THE QUESTION OF REPRESENTING DESIGN BASED ON PRECEDESNTS

A Review of the Evolutionary Biological Analogy in the Making of Design Tools

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Abstract. This paper is a critical appreciation of the application of the evolutionary analogy in representing the use of precedents in design. It departs from architectural practice and the architects’ possible cognitive use of the tools already developed. Pursuing this, two applications of the evolutionary model in design are reviewed. Furthermore, the paper looks into ways the analogy was applied to minimize risks of misapplication and maximize innovation.

1. Introduction

As is well known, architects make use of their previous experience in searching for solutions. In particular, they draw from precedents of their own work, examples from their memory or from their archives. Design precedents are, then, 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” 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”. Departing from architectural practice and this analogy between design and evolution, one may apply evolutionary models to reuse design precedents to support innovation rather than simple imitation. The idea is even more attractive when one takes into consideration the possibility of simulating the phenomenon of evolution with the use of a computer, whereby a large number of “genes” could be stored, retrieved and adapted with efficiency. However, the analogy between the domains of evolutionary biology and design has often been 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 analogy misrepresents the design process itself. However, if
these misrepresentations are controlled and the use of the analogy is systematized, then efficient tools improving the effectiveness of the design process can be developed. Therefore, this paper investigates, in general, the problems involved in the representation of the design process and in particular the problem of recalling design precedents intending to support innovation. Pursuing this, two main applications of the evolutionary model in design are reviewed. The paper then the applications’ advantages and disadvantages, as well as their misunderstandings. Furthermore, the paper looks into ways the analogy was applied to minimize risks of misapplication and maximize innovation, and it reflects on the cross-disciplinary application of analogy in the generation of new design tools. Therefore, while describing the applications, the paper provides a brief comparison of the main concepts and mechanisms from Evolutionary Biology and of those used in the applications. Finally, the paper suggests how the use of concepts and mechanisms of Evolutionary Biology could help the development of a tool systematically supporting the reuse of precedent solutions in design.

2. Some Applications Of The Evolutionary Biological Analogy In Design

The analogy between design and nature can already be found in the writings of Aristotle. However, the nineteenth century was a fertile period when several biological theories were running. The idea of evolution in those analogies, though, was frequently and strangely inspired by the work of Georges Cuvier. This is the case, for example, with Gottfried Semper who, according to Adolf Max Vogt, “created a concept somewhat parallel to Darwin’s – not inspired by Darwin, however, but by Cuvier, who had advanced his typology forty years earlier.” Philip Steadman (1979) says as well that the evolutionary analogy “from James Fergusson and from Horatio Greenough, is prior to the publication of The Origin of Species.” The notion of Progress is what has driven those authors from other domains to the concept of Evolution in Design.

(1) Cuvier was an anti-evolutionist, in fact he believed in the fixity of the species
(2) Semper, art historian and architect, is the author, of at least three kinds of biological analogies as classified by Steadman.
(4) Fergusson was a historian, leading English Rationalist of his day and an opponent of Ruskin’s views.
(5) Greenough was an American sculptor and writer.
(6) Steadman, Philip - “The evolution of Designs” (1979), The Darwinian analogy, p.: 85
The twentieth-century advances in genetics associated with the last decade’s developments in the Computer Sciences made the analogy richer, and capable of producing many design tools. In the case of recalling design precedents, the search for a good representation of design knowledge in a way that can be reused has become essential. Therefore, we shall now review two recent applications of the evolutionary model in design.

One may suggest many examples of recalling design precedents; however, few deal with the problem of adaptation to produce innovative artifacts. One may ask why we did not, for instance, take the example of recalling precedents using shape grammars.

Many applications make use of shape grammars, which are composed by an alphabet of forms and rules that regulates the relation between these forms in design. Shape grammar is constructed manually by extracting the alphabet and forms from design precedents. Several grammars can be built based on the same set of precedents; the automated grammar will generate designs according to the style of the design precedents. The style is implicit in the rules of this grammar, therefore, it is rather influenced by the perception of the grammar's author. Shape grammar is a generator of designs with the same style, the style implicit in its rules. Once the grammar is ready, the architect is ruled out of the design process, and any kind of emergence in design is ruled out together with the architect. This occurs because the grammar will judge as “bad” any thing that does not follow the rules, and this will happen before someone can judge the fitness of the generated design.

Therefore, we have selected two examples which are less concerned with the recalling of precedents, but which are to a great extent involved in the generation of innovative design. The applications use some knowledge-based design precedents in the form of parameters and/or concepts; and both develop their artifacts from automated generative procedures that are not based on geometry.

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'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 artifacts produced by their tool are unique, i.e. they are not repeatable; unlimited, i.e. the tool can produce an endless number of objects or scenarios; and it is claimed that the idea behind the generation of the objects is recognizable (figure 1).
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 theme, i.e. one may have countless successful examples or scenarios.

According to Soddu and Colabella, those are the achieved goals in his project “Argenia 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 database 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 use 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.

**Figure 1. Goals of Argenía Design of a series of chairs**

Soddu and Colabella have been applying a morphogenetic approach 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.” Soddu and Colabella try to create a new market where an industry can buy a “morphogenetic idea-project” to produce, for example, an endless sequence of 3d-models of chairs (see figure 2). “The customer”, they say, “can choose his unique object by activating, on the Internet, the generative tool and sending his request to the industry.” In the same sense, “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.”

According to Soddu and Colabella, development happens conforming to a set of “generative procedures” built in the representation (idea and design logic). In this respect, one could say that the generated chairs are of the same fitness. Although, in the case of the chairs, it is difficult to understand that there is one
idea and one design logic behind it. Even more difficult is to understand whether a minimum of assemblage logic exists that will enable the industry to produce unique chairs with effectiveness.

This system possesses **heritability**, the chairs are offspring of the same idea and design logic. The system produces **variation**; each of the chairs is unique. In addition, it posses a **selection mechanism**; the client (the buyer), according to his/her aesthetic values, selects one of the chairs on offer to be produced (mechanism to be compared with “sexual selection”). However, the process is **not cyclical**. The selected population will produce no new generation. Evolution in nature needs variation but it depends on the accumulation of these variations within innumerable generations. After generations, one could see the emergence of a new species, which in the case of Soddu’s chairs means different ideas and design logic.

In Soddu and Colabella’s model, designers participate at the level of the idea-product, but they lose all the control of the object-product generated by their software. Because clients buy idea-products that 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.

![Figure 2: Celestino Soddu's system for generation of chairs](image)

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. For example, Darwin and Wallace came independently to the idea of Natural Selection; marsupial and placental mammals converge in “design” because they fill the same environmental niche. Thus, 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.

2.2. THE FORM GENERATOR MODEL

John Frazer’s (School of Design, The Hong Kong Polytechnic University) *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) 7. 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.

Frazer’s application does not rely on the use of design precedents. However, it is a pioneering work and as such, its analogy and its concepts influence several applications. In addition, it proposes a switch of the design process paradigm with the idea of the extended architect. One of advantages of his tools is that of architect, client and user interaction during the conceptual phase of the design process. A second advantage concerns the powerful generative mechanisms used to produce form, space and structure.

Frazer takes the biological evolutionary model as a source of inspiration. His 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 understanding the way in which Frazer reduced the biological evolutionary model, his terminology is briefly described here.

In nature, *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 computer scientists, changes the order of the factors. In this process, Frazer has at least five main concepts diverging from the biological evolutionary model. First, he concentrates on the evolutionary process during a seed development i.e. **epigenesis**. Second, 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 “individual”. Frazer's seed is still to be fertilized 8. Third, he uses an Epigenetic Algorithm 9 to breed a population and not to develop the individuals 10. Fourth, the fertilization of the seed is done using John Holland’s 11 genetics operators: crossover and mutation 12.

In nature, crossover is a mechanism that happens before fertilization, during gamete forming. Crossover (see figure 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 of the number of chromosomes of the cell that originated it. Its chromosomes are not paired, and thanks to the crossover

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(7) Frazer, John– An Evolutionary Architecture, p. 9
(8) ibid. p. 89
(9) ibid. p. 83
(10) ibid. p. 89
(11) Holland, John: 1992, adaptation in Natural and Artificial Systems
(12) Frazer, John– An Evolutionary Architecture, p. 98
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. 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. Because changes in the environment immediately redirect the development of the organism, natural selection has a much less important role in it than epigenesis, at least in what concerns the initial concepts. The process produces artifacts with optimal fitness.

Concerning procedural knowledge, in Frazer's tool, the design knowledge, to help architects to “remember and reuse” some of their successful solutions, is not built into his application. The architect provides the first step of forming a concept. Although as Frazer says, “the prototyping, modeling, testing, evaluation and evolution all use the formidable power of the computer.”

Moreover, 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 Bryan Lawson's analysis and critique of Frazer's application (Lawson, 1997), he says that “the experience and skills required of a designer to work with such tools may well be quite different to those needed for a traditional design process.” Indeed, in his paper together with J.M. Connor,

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(13) ibid. p. 89
(15) Lawson, Bryan; 1997, How Designers Think, the design process demystified – chapter 16 Designing with computers, pp. 290-291
“A Conceptual Seeding Technique for Architectural Design”, Frazer 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.” In other words, Frazer’s tools for an evolutionary architecture “are clearly not intended to reinforce existing practice.”

3. Critique

This paper focuses on the problem of representing the design process as a process of reuse and redesign of accumulated previous solutions. In doing so, it analyzes the possibility of using an evolutionary model to represent it. Finally, it addresses the use of analogy in research.

3.1. THE SYSTEMATIZATION OF THE ANALOGY:

A systematized use of the analogy could help us to understand the concepts and the degree of similarities between the two fields involved. This would help us to get a deeper impression of the selected theory and the possibility to analyze its potentials in solving the problems of our own field; and last but not least, it would help in what concerns research cooperation. Next, we are going to analyze those ideas.

As a principle, if we are using an analogy, the two evaluated processes must have some similarities; i.e. the result should not be the opposite model. The analogy is taken in most of the cases as an inspiration, but from inspiration to true comparison there is a shade of possibilities. In the evolutionary analogy, the minimum should be concerned with the notion of evolution.

In the electronic emulator of building scenarios, the process of evolution is not complete because evaluation is not the “making” of one family of artifacts, which will be extinct because there will be no other generation to carry out the successful variations.

In the form generator model, the use of the analogy is not systematized, its concepts diverge mostly from the originals. There is confusion between ontogeny and phylogeny (Gould, 1977). Evolution may happen during ontogeny, which is related to epigenesis, although phylogeny, the taxonomy of the species that emerged through time, cannot be ruled out.

(17) Frazer, John – An Evolutionary Architecture, p. 60
3.2. THE USE OF PRECEDENTS AND ARCHITECTURAL PRACTICE:

The objective of the applications analyzed was the production of scenarios or artifacts through generative procedures. Both applications were not relying on design precedents but rich in the use of morphogenetic mechanisms. Shape grammar systems, on the other hand, are based on knowledge-based precedents. However, looking into a system based on shape grammar within an evolutionary model, we do not see much improvement towards innovation. If we use “crossover” between “individuals” of the same style, it is unlikely that it will result in a breaking of the paradigm. Only mutation can bring a breaking of pattern to the system and bring new concepts to the making of the artifacts. Therefore, it is likely that if a good fitness algorithm is built in the tool or if the architect upgrades the grammar with more forms and rules (a purposive mutation), the system may become more innovative.

None of the applications relies on the use of past experience to evolve new types. However, in real practice, architects use design precedents in solving their design problems. Moreover, design precedents are available sources of knowledge. Therefore, there is no reason to discard this knowledge. Arguing that it is a pity not to use the whole capacity or potential of the computer seems to us an insufficient reason to discard the design precedents.

4. Conclusions

Drawing from the literature of the last ten years of applications of the Evolutionary Model in Design, this paper analyzes design tools and identifies the following causes for this failure:
1. Confusion between the scientific notion of evolution and the cultural, value-added, notion of progress.
2. The reduction of the notion of evolution to that of biological transformation eliminating the notion of fitness.
3. The arbitrary and/or over-ruled application of Shape Grammars in combination with Genetic Algorithms (GAs) reducing the possibility of emergence in Design.
4. The reduced amount of design knowledge built in the systems
5. In most cases, the models do not respond to the demands of architectural practice.
6. In addition, there is the problem of creating new markets. In general, it brings at least three problems to be solved. Is this market acceptable or fair for the professionals involved? Is the market viable for the industry? If it is, is that affordable for the buyer?

If we are pursuing a minimum of similarities in the analogy that involves genetics, the second similarity is likely to be “DNA is instructions and not
structures”. This could be a reason to prefer the epigenetic approach of Frazer above the pre-formatist approach (which is, by the way refuted in biology) based on geometry.

The advance in the morphogenesis, growth and differentiation from a seed to a complete artifact, as proposed by Frazer, seems to have the potential and probably the robustness to be used in a precedent-based support system.

For future developments in this direction, there are at least four suggestions in building a model:

1. We need to stipulate clear design criteria on how architects could probably recall design precedents and what should be recalled.
2. The analogy and its concepts should be re-evaluated and systematized and the two levels of evolution (ontogeny and phylogeny) should be made clear.
3. One should be able to say where the analogy starts and ends (the same goes for the use of refuted theories; there, too, a minimum number of similarities must be pursued).
4. There should be a way to transform the traditional drawings into a “seed” (this concept, too, should also be evaluated and systematized), which could be manipulated and adapted by the architect to fit new situations.

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