CHALLENGES AND FALLACIES IN COMPUTER APPLICATIONS OF THE EVOLUTIONARY ANALOGY IN DESIGN METHODOLOGY

Biology and Computation to Revolutionize Design Practice

FOR LE CARRE BLEU

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Paper description

The objective of this paper is to show the use of the analogy of the biological evolutionary model in computer-based architectural design. The paper shows a brief description of the evolutionary model and the interpretations made of it in Genetic Algorithms. The paper presents evolutionary model applications in design considering their progress and their shortcomings, their misunderstanding and fallacies in answering designers' problems in architectural practice.

Keywords:

Evolution, evolutionary design, evolutionary architecture, morphogenetic design, analogy, evolutionary model.

Introduction

One would think that the analogy between architecture and the theory of evolutionstarted after Charles Darwin's *On the Origin of Species* (Darwin 1859). However, the fact is that the idea of evolution permeated theories of architects and theoreticians such as Semper and Viollet-le-Duc before the publication of Darwin's book. Indeed, they were much inspired by the anti-evolutionist Cuvier (Steadman 1979). Darwin himself used the term evolution only once in *The Origin*, because at that time this word was used by biologists meaning development/evolvement of the embryo, while architects and design theoreticians used the notion of evolution because they associated it with the notion of progress and optimization.

However, the use of this analogy is not to prove that the biological evolutionary model is equal to architecture or to the architectural process; researchers are using it to explore their similarities and to generate ideas on how to deal – for example – with the phenomenon of change in design. But it must be controlled and systematized to produce tools that perform with effectiveness. Therefore, the objective of this paper is to show the use of evolutionary models in computer-based architectural design, their progress and their shortcomings. The paper's first part briefly describes the problems in defining Evolutionary Architecture. The second part briefly describes some applications, some of the confusion in the notion of evolution, some misunderstandings in the Evolutionary Model Application in Design, and a comparison of some concepts with the concepts applied in the Darwinian Model and Genetics. Finally, the third part provides a summary and some conclusions on the use of the evolutionary model.

1. Evolutionary Architecture

Evolutionary Architectural Design is not easy to define because it has been used in different ways. Thus one can read Eugene Tsui's "Evolutionary Architecture" (Tsui 1999) and not find any direct mention of computational tools, while in Frazer's "An Evolutionary Architecture" (Frazer 1995), it is the starting point. Both use an analogy with the evolutionary model, although with some different views. Frazer pursues his evolutionary architecture by trying to imitate the evolutionary process. His computation tool is meant to generate architectural form, while Tsui is more interested in learning from the objects of nature, the animals' habitat and its adaptability to the environment, the materials and the technique involved (see illustration 1).

Illustration 1: the work of Eugene Tsui

Evolutionary design is also used to mean transformation of forms, which does not carry the concept of fitness so particular to natural evolution, as well as meaning progress, which is more difficult to clarify. Both progress and evolution mean improvement, and both implicitly bear the idea of time. However, evolution is constrained by time and environment, while the notion of progress is overloaded with the idea of universality. Furthermore, evolution involves chance, and even a catastrophe is a chance for some species to survive. Therefore, only when it is ideally assumed that the environment is one and unchangeable or always *better* than before, do evolution and progress coincide.

Currently, although with some exceptions such as Tsui's architecture, most evolutionary models make use of evolutionary computation to generate them, whereby Genetic Algorithms (GAs) are the most used. "The beginning of genetic algorithms," say Dipankar Dasgupta and Zbigniew Michalewicz (Dasgupta and Michalewicz 1997), "can be traced back to the early 1950s when several biologists used computers for simulations of biological systems. However, the work done in the late 1960s and early 1970s at the University of Michigan under the direction of John Holland led to genetic algorithms as they are known today."[1]

The evolutionary model used by John Holland (Holland 1975) departs from an analogy with the Darwinian Model and Genetics. However, "the reader", says Holland, "should be warned that the generalized operators (…) are idealized to varying degrees. This has been done to emphasize the basic functions of the operators, at the cost of exploring the complex (and fascinating) biological mechanism underlying their execution. Even so an attempt has been made to keep the correspondence close enough to allow ready translation of the results to the original biological context."[2] As in any heuristic analogy, Holland reduces the Darwinian Model to handle problems such those of optimization. His algorithm has proved to be robust enough to solve many problems in different areas. However, evolutionary design researchers have modified Holland's GA in innumerous ways by means of handling complex issues involving ill-defined problems in designing.

The next part of this article analyzes three representative applications which approach the architectural design from different angles and levels. All three demonstrate clearly the challenges and fallacies of the analogy.

2. A brief description and analysis of three applications of Evolutionary Design

In solving a problem in design, architects make intensive use of their domain knowledge, i.e. of the design knowledge inherent to this process. Hence, making new tools to help architects to perform their tasks demands consideration of this domain knowledge, in addition to the cognitive aspects involved in using future plausible models.

To understand the potentials and shortcomings of applications from a survey on the last 10 years of evolutionary models in architecture, it is necessary to go through the whole process of making a tool, starting with their objectives and going through the terminology borrowed from the analogy. Thereafter, one must ask at which hierarchical level was the analogy applied (at the process or object level), as well as how, where and when the biological evolutionary model was reduced. Finally, one should analyze the domain knowledge built in the tool, and, when possible, evaluate the results of the tool.

2.1 The Electronic Emulator of Building Scenarios

Celestino Soddu and Enrica Colabella (Milan Polytechnic University, Italy)'s Argenìa Design is a Model for Electronic Emulation of Building Scenarios and for managing these scenarios in the manufacturing process. "This tool," says Soddu (Soddu 1994), "is, in fact, a *design of species*, and we can use it as an artificial DNA to generate a multiplicity of architectural or environmental possible events."

Soddu and Colabella have been applying the idea to architecture as well as to industrial design. Their idea is that "the morphogenetic approach can realize operative meta-projects that are new design products. These are something like idea-products, plus these are able to generate an endless sequence of object-products. The idea-projects create a new market: an industry can buy a morphogenetic idea-project of lamps, for example, and use the endless sequence of generated 3D-models to produce always different

(1) [1] Dasgupta, Dipankar and Zbigniew Michalewicz - "Evolutionary Algorithms, An Overview" in Engineering Applications page 6

(2) [2] John Holland - Adaptation in natural and artificial systems, page 97

lamps (the idea-project can be used as an auto-reprogramming tool for robots). The customer can choose his unique object by activating, on the Internet, the generative tool and sending his request to the industry... or...a Mayor can order the idea-project of evolution (this means an increasing complexity) of his town and use it to control the incoming possibilities and the identity in progress of the environment."

Soddu and Colabella's model is based on an analogy at the process level, in particular on the development process of idea-products, and not in the evolution of the ideas, i.e. from one idea-product to another.

The role of fitness in Soddu and Colabella's model is of great importance to understand the reduction which they applied in the biological evolutionary model. Soddu and Colabella's model produces scenarios of an idea-product, i.e. it is specific for one kind of design (one *species*) and can not be applied for architectural projects in general. After the establishment of the parameters in the tool, it provides variation of the same

> According to Soddu and Colabella, those are the achieved goals in his project " Argenìa Design of a series of chairs":
>
> 1. The idea is recognizable notwithstanding the differences among the individual chairs.
> 2. The Argenic design has not been realized through a data base compilation: we have not used, in the code, a sequence of pre-defined shapes but a series of generative procedures.
> 3. The logic that guides to the codes of generation and control is an emulation of the subjective procedures that we, as designers, normally use. We have represented and used this logic in a fractal way, from the overall form to the detail, so as to produce chairs that are identifiable in terms of the idea and design logic that we have adopted, but with the impossibility to foresee the final form.
> 4. The system emulates normal procedures of chair design. These procedures are activated by codes that emulate the evolution of design as dynamic chaotic system, therefore a system highly sensitive to the starting data.
> 5. Each chair is unrepeatable, as in all scenarios produced by dynamic chaotic systems. So we can reach the uniqueness that is one of the objectives of an Argenic Design. Soddu, C. and Enrica Colabella - Argenic Design - Design in Context Conference, Stockholm European Academy of Design, 23-25 April 1997

theme, i.e. one may have countless successful examples or scenarios.

In Soddu's generation of chairs (see illustration 2), development only happens if the object conforms to the set of rules built in the representation (idea and design logic), in this aspect, the generated chairs have the same fitness. This system possesses heritability, the chairs are offspring of the same idea and design logic. It produces variation, the chairs are each of them unique. And it posses a selection mechanism, the client (the buyer), according to his/her aesthetic values, selects one of the offered chairs to be produced (mechanism to be compared with “sexual selection”). However the process is not cyclical. The select population will produce no new generation. Evolution is not a process of one generation. It is not only variation within one generation, it depends of the accumulation of these variations within innumerous generations. After generations, one could see the emergence of a new type, maybe with a slight different idea and design logic.

The design knowledge in Soddu and Colabella's tool is built in parameters, which represents their idea-product. In their model, designers participate at the level of the idea-product, but they loose all the control of the object-product generated by their software. Because clients buy idea-products which can produce an unrepeatable number of object-products, the creation process will be concentrated in very few hands, and even for those very few designers the number of assignments is likely to diminish.

Authorship is likely to be a problem, because it seems very difficult to prove that a "unique chair" generated by the tool belongs to the oeuvre of a certain designer. Darwin and Wallace came independently to the idea of Natural Selection. Marsupial and placental mammals convergein "design" because they fill the same environmental niche. Since the tool will produce an infinite and unrepeatable number of designs, there is a probability that convergence in design will occur, or at least doubts will occur about the origin of many products.

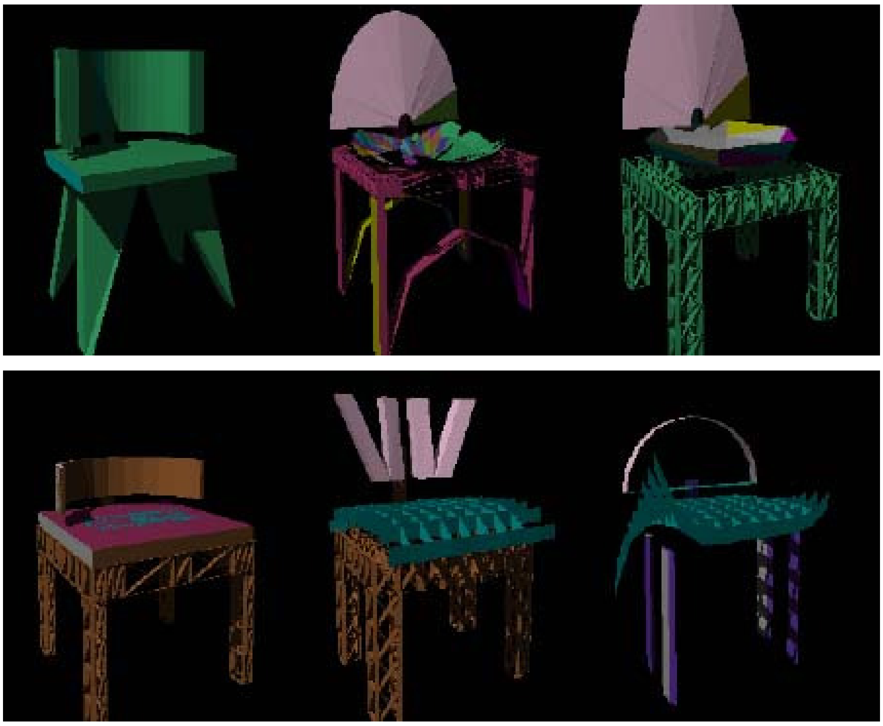


illustration 2: Celestino Soddu's chairs

2.2 The Form Generator Model

John Frazer (School of Design, The Hong Kong Polytechnic University)'s *An Evolutionary Architecture* (Frazer 1995) describes a model for form generation. The objective of his model is "to achieve in the built environment the symbiotic behaviour and the metabolic balance that are characteristic of the natural environment."

Therefore, *An Evolutionary Architecture* "investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of morphogenesis in the natural world" (Frazer 1995). [3] He proposes the model of nature as a generating force for Architecture, considering Form, Space and Structure as the outward expression of architecture. By applying some generative rules, he then accelerates and tests his process of evolution.

Unlike Tsui, **Frazer**'s analogy concentrates on the process level. Central in his study is the process of how to grow a *seed* toward a final structure, i.e. development or epigenesis. To help understand the way in which Frazer reduced the biological evolutionary model, his terminology is briefly described here.

Gamete forming, mating and development may be considered as one process. However, the mechanisms involved in each of these phases follow a determined order. Frazer, like most of the Evolutionary Computation Scientists, changes the order of the factors.

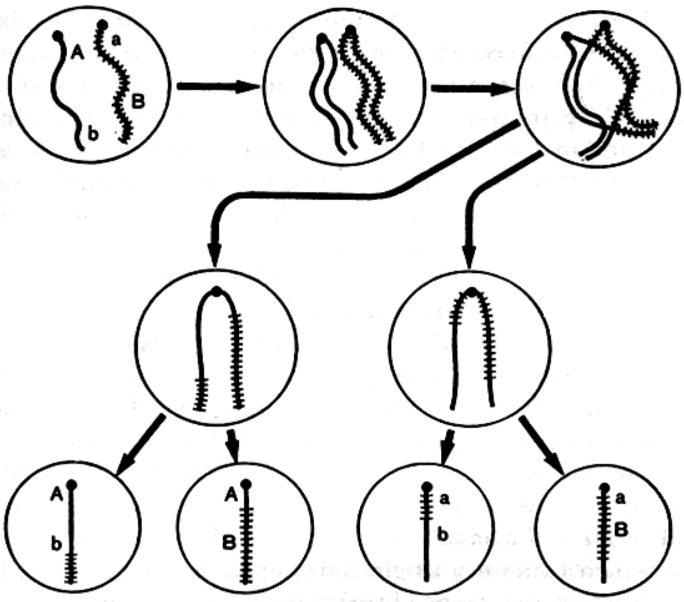
Frazer has at least five main diverging concepts from the biological evolutionary model. First, he concentrates on the evolutionary process during a seed development. Second, he uses an Epigenetic Algorithm to breed a population by crossover or mutation (Frazer 1995)[4]. Third, his idea of seed diverges from the biological one; in biology, a seed corresponds to a zygote, a fertilized cell in higher organisms, which will generate an organism. Frazer's seed is still to be fertilized. Fourth, the fertilization of the seed is

(3) [3] Frazer, John– An Evolutionary Architecture, page 9

(4) [4] page 89

done using Holland's genetics operators: crossover and mutation. In nature, crossover is a mechanism that happens before fertilization, during gamete forming. Crossover (see illustration 3) happens during meiosis, before mating, by each of the future parents alone in the formation of their sexual cells (gametes). A gamete has half the number of chromosomes of the cell that originated it. Its chromosomes are not paired and, thanks to the crossover mechanism, not identical to the chromosomes of the original cell. The process of breeding involves no crossover, the gametes fuse and their chromosomes are paired to form the zygotic cell.

Heredity



The behaviour of a pair of 'homologous' chromosomes during meiosis. The original paternal chromosome, and segments of chromosomes which are copies of it, are shown cross-hatched, although in practice there is no visible difference between a pair of homologues.

Illustration 3: Crossover in nature, according to John Maynard Smith, The Theory of Evolution, pp. 61

The development of this zygotic cell into an organism, by growth, morphogenetic movement and differentiation is called epigenesis. The fifth divergent feature of Frazer's model involves the role of the environment in the development of the seed towards an organism. Frazer's seed evolves according to the environment. The environment may also change during the process and even then, it can highly influence the seed growth. Consequently, Frazer's idea of fitness also diverges from the biological one. In Frazer's concept, natural selection has no role in it since changes in the environment redirect immediately the development of the organism. He considers fitness to be such that if he modifies the artificial environment, the seed growth, by cellular automaton, will be forced to adapt to the new situation.

Frazer built into his tool some conceptual knowledge for the production of form. But since architecture is not only form but also function, one may conclude that the design knowledge in the system is not sufficient to produce architecture (see illustration 4). Buildings accommodate functions that are developed and archived in the memory of the architects. Their successful layouts are remembered, reused and adapted into new situations. In Frazer's tool, the design knowledge to help architects to "remember and reuse" some of their successful solutions are not built in his application, neither are there the physical built environment or the social aspects inherent to the project. Users and clients may play with the system but they are in fact playing with form.

Illustration 4: John Frazer's evolution

Concerning procedural knowledge, Frazer does not consider architects and their practice as the target group for his tool. Architects who wish to use the tool must adapt to an imposed methodology. In his paper together with J.M. Connor, "A Conceptual Seeding Technique for Architectural Design", he says that it "rejects the notion that a CAD approach should reflect the traditional non-cad architectural methodology on the grounds that, first, the present architectural design process is fundamentally unsatisfactory in any known form and not worth imitating and, second, imitating the human process is unlikely in any case to represent the most imaginative use of a machine."[5] In other words, in his "An Evolutionary Architecture", he says that his tools "are clearly not intended to reinforce existing practice."[6]

Moreover, in Lawson's analysis and critique of Frazer's application he says, that the generator is "surprising but predictable, therefore not truly creative," and that "the experience and skills required of a designer to

> "*The Extended Architects' working methods. The obvious corollary of this is:*
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> (a) *The generic approach already adopted by many designers has to be made explicit, rigorous, and stated in terms which enable a concept to be expressed in genetic code*
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> (b) *Architects have to be very clear about the criteria for evaluating an idea*
>
> (c) *Architects have to be prepared to accept the concept of client- and user-participation in the process*
>
> (d) *The design responsibility changes to one of overall concept and embedded detail, but not individual manifestation*
>
> A diminished need for architects in the process of initial generation. While there would still need to be enough architects to guarantee a rich genetic pool of ideas, the role of the mass of imitators would be more efficiently accomplished by the machine. In this new context architects might have a role closer in concept to that to an extended phenotype, and I thus suggest the designation 'extended architect'[1]." John Frazer – An Evolutionary Architecture, page 100

work with such tools may well be quite different to those needed for a traditional design process." [7]

2.3 The Self-Improving Codes of a Genetic Representation Model

John S. Gero (Department of Architectural and Design Science, University of Sydney, Australia) has been researching several types of models together with his partners. Gero and Thorsten Schnier's higher-level representations of form, based on the paper "Learning Genetic Representations as alternative to Hand-

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(5) [5] Frazer, John and J.M. Connor, "A Conceptual Seeding Technique for Architectural Design" - ParCċ 79 International Conference on the Application of Computers in Architectural Design, conference proceedings, pp. 425-434.

(6) [6] Frazer, John– An Evolutionary Architecture, page 60

(7) [7] Lawson, Bryan – How Designers Think, the design process demystified – chapter 16 Designing with computers, page: 290-291

coded Shape Grammars," is a very interesting example, because it concentrates on the level of design representation. It aims to evolve a new, higher-level representation of form, based on self-improving codes of a shape-grammar, suitable for subsequent "evolution of house plans in a specific architectural style."

The analogy of Gero and Schnier is applied on the genetic level. Central to this study is the "evolution of genes”, that is, not directly meaning the evolution of organisms. Gero and Schnier's new representation is based on vectors, which will evolve and be recognised by the tool, forming more complex genes and reducing the number of genes connected to a particular design. The notion of biological evolution carries implicitly the idea of emergence of a new branching in design by accumulating mutations over time. Gero and Schnier's model is limited in this aspect because the tool, although evolving genes, produces only houses in the style of Frank Lloyd Wright.

In their application, they follow Langton's notion of genotype and phenotype (Langton 1988), whereby a genotype is a "set of genetic instructions that make up the genetic code, while the phenotype is the structure that is produced as the result of the interpretation of the genotype." This is similar, indeed, to the biological evolutionary model.

The design knowledge here is built into the rules of a shape-grammar which evolves over time. However, using a shape-grammar to evolve housing plans has some bottlenecks, such as "is the code evolving?" and if it is, are the designs of Frank Lloyd Wright also evolving? Or do they have, like Soddu and Colabella's model, all the same fitness? This may be the case of evolutionary genes but not of evolutionary design. Though if these genes could evolve into unexpected ones, in place of just more complex ones, there would be a chance that the shape-grammar would allow emergence in design and go above the generation of houses according to the Frank Lloyd Wright style.

3. Summary and some Conclusions:

This article provided an analysis of three applications of major researchers in the field of Evolutionary Design to show their efforts, their successes and their shortcomings. Beside those examples and departing from the same analogy, some tools have being developed to optimize, reuse, adapt and combine design precedents. These tools try to handle problems which come from architectural practice, where, as is well known, architects make use of their previous experience in searching for solutions. They draw from design precedents of their own work, from examples registered in their memory and archives. Design precedents are reused, optimized and/or adapted to fit new situations. In this process, other building types may eventually emerge. As architects recall these precedents, case after case, a kind of “genealogical path[8]” of solutions emerges in their mind. Using this analogy, one can say that “genes” of designs are transferred from generation to generation, creating an “Evolutionary Design Process” (see illustration 5).

Illustration 5: a genealogical path in Santiago Calatrava's bridges?

(8) [8] Tzonis, Alexander – Santiago Calatrava, The Poetics of Movement– chapter 2: Germinal Projects, page: 30-65

All in all, the analogy between the domains of evolution and biology is often unproductive and misapplied. The problem is not so much that, in applying the analogy, the meaning of many biological concepts used is distorted, as the fact that the analogy misrepresents the design process itself.

Most applications, and not only those illustrated in this article, present more than one of the following bottlenecks:

a. Confusion between the scientific notion of evolution and the cultural, value-added, notion of progress;

b. Reduction of the notion of evolution to that of biological transformation eliminating the notion of fitness;

c. An arbitrary and/or over-ruled application of Shape Grammars in combination with Genetic Algorithms (GAs) reducing the possibility of emergence in Design;

d. A reduced amount of design knowledge built in the systems;

e. A lack of understanding of the cognitive processes used by designers. Some tools ignore the architect cognitive aspects and dictate their work methods upon the architects; while other tools even try to replace the architect with a machine.

f. A failure in providing a measure of fit in the environment.

g. A lack of consideration in the adaptation of buildings to the external environment as well as to the internal structure of the individual as they constrain a possible solution.

Therefore, the current applications of evolutionary models are extremely limited.

Evolutionary models can help architects to perform their tasks more efficiently and more effectively. One way to carry out this plan is by reevaluating the analogy and to see where it can be extended or reduced in other ways. However one must not forget to include design knowledge in the system. Frazer's "seed" carries a minimum of data if compared with the information carried by a design precedent. Therefore the idea of using design precedents to represent the design knowledge seems to be the natural approach. Not that DNA carries structure as it was meant by the biological " preformationist " approach; DNA carries information, instructions. In spite of that, just like good breeders in artificial selection, we can look to the phenotype (the structures) of our design precedents to select the best mating individuals to fit our purposes.

Here remains the question of how far to extend the analogy, because it is necessary not to lose focus onthe problems which one is addressing in design. But it is also necessary to not reduce the model before one can get a glimpse of its potential in helping architects in practice. The use of analogies can lead to misrepresentations, unless it is controlled and systematized. This requires a deep analysis of: one's own analogy and the one used in the genetic algorithm; where are those analogies conflicting with each other and the achievements of one's objectives. In summary, If researchers decide to use GA's to make tools to support architectural design, they will have to follow Holland's rationale to understand his metaphor, his representation and last but not least, his examples. It is necessary to understand what makes architectural design peculiar and then to analyze these peculiarities with those of Holland's examples. If they do not match, a review of his representation will be necessary.

At the operation level of the tool, one should insist on a deeper look into the biological model, because the crossover in nature creates a greater diversity than crossover in the above examples. The gametes are a recombination of the chromosome of the father and the mother of the individual-reproducer. That means that there will be a greater chance that the offspring will inherit the "good part" of the genetic material of both parents and, therefore, there will be a chance that an offspring can be stronger than its parents are. Furthermore, there will be a greater opportunity to enhance diversity within the population. This may reduce the chance of convergence of the individuals.

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