REUSING ARCHITECTURAL PRECEDENTS IN EVOLUTIONARY DESIGN

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Abstract. This paper departs from the so-called generally accepted fact that architects recall their own design solutions to solve new problems. This practice, however, as it is usually carried out, by using their memory and archives, is neither very efficient nor effective. Therefore, this paper investigates the possibility of reusing architectural precedents within the framework of computer-based evolutionary design. The paper questions the potentials of current models in representing the reuse of previous solutions as well as in adapting them to fit new environments. It also speculates on the development of a new approach for the representation of a model for the reuse of architectural precedents.

Keywords: precedents, analogy, evolution, evolutionary design, evolutionary architecture, morphogenetic design, evolutionary model, design solution change, design adaptation, and design solution fit, reuse.

Introduction

"One of the most remarkable characteristics of the human race," say Eberhardt Rechtin and Mark W. Maier (1997), "is its ability not only to learn, but to pass on to future generations sophisticated abstractions of lessons learned from experience.[1]" Concerning the particular case of architectural practice, Rechtin and Maier (1997) say that most of the time architects "have neither the time nor the opportunity to gain the experience needed to create first-rate architectures from scratch.[2]"

Architects often recall their own design solutions to solve new problems. This practice, however, as it is usually carried out, by using their memory as well as their archives, is neither very efficient nor effective. Therefore, the objective of this

(1) [1] Rechtin, Eberhardt and Mark W. Maier, *The Art of Systems Architecting*, chapter two, 1997, p. 24.
(2) [2] ibid.

paper is to investigate the possibility of reusing architectural precedents within the framework of computer-based evolutionary design. The paper questions the potentials of current models in representing the reuse of previous solutions as well as in adapting them to fit new environments. It also speculates on the development of a new approach for the representation of a model for the reuse of architectural precedents.

This paper reflects on three levels: on the level of the analogy; on the level of the representation of the design precedents; and on the level of the cognitive aspect of the architects using such a model in their daily work. The first part attempts to define what is a precedent. The second part tries to define the role of the analogy with the biological evolutionary model, in particular related to the making of a system to recall design precedents. The third part describes and analyses the representation of two models. The fourth part investigates the minimum criteria these models should conform to in order to be an effective tool for the reuse of design precedents in architectural practice. Finally, the fifth part summarizes the advantages and disadvantages of the reviewed models and gives directions towards a better representation for the reuse of design precedents when using an evolutionary model.

Precedent Representation in Design Systems

One can say that there are two main categories of design precedents: the knowledge-based and the case or content-based precedents. Knowledge-based systems make use of design prototypes and/or a set of rules (such as in shape-grammars) derived from the analysis of former projects (cases). These systems are often called generative systems. Case-based systems use design representation(s) of former projects. The representation varies from system to system in the level of detail as well as in the number of instances that are represented (project history). Some case-based systems make use of constraining rules.

There is a sub-category which may belong to both above-mentioned categories: the analogies at project level. For example, the analogies of Eugene Tsui (Illustration 1) between organisms' habitats in nature and human homes; and the analogies made by Santiago Calatrava (illustration 2) between the human body and bridge structures. Though belonging to another field or search-space, these analogies are also cases. However, when architects recall such "cases", they must afterwards derive principles (knowledge) from them so that they may transfer their knowledge and apply it in their own field[3].

In this paper, when we further talk about precedents we are mainly concerned with the case/content based precedents.

(3) [3] (1) Tzonis, A. *Huts, Ships and Bottleracks: Design by Analogy for Architects and/or Machines*, (first published by:) *Archithese* 30 (3) p.p. 16-27, 1990

Illustration 1: Eugene Tsui's Residence for Florence and Willian Tsui ↓

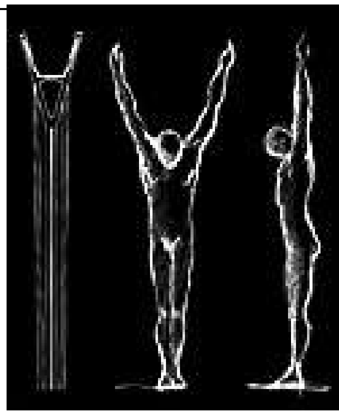

Illustration 2: An analogy of Santiago ↑ Calatrava.The bridges structures and the Human body

The Role of the Analogy with the Evolutionary Model

The analogy with the biological evolutionary model pursued in this paper is at the design process level and is intended to help in the making of a system to recall and adapt design precedents. It is, if compared with the role of the analogy of the above example, at a meta-level.

The analogy at this meta-level supports the reuse of elements of design precedents, such as in nature, when new organisms "reuse" the genes of their ancestors. Like most researchers in this new field of evolutionary design, we are not looking for a true comparison of the two processes. However, we are looking for some similarities that may help us to develop this specific model.

The advances in the computational field of genetic algorithms, as carried out by John Holland, induced the development of several evolutionary models, some of them in the design field. Next, we analyze two models to show the use of their analogy, with the intention of finding which similarities these models have with a system used to recall and adapt precedents into new situations.

Questioning Current Model Representations

This part describes and analyzes two different applications that use an evolutionary model. We analyze their analogies related to their goals and whether the interfaces between model and architects are acceptable in practice.

1. THE ELECTRONIC EMULATOR OF BUILDING SCENARIOS

Celestino Soddu and Enrica Colabella's (Milan Polytechnic University, Italy) 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.”

DESCRIPTION OF THE TOOL[4]:

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 (illustration 3).

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 illustration 4). “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.”

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. The design knowledge is built in the model as parameters of form, growth and movement of the artifact involved.

Illustration 3: goals of Argenìa Design of a series of chairs

ANALYSIS OF THE TOOL[5]:

This system possesses **heritability**, the chairs are the offspring of the same idea and design logic. The system produces **variation**; each chair 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 (a mechanism to be compared with “sexual selection”). However, the process is **not cyclical**. The selected population will produce no new generation. This means that there will be no accumulation of the mutations. Evolution in nature needs variation, but it depends on the accumulation of these variations within innumerous generations.

Fitness is also a concept of great importance in biological evolution. In nature, evolution does not occur if there is variation but not in fitness, i.e. if the differences among the organisms do not matter for survival. 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

(4) [4] Moraes Zarzar, K. - based on "Challenges And Fallacies In Computer Applications Of The Evolutionary Analogy In Design Methodology, Biology and Computation to Revolutionize Design Practice", *CAADRIA 2000* not yet published

(5) [5] Moraes Zarzar, K. - based on "Challenges And Fallacies In Computer Applications Of The Evolutionary Analogy In Design Methodology, Biology and Computation to Revolutionize Design Practice", *(*submitted to:*)Le Carre Bleu,* 2000

their generated chairs are of the same fitness: Soddu and Colabella's model provides countless successful examples or scenarios. In the case of the chairs, though, it is difficult to understand, looking to its results, 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.

Illustration 4: Celestino Soddu's system for generation of chairs

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.

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.

Nevertheless, the production of scenarios for the development of cities seems to be the great advantage of this system. The tool provides several scenarios according to the changes planned, what may help in making decisions to avoid undesired impacts on the future of the city. The tool is then used and even

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

transformed during many years which compensate for the time spent in building laborious parameters.

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 this model is "to achieve in the built environment the symbiotic behaviour and the metabolic balance that are characteristic of the natural environment." Therefore, says Frazer, *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)[6].

DESCRIPTION OF THE TOOL[7]:

Frazer 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 the process of evolution.

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. 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.

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 in forming a concept, although, says Frazer, "the prototyping, modeling, testing, evaluation and evolution, all use the formidable power of the computer."

ANALYSIS OF THE TOOL[8]:

Frazer takes the biological evolutionary model as a source of inspiration. However, his concepts, sometimes, diverge greatly from the process in nature. To help understand 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

(6) [6] Frazer, John– *An Evolutionary Architecture*, Architectural Association, London, 1995, p. 9

(7) [7] Moraes Zarzar, K. - based on "Challenges And Fallacies In Computer Applications Of The Evolutionary Analogy In Design Methodology, Biology and Computation to Revolutionize Design Practice", (submitted to:) *Le Carre Bleu* 2000

(8) [8] Moraes Zarzar, K. - based on "Challenges And Fallacies In Computer Applications Of The Evolutionary Analogy In Design Methodology, Biology and Computation to Revolutionize Design Practice", (submitted to:) *Le Carre Bleu* 2000

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's development i.e. epigenesis, ignoring the role of phylogeny. 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[9]. Third, he uses an Epigenetic Algorithm[10] to breed a population instead of developing the individuals[11].

Fourth, the fertilization of the seed is done using John Holland's[12] genetics operators: crossover and mutation[13]. In nature, crossover is a mechanism that happens before fertilization, during gamete forming. Crossover (see illustration 5) 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 original parental chromosomes. 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[14]. Because changes in the environment immediately redirect the development of the organism, **natural selection** has a much less important role in it than growth, morphogenesis and differentiation that belongs to the concept of epigenesis. As a result, the process produces artifacts with optimal fitness, which again eliminates the role of natural selection.

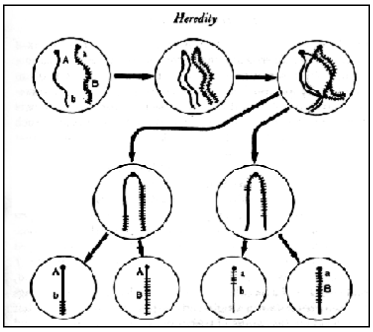

Illustration 5: "Crossover in nature," according to John Maynard Smith

(9) [9] ibid. p. 89
(10) [10] ibid. p. 83
(11) [11] ibid. p. 89
(12) [12] Holland, John - *Adaptation in Natural and Artificial Systems*, 1992.
(13) [13] Frazer, John– *An Evolutionary Architecture*, Architectural Association, London, 1995, p. 98
(14) [14] ibid. p. 89

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." [15] Indeed, Frazer and J.M. Connor's paper, "A Conceptual Seeding Technique for Architectural Design", 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."[16] In other words, Frazer's tools for an evolutionary architecture "are clearly not intended to reinforce existing practice."[17]

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.

Minimum Adequacy Criteria

Design problems, though ill defined, have an initial state (brief or program), which is transformed until they finally produce a set of working drawings that describe a solution. During this problem-solving process, says Ömer Akin[18], architects make use of many search strategies that minimize the large number of transformations necessary to reach a solution.

We think that one of the strategies that architects use to minimize transformations is the use of experience, the adaptation of design precedents relying on their memory and their archives. The model for the reuse of design precedents is, therefore, thought to help architects, in particular architect teams, to find design precedents to support their actual work.

After briefly analyzing the two knowledge-based applications for the generation of designs, we provide some adequacy criteria for a model for the reuse of design precedents. Only after developing criteria for this model, we can evaluate the reviewed processes and see whether the applications are robust enough to support the new model. The success of the proposed model could be later measured according to these criteria. Some adequacy criteria for our provisional model derived from a case study on a series of projects by the architect J.J.P. Oud, and some derived from a literature review on design methods, which drove us to the architects' problem- solving strategies.

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(15) [15] Lawson, Bryan, chapter 16 Designing with computers, *How Designers Think, the design process demystified,* 1997, pp. 290-291

(16) [16] Frazer, John and J.M. Connor, "A Conceptual Seeding Technique for Architectural Design" - *ParC 79: International Conference on the Application of Computers in Architectural Design*, conference proceedings, pp. 425-434.

(17) [17] Frazer, John, *An Evolutionary Architecture*, Architectural Association, London, 1995, p. 60

(18) [18] Akin, Ömer - *Psychology of Architectural Design*, Pion Limited, London, 1986

During J.J.P. Oud's case study, we observed/explored the design process in relation to the reuse and adaptation of design precedents to draw adequacy criteria for this evolutionary model. The unit of analysis was a group of historically ordered social housing projects that he designed when he was working in the municipality of Rotterdam. Generalizing from this case, we produced our first criteria:

a. Given that architects often use part of a design precedent and not the whole of it, the model ought to have mechanisms to explore, select and recall parts of a project.

b. Given that precedents are not simply used, but most of the time adapted to the new situation, the model ought to have mechanisms to support adaptation.

c. Given that some elements (like bridge structural elements) are often recruited from diverse design precedents, the model ought to provide mechanisms to search per elements.

d. Given that elements and parts may be scattered through several design precedents, the search result of the recollection system ought to be able to provide not only the fittest, but also several precedents.

Having these criteria from a series of projects would not produce a suitable tool unless we could provide a tool that matches the architects' design strategies. This brings us to the study of design methods to solve the problem of interface between the model and its user.

One difficulty is that designing is not completely similar to general scientific problem-solving. Design is concerned with how things ought to be, instead of with how the things are (Simon, 1996)[19].

In architecture, changing the rules and the use of analogies are part of the process, while in science, representation and transformation are known a priori (Akin, 1986)[20]. Moreover, architects also go back and forth in the search for the solution to their problem, reflecting while acting (Schön, 1985). Therefore, the model must provide the designers not only with multiple views of the design precedent but also with different stages of development/ontogeny with a historical view of the diverse instances of the design precedent.

Furthermore, given that architects are active agents in the process, the model ought to have mechanisms which enable the architect to recall, add, subtract, mutate or substitute elements of the precedent. They may adapt beyond the design precedent complexity (Recapitulation) or from a selected instance (Paedomorphosis) by the use of some generic representations (Achten, 1997)[21]. That is to say, genetic mechanisms are imbedded in the model, however, it is artificial selection and not Darwinian natural selection that is used to guide retrieval and the recombination of precedents.

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(19) [19] Simon, Herbert - *The Science of the Artificial*, MIT Press, Cambridge, 1996

(20) [20] Akin, Ömer - *Psychology of Architectural Design*, Pion Limited, London, 1986

(21) [21] Achten, Henri - *Generic Representations*, TU Eindhoven, 1997

Finally, the protocol for recruitment to be used in the recollection of precedents must support the architect's cognitive process; and design precedents must be retrieved in manageable documents (no photos).

Towards a Good Representation

According to the criteria above, we can now evaluate the potentials of the reviewed applications to support the reuse and adaptation of design precedents.

1. EVALUATION OF THE MODELS

The disadvantages and advantages of the applications to support our model are:

a. The notion of evolution is reduced to that of biological transformation eliminating or distorting the notion of fitness.
b. The evolution is stressed during ontogeny, which is related to epigenesis or the development of a project, instead of during phylogeny, the history and relationship between ancestors or former projects.
c. Frazer's model shows a reduced amount of design knowledge built into it.
d. Soddu and Colabella's model has a great amount of parameterized design knowledge on form, growth and movement. However, these parameters are not evolving (see chair's model analysis).
e. The demands of architectural practice are not answered

We think that the mechanisms used to “evolve” design in software, though, should be considered in their potential to represent design precedents. This representation may facilitate the adaptation of the precedent to fit new situations. However, a systematization of the analogy is necessary.

In the paper presented by the author at CAADRIA 2000 (Moraes Zarzar, 2000), four suggestions were given towards the making of a model for the reuse and adaptation of design precedents[22]:

a. The analogy and its concepts should be re-evaluated and systematized and the two levels of evolution (ontogeny and phylogeny) should be made clear.
b. We need to stipulate clear design criteria on how architects could probably recall design precedents and what should be recalled.
c. 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.
d. 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).

(22) [22] Moraes Zarzar, K. -"The question of Representing Design Based on Precedents, A review of the Evolutionary Biological Analogy in the Making of Design Tools", CAADRIA 2000

2. THE SYSTEMATIZATION OF THE ANALOGY[23]

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.

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. An evolutionary analogy should at least be concerned with the key notions, such as the notion of evolution and genetics.

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 and there is confusion between ontogeny and phylogeny (Gould, 1977)[24]. 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.

3. FINAL NOTES

In *The Art of Systems Architecting* (Rechtin & Maier, 1997), Rechtin and Maier say that a system [model] has 5 views, each having its own models [sub-models]. Thus, a system has a Purpose, i.e. the system architect must know "what the client wants". The system has a Form View, which tells us "what the system is"; a Behavioral or Functional View, which tells us "what the system does" [maybe how the system works would be a more interesting question]. A system has a Performance View, which tells us "how effectively the system does it"; a Data View, which has "the information retained in the system and its interrelationships"; and finally it has a Managerial View, which is "the process by which the system is constructed and managed"[25]. The Managerial View could, in our opinion, be divided into two views: the method of how to construct the system, and the implementation, or how the system should be managed and maintained.

(23) [23] Moraes Zarzar, K. - based on "The question of Representing Design Based on Precedents, A review of the Evolutionary Biological Analogy in the Making of Design Tools", *CAADRIA, 2*000

(24) [24] Gould, S. J. - *Ontogeny and phylogeny*, Belknap Press of Harvard University Press, Cambridge, Mass. 1977

(25) [25] Rechtin, Eberhardt and Mark W. Maier, chapter seven, *The Art of Systems Architecting*, 1997, p.122.

To meet our purpose, we decided to explore, heuristically, the evolutionary model, meaning that the form, behavioral and data view derive at some extension from this analogy.

That is the reason why we should define the limits of the analogy by exploring its similarities with the process in architecture and eliminating the rest. This way, one can decide which information the system should retain without either being lost in the multitude of theories, processes and taxonomies of Evolutionary Biology; or being shallow and miss the opportunity to get a real contribution from this analogy.

Generally speaking, these views of a system give some guidance on how to proceed in the making of our model, but it is far from telling us the content or the answers to the questions asked in each view to build the model. However, a systematized evolutionary analogy may provide us with the content. It may provide us with definitions of essential concepts, their mechanisms and system's views, which may guide us towards a suitable taxonomy for the reuse of design precedents.

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