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Computational Organicism: Examining Evolutionary Design Strategies in Architecture

Abstract. The diverse forms of nature, in particular and biological forms, have long been a preoccupation of the architect. As a special category of natural form, biological organisms exhibit extraordinary levels of design adaptability across multiple generations based upon the inherent ‘intelligence’ of the evolutionary mechanism. Evolutionary design theory in architecture seeks to harness this generative intelligence as the foundation for a new architectural design process. This paper investigates the lineage of evolutionary thought in architectural design, paying particular attention to the current trend towards experimentation with generative algorithmic procedures and the theorization of an evolutionary architecture.

Only nature is inspiring and true; only Nature can be support for human works. But do not render Nature, as the landscapists do, showing only the outward aspect. Penetrate the cause of it, its form and vital development...

Charles L’Eplattenier, 1906, quoted in [Le Corbusier 1925: 198]

Underlying the many visible elements of animal form are remarkable processes, beautiful in their own right in the way that they transform a tiny, single cell into a large, complex, highly organized, and patterned creature, and over time, have forged a kingdom of millions of individual designs.

Sean B. Carroll [2005: 4]

The idea of evolution as we understand it today – a process of natural selection operating within a population of variable replicators – was first introduced to the scientific community by Charles Darwin and Alfred Russel Wallace at the Linnean Society of London in 1858, and was given its first public exposure the following year with the publication of Darwin’s book *On the Origin of Species*. In this seminal work, Darwin lays bare for the first time the mechanism of design in the biological world. Then, just four years later, the *Revue Générale de l’Architecture* coined the term “Organic Architecture” as a means of relating architecture to the “organized life of animals and vegetables” as opposed to the “unorganized existence of the rocks which form the substratum of the world” [Collins 1965: 156]. Regardless of whether the editors of the *Revue* were aware of Darwin’s controversial theory at the time, and despite the fact that the rhetoric of organicism in architecture has subsequently been as variable as the forms that Darwin’s theory describes, the distinction set forth by the *Revue* still remains fundamentally relevant.

Today the debasement of geological forms as “unorganized” is clearly disputed by current scientific theories of self-organization and emergence, which ascribe to matter the inherent generative capacity for spontaneous development of complex order. And even

though organic life is now generally viewed by science as being subject to the same dynamic processes of self-organization as inorganic matter, there still remains one fundamental distinction between the two, and that is DNA: that uniquely productive two-dimensional expression of organic matter that propels the development and evolution of complex adaptive forms among populations of organisms over time. Although we no longer view geological structures as purely informal – as did the editors of the *Revue* in 1863 – the fundamental distinction between rocks and living organisms remains; rocks do not evolve, but plants and animals do. Thus, I believe that the various theories surrounding the pursuit of “organicism” in architecture must be viewed largely in the context of evolutionary thought. After all, in the intervening 150 years since the near simultaneous debut of both Darwin’s famous theory and the early rhetoric of organicism in architecture, evolutionary science has come to dominate the field of biology. To biologist Sean B. Carroll, the role of evolution in biology is primary: “...evolution is much more than a topic in biology – it is the foundation of the entire discipline. Biology without evolution is like physics without gravity” [Carroll 2004: 294]. Furthermore, the subsequent breakthroughs in heredity, morphogenesis, and evolutionary development have profoundly transformed our understanding of organic forms and the processes by which they are created, and figure prominently in the contemporary pursuit of a “living” architecture [Hensel 2006].

Many architects today appeal to some notion of evolutionary thinking as a strategy for architectural design. Recent scientific discoveries concerning the distinctly computational mechanisms underlying evolutionary biology, paired with ever-increasing sophistication of digital design software, have inspired and enabled architects to experiment with such tools as genetic algorithms and environmental morphogenetic simulation. The resulting proliferation of formal variety represents a temporal *becoming* that is neither metaphorical nor symbolic, but operative and literally creative. Such a conception of form rejects the recognition of final or ultimate forms in favor of a continuum of evolutionary forms that are continually renewed, either by the influence of external dynamical forces, or through the unfolding of endogenous processes of growth and mutation. This paper investigates the lineage of evolutionary thought in architectural design, paying particular attention to the current trend towards experimentation with generative algorithmic procedures and the theorization of an evolutionary architecture. The motivations for these projects are interrogated through the writings of their proponents. To what extent are they practical – striving for an iterative design optimization through the power of computational variability – and to what extent might they belie an underlying philosophical project, seeking to model a theory of architectural design after the generative processes of nature?

Nature’s fecundity, its capacity to produce extraordinary diversity, and our intuitive appreciation of the beauty, economy, and sublimity of biological systems have long inspired admiration and mimicry in the fields of architecture, design and engineering. The use of biomimetics, or the strategic application of adaptive biological design principles to manmade systems, is just one example. Subsequent to the publication of Darwin’s theory, evolution has captured architects’ imaginations as a way of thinking about design. But before it was theorized as a procedural method for architectural design, the notion of evolution was considered primarily as a conceptual analogy. In *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts*, Philip Steadman offers an explanation for why theories such as organicism, speciation, and

evolution have been used so often as metaphors in the history of architecture. According to Steadman:

... there are characteristics of designed objects such as buildings, and characteristics of the ways designs are produced ... which lend themselves peculiarly well to description and communication via biological metaphor. The ideas of 'wholeness', 'coherence', 'correlation' and 'integration', used to express the organized relationship between the parts of the biological organism, can be applied to describe similar qualities in the well designed artifact. The adaptation of the organism to its environment, its fitness, can be compared to the harmonious relation of a building to its surroundings [Steadman 1979: 4].

Steadman proceeds to classify historical uses of the biological analogy in architecture, identifying several variations on the theme, including preoccupations with growth, anatomy, and classificatory systems. However, as it relates to architecture, his discussion of Darwinism hinges on an understanding of an "evolutionary" development of styles or design trends across time. In other words, his view that the "phenotypic materials" of older styles were adopted and subsequently "mutated" by later architects considers evolution in architecture as a lineage of stylistic tendencies and gradual mutations, punctuated by occasional instances of sudden innovation.

For Steadman, then, architectural evolution is a metaphorical tool for historical analysis, a lens through which the historian can understand a genealogy of styles, which are seen as distinctly historical entities whose forms have progressed over time toward states of higher optimization (for a discussion of the problematic social implications of this view see [Cogdell 2004]). In their search for an architectural theory of evolutionary design, today's organic architects require a very different theoretical framework – one that has the capacity to be generative rather than simply analytical. Nonetheless, Steadman's attempt at a comprehensive analysis of biological metaphor in architecture marks a critical turning point in the development of evolutionary architectural thinking. The timing of this publication (1979) is significant, appearing at a time when operational applications of biological thinking in the form of genetic algorithms had been tested in other fields such as sociology and economics, but had only just begun to be applied to the realm of architecture.

Contemporary architecture's interests in evolutionary systems and biological adaptation have been directly inspired by Darwin's theory of evolution, as well as by the subsequent lineage of scientific achievements in genetics and morphogenesis. Many architects have become interested in adapting this method of form generation and selection as a way to tap into the productivity of the natural world. In 1995, John Frazer published the pioneering *An Evolutionary Architecture*, in which he describes over two decades of research at the Architectural Association, which investigated "...fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of morphogenesis in the natural world" [1995: 9]. He identifies several important motivations behind this endeavor:

Architecture is considered a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection. The aim of an evolutionary architecture is to achieve in the built environment the symbiotic behavior and metabolic balance that are characteristic of the natural environment [1995: page].

To this end, Frazer – who worked under Cedric Price on the Generator project – has examined several technical aspects of the evolutionary design model and their architectural application. His research with students at the AA and the Cambridge University mathematics laboratory represented the first comprehensive attempt to develop both the conceptual and the computational framework required for the generative design of architectural forms, as well as their evolutionary response to environmental factors. He identifies the requirements of the evolutionary model as follows: “a genetic code-script, rules for the development of the code, mapping of the code to a virtual model, the nature of the environment for the development of the model and, most importantly, the criteria for selection” [1995: 65].

Fig. 1. Frazer's Reptile units [1995: 70]. Reprinted, by permission of John Frazer

By the late 1960s, Frazer had already experimented with the first of these elements. His “Reptile” structural system (rep-tile for repetitive tile) was an early attempt at creating a generative formal system capable of being manipulated in the computer as a “genetic code” (fig. 1). Reptile was a component-based approach that utilized a pair of simple structural units. These units could be combined in a number of ways to create a variety of complex forms, and these combinatorial instructions could be manipulated as code within the computer. Although Frazer was already aware of the limitations of a component-based system, and was looking for a more universal process-oriented approach, the required computational power for more complex systems was not yet available. Much later, in 1991, he developed the “Universal Interactor” as a means of influencing the development of his genetic experiments with external environmental factors. The Universal Interactor project consisted of a series of antennae that recorded various environmental data, which were then used to influence the development of the computer model. Later, software packages capable of modeling dynamical environmental forces, such as Maya, would become popular tools for the architectural exploration of environmental influences. These were not readily available to architects at the time of Frazer's research.

Frazer observed that many of the breakthroughs necessary for the development of an evolutionary model of design occurred outside the field of architecture. In addition to the dramatic achievements of genetics and evolutionary biology, innovations in mathematics and computational modeling provided the impetus for many of the early experimentations with evolutionary design techniques. For example, a significant milestone in the development of evolutionary design tools came with the publication of John Holland's *Adaptation in Natural and Artificial Systems*. Affiliated with the University of Michigan and the Santa Fe Institute, Holland is credited with the development of the earliest genetic algorithms in computer science. His work on this subject began in the 1960s, when he identified evolutionary adaptation as the common feature of biological, social, and economic systems. In each field he identified analogous inputs – structures, operators, and performance measures – all of which allowed for the systematic modeling of adaptation through the use of computational genetic algorithms.

Fig. 2. Example of Dawkins' biomorphs, developed over 29 generations in his EVOLUTION software [Dawkins 1996: fig. 4]. © Richard Dawkins 1996, 1987, 1986. Reproduced by permission of the publisher, W.W. Norton & Company, and by permission of SLL/Sterling Lord Literistic, Inc.

Following Holland's pioneering use of genetic algorithms in the analysis of complex systems, one of the earliest and most widely known applications of evolutionary design experimentation was Richard Dawkins' "biomorphs." In *The Blind Watchmaker*, Dawkins developed a simple genetic algorithm to "evolve" populations of simple two-dimensional graphic elements (this application is available online as a java applet: <http://physics.syr.edu/courses/mirror/biomorph/>). His early experiments breeding these "biomorphs" (fig. 2) in a digital environment represented a milestone in the development of artificial evolutionary strategies: he was among the first to illustrate clearly that in the

absence of a preconceived design, complex forms could be produced from very simple origins through the iterative process of replication, mutation, and selection. A few years later, Frazer himself was able to further his own architectural experiments by following Dawkins' example and by modifying John Holland's genetic algorithms to account for the influence of environmental data.

While it is clear that the development of the genetic algorithm, as well as other programming systems, have made available the necessary computational tools to explore variable populations of designs in the computer, it should be noted that this type of design strategy has also been implemented by hand. William Latham's experimental use of evolutionary techniques as a method of form generation in art is notable, as his work attempts to address the application of aesthetic judgment as the sole determinant of a design's "fitness." His work is directly inspired by natural systems and their tendency toward the development of complex designs from simple recursive operations. Beginning a few years after the publication of Dawkins' biomorphs, Latham conceived an evolutionary design methodology as a manual exercise that performed a series of recursive plastic deformations on a collection of simple forms. This process results in a complex drawing of a phylogenetic tree diagram, which Latham calls the "FormSynth tree" (fig. 3). This diagram chronicles the "evolution" of the original shapes into a variety of complex forms, of which only a few would be selected for fabrication as physical sculptures.

Fig. 3. Hand-drawn FormSynth tree [Todd and Latham 1992: 107]. Reprinted by permission of William Latham

Together with Stephen Todd, Latham developed a custom software tool to automate the processes of three-dimensional form generation and mutation. However, Latham did not automate the process for determining the fitness criteria for replication. Similar to

Dawkins, Latham asserts his role as an artist by subjectively selecting one or more iterations of mutation at each generation according to his own aesthetic judgment. Accordingly, his process could be thought of as a form of genetic breeding, where the artist “steers” the development of form by reacting to generation after generation of random mutation. While not yet architecture, Latham’s work as an artist is informative in the way that it uses an evolutionary strategy in an opportunistic way as an effective proliferation of formal variation. The unique choices that Latham faced while steering this selection process are similar to those faced by an architect who might choose to employ this type of evolutionary design strategy. As Dawkins’ analogy of the blind watchmaker suggests, evolution is a mechanism that proceeds without intentionality, in the absence of a designer. Accordingly, an evolutionary approach to design seems to require a fundamental reconsideration of the architect’s role in the design process.

With this question in mind, Manuel Delanda establishes a theoretical groundwork for the application of genetic algorithms to the architectural design process. In a 2001 essay entitled “Deleuze and the Use of the Genetic Algorithm in Architecture”, Delanda adopts a Deleuzian philosophy of form generation, advocating use of population thinking, intensive thinking, and topological thinking as ways to theorize a new role for the architect as the designer of evolutionary architectonic form. His proposal for a virtual process of evolution attempts a comprehensive analog to biological evolution by addressing issues of morphological heredity among variable populations of architectural structures, all of which would be selected for reproduction according to environmental fitness (structural viability in his example), among other subjective criteria. Assuming that the architect is able to overcome the technical challenges of visual representation and environmental responsiveness – most likely by bringing together a three-dimensional CAD package with an engineering platform for structural analysis – he then moves on to address the conceptual challenges posed by such an endeavor.

For Delanda, the main task of the architect becomes the design of a sufficiently productive search space. The primary advantage of genetic algorithms, which he identifies as a special case of search algorithms, is their propensity to “discover” unexpected problem solutions that had not been previously considered. Consequently, only a wide search space is likely to offer a truly innovative result. In his words:

... the space of possible designs that the algorithm searches needs to be sufficiently rich for the evolutionary results to be truly surprising. As an aid in design these techniques would be quite useless if the designer could easily foresee what forms will be bred. Only if virtual evolution can be used to explore a space rich enough so that all possibilities cannot be considered in advance by the designer, only if what results shocks or at least surprises, can genetic algorithms be considered useful visualization tools [Delanda 2002: 9].

The process of “breeding” buildings in virtual environments presents a radical reconfiguration of the architectural design process. Again, Delanda does not see this as the relegation of the architect to the level of “prize-dog” or “race-horse breeder”; rather, he imagines the architect as a designer of abstract architectural “body plans” from which tremendous diversity can evolve. Delanda draws on Deleuze’s identification of topological invariants as the abstract morphological commonality among related forms that are distinct in metric space, encouraging architects to become the designers of

“abstract diagrams” – topological forms that would serve as the undifferentiated inputs to the automated search procedures of an evolutionary algorithm:

... if evolved architectural structures are to enjoy the same degree of combinatorial productivity as biological ones they must also begin with an adequate diagram, an ‘abstract building’ corresponding to the ‘abstract vertebrate’. And it is at this point that design goes beyond mere breeding, with different artists designing different topological diagrams bearing their signature [Delanda 2002: 12].

Here Delanda’s assertion of “artistic” autonomy differs from William Latham or Richard Dawkins, who guided the selection of forms at every generation of their evolutionary processes. For the true power of an evolutionary process to be harnessed, Delanda believes, seemingly useless formal developments must be allowed the chance to propagate through many generations, recognizing that these mutations may eventually develop into unexpectedly useful features. This is the most radical aspect of an evolutionary logic: truly advanced structures do not emerge within the span of only a few generations but develop gradually, over long durations. In a sense, then, the designer must resist the temptation to exert excessive control of the selection process, to allow for the possibility of the useful anomaly. Accordingly, Delanda de-emphasizes the designer’s role in the evaluation of selection criteria. Rather, by proposing an exploration of diverse architectural “body plans,” he emphasizes the importance of the initial “seed germ” and the subsequent rules for automated formal differentiation as the factors most influential to the outcome of the design process.

In 2001 a team of architects and computer scientists at MIT developed an experimental design tool called *Genr8*, which incorporates evolutionary computation, generative computation and environmental modeling into one unified software package. Though primitive, *Genr8* was seen as offering architects a valuable opportunity to work within the framework of an evolutionary design environment. Developed for the 3D modeling platform Maya by Martin Hemberg of the Architectural Association and Dr. Una-May O’Reilly of MIT’s Emergent Design Group, the plug-in was intended to “instrumentalise the natural processes of evolution and growth, to model essential features of emergence and then to combine these within a computational framework” [Menges 2004: 49]. With *Genr8*, designers are limited to the use of surface geometries, but these surfaces can be “grown” in a virtual environment using a three-dimensional L-system as the formal “genetic” coding. Growth of these surfaces is influenced by any number of virtual forces that the user situates in three-dimensional space, providing for the simulation of gravity, wind, and other environmental influences. Inclusion of an evolutionary module allows for populations of these surfaces to be selected for replication across many generations according to the designer’s intent. The opportunity for multiple, parallel selection criteria is the most interesting feature of *Genr8*. Unlike traditional genetic algorithms, which typically evaluate a single selection criterion, *Genr8* allows the designer to both automate the selection process, and to manually intervene according to an entirely subjective set of criteria. This suggests an interesting parallel between functional optimization and aesthetic preference.

As an experimental application of these opportunities, the architect Achim Menges co-opted this tool for the design of a strawberry bar at the Architectural Association’s annual project review (figs. 4 and 5). For this project, Menges attempted to optimize both the design and fabrication of the bar using an evolutionary design strategy. In his

words: “The potentials and limits from initial form generation to the actual manufacturing process were explored by shifting the investigation towards performative patterns that evolve as species across populations and successive generations whilst maintaining structural capacity and geometric characteristics” [Menges 2004: 52]. Interestingly, Menges identified multiple populations of forms for selection rather than individuals, as seen in Latham’s work. According to Menges,

the criterion for evaluation was the relative fitness amongst the emergent species rather than the absolute fitness ranking of any particular individuals ... The individual of the chosen species that grew in the last and most developed generation was then selected [Menges, O’Reilly and Hemberg 2004: 53].

In this way, Menges enabled the development of multiple species of designs to develop adequate complexity, and a subsequent richness of design variation was achieved.

Fig. 4 (left). Population of surface species produced in Genr8

Fig. 5 (right). Final design model, from [Menges, O’Reilly, and Hemberg 2004: 52-53].

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Underlying Manuel Delanda’s proposal for an evolutionary architecture is a pragmatic motivation, and his advocacy of genetic algorithms and generative systems is opportunistic. Similar motivations are also evident in the writings of John Frazer, William Latham, and Achim Menges. In their work, natural biological processes of design are emulated not from a mystical desire for communion with a divine force of creativity, but rather in recognition that human design methodologies have yet to produce either the sophistication or the diversity of the natural world. In this sense many architects today have turned to nature in the hope of producing increased efficiency, economy, variety, and innovation. Despite the pragmatism of this approach, there are indeed profound implications for the practice of architecture. If we accept Dawkins’ assertion that nature “builds its watch blindly,” so too must architecture open itself to the emergence of the unexpected [Dawkins 1986]. Similarly, Inge Rocker asserts that such a

transition away from “a priori ideas towards one of evolution ... requires us to ... examine the current emphasis that is placed on originality, authorship and identity in architectural culture” [Rocker 2002 10].

Although evolutionary systems represent just one set among a diverse array of tools made available with the widespread use of the computer in the design process, the potential of these systems is profoundly far reaching. The development of an evolutionary methodology demands an entirely new design intuition. Recently, as architects and designers have become more accustomed to the use of dynamic simulation tools and hierarchical parametric software, they are developing a sensibility for a formal design process which privileges plasticity and mutability over fixity and stasis. According to Rocker, architects have departed from “... the traditional, predominantly ontological comprehension of architecture” [2002: page] She suggests that architecture is now “... an evolving and dissolving differential data-design that no longer simply ‘exists’ but rather ‘becomes’ ...” [2002: 11]. Clearly, an understanding of formal variability is one important step toward an evolutionary design model, but a truly robust genetic system must also incorporate all of the elements previously mentioned by John Frazer, including generative formal strategies, evolutionary computation, and environmental modeling. Armed with these tools, architects will have the power to construct multiple, dynamic processes of formal generation across variable populations of species through time, guiding these forms through a perpetual state of becoming. Only then will the mechanisms of design in the natural world be activated as truly generative agents for a computational organicism in architecture.

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