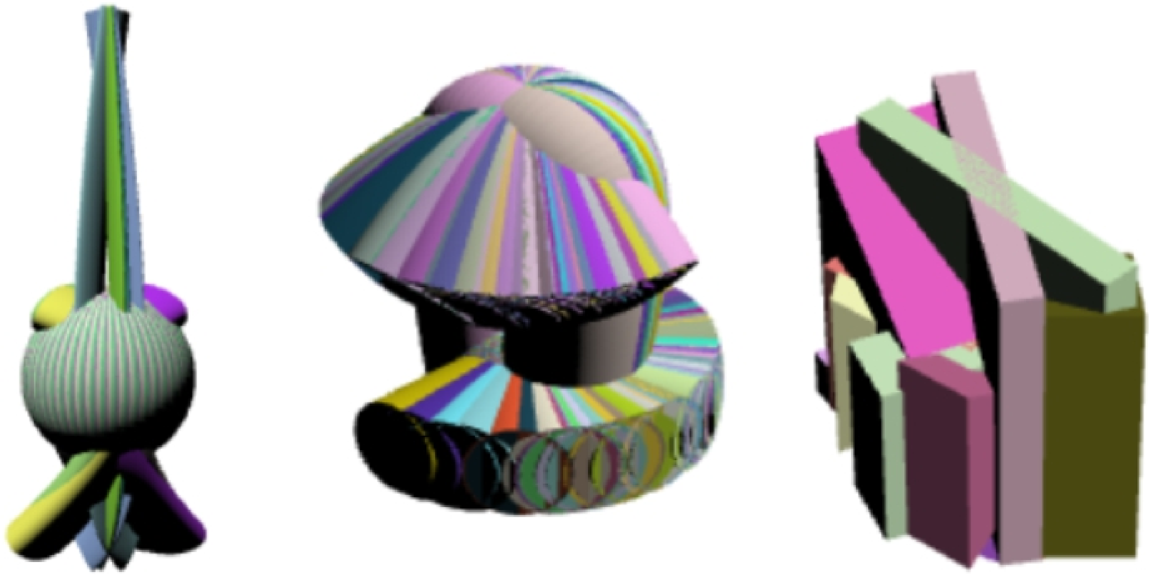

Figure 10. Examples of phenotypes

The alghoritm is designed to generate phenotypes which are well balanced, with some relations of order (like symmetry or alignment to the same plane) and the limited number of geons. Figure 10. presents some phenotypes preferred by the fitness function.

7. Conclusion

The aim of this paper is to present a new approach to aesthetic-oriented creative design. A genetic algorithm as a part of a digital tool has been proposed in the creative design process. Evolutionary process has been used to stimulate the creativity of the designer and to suggest optimal solutions with regard to the defined aesthetic measure. Aesthetic evaluation mechanism for architectonic object prototypes has been encoded in the fitness function.

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