Evolutionary Computing and the Potential for Urban Resilience

"The environment must be organized so that its own regeneration and reconstruction does not constantly disrupt its performance."
- Christopher Alexander[1]

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This paper addresses methodological issues related to the implementation of evolutionary and computational solvers toward the production of a systemically oriented architecture. Certainly, the extensive use of parametric tools has expanded the generative and representational nature of architecture, creating different forms of scalar interactions, which appear to be more contingent to specific territorial conditions typical of ecosystems exposed to major climatic changes. While relatively exuberant in its formalistic nature, the idiosyncratic narrative of evolutionary computing demarcates a pedagogical framework, which appears to be rationally bound to disciplinary contingency and open to new methodological circumstances.

Conceptually speaking, computational design strategies, understood as systemic and methodological paradigms, provide a framework of complexity that links form, program and structure. The vast majority of those algorithmic models normally look at the organizational complexity of bio-analogues complex systems, whose form adaptation appears to be in constant feedback with the intrinsic nature of its organic structure. The importance of such praxis has to be found in its capacity to create scenarios characterized by diversity and adaptability.[2] Methodologically speaking, computation involves processing information algorithmically while creating a set of procedures regulated by precise mathematico-logical rules that generates operations necessary to solve a given problem. Broadly speaking, an algorithm is a sequence of explicit and finite instructions defined by particular scripts, which can be manipulated, customized, and adapted; it is a strategy codified to solve a specific problem.[3]

While my paper address systemic adaptation to specific climatic agents, I believe that it is opportune to look at evolution and its procedural emergence of a new ideological framework which is characterized by complexity and patterns of flow. Evolution is generally understood as the change in the inherited characteristics of biological populations over successive generations. These processes generate diversity at every level of biological organization, including species, individual organisms and molecules such as DNA and proteins.[4] Evolution is essentially a methodology that seeks solutions for survival to changing ecosystems. Additionally, this process necessitates the establishment of particular self-organized patterns of evolutionary formations that might create new situations and new scenarios relatively intertwined with some of the peculiarities of a given ecosystem. Thus, how do we regulate and control this complex system so that we can manipulate its systemic and generative nature? To answer this question, it is important to survey the work of Lawrence Fogel, who sought intellectual adaptation through algorithmic mechanization. In *Intelligence Through Simulated Evolution*, he stated that:

> "As effort to measure the intelligence of decision making has progressed, there has been a concurrent inquiry into the logical structure of intellect. This inquiry has grown out of purely philosophical speculation into the mechanization of various hypotheses with a view toward demonstrating their validity. It is now generally agreed that a better understanding of the organization of intellect can be demonstrated by constructing a device that exhibits what is said to be intelligent behavior."[5]

The device mentioned by Fogel is what is generally called an evolutionary solver, which is essentially a subset of evolutionary computation, a generic population-based metaheuristic algorithm characterized by strategies that guide the search process in order to find the fittest solution. Within this non-deterministic system, candidate solutions are generated by association between genomic inputs and fitness functions, which eventually determine the quality of the solutions. Evolutionary assembly, or the selection of the most appropriate forms, takes place after the repeated application of the above-mentioned operators has come to a stagnant halt (Figure 1).

While evolutionary solvers have come a long way since Lawrence Fogel first proposed them in 1961, their use in architecture and urban design has been limited by stylistic developments that have erroneously identified computational strategies as the ultimate legitimation of aesthetically driven

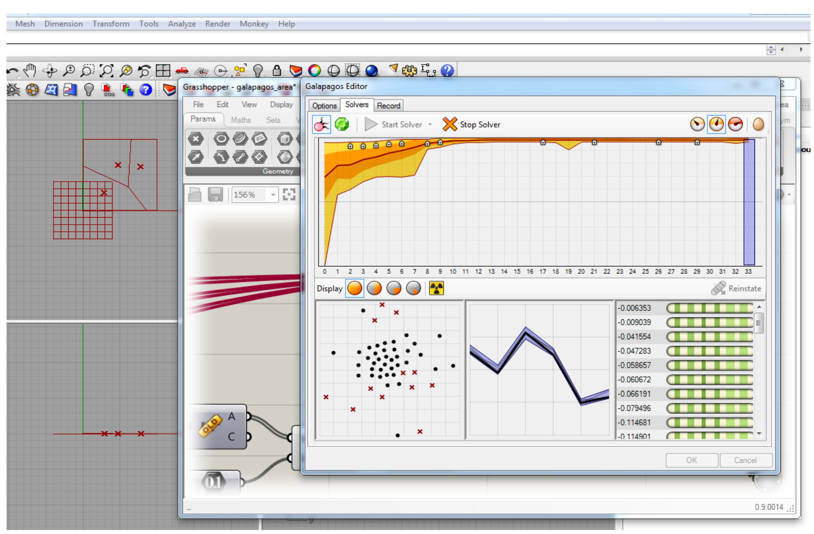

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Figure 1: Optimized solution as processed by Galapagos editor

methodologies. Indeed, form does not arise from chaos, but it emerges from a very contingent system based on mathematical laws that justify pattern-making processes. Thus, considering the evolutionary qualities of this model, how can we design, program, and then transform our built environment so that it becomes completely responsive to the hosting ecosystem and its climatic agents?

My paper theoretically and pedagogically breaks down an alternative process, which discards the indexicality of typical sustainable developments while focusing on the implementation of ecological and algorithmic models of urbanization. This methodology involves an approach based on the generative characteristics typical of self-organizing systems, which seek urban adaptability while processing human and climatic feedback in the form of visual scripting language; eventually, this process generates morphogenetic urban solutions more consistent with the dynamic qualities of a specific bio-network.

EVOLUTIONARY COMPUTING: A SYNOPSIS

> "Given the potential for evolution to optimize solutions to problem, it seems only natural to run to evolution toward the problem of how to best search for those solutions: essentially to use evolution to optimize itself." – Lawrence Fogel[6]

Evolutionary computation is a branch of computer science that looks at biological models of morphogenetic behavior in order to solve complex computational problems that require adaptability to changing environments.[7] This process is based on the understanding that evolutionary processes provides a method for parsing, filtering and evaluating a large amount data while generating a finite number of adaptable solutions. However, this paper does not support a typical formalist agenda that fetishizes bio-analogue formations; instead, I argue that it is only through the use of certain computational strategies and the development of precise generative algorithms that optimize variance, that we can establish a new mathematico-logical praxis more responsive to climatic issues, and more open to optimal morphogenetic variance.

Like mentioned before, evolution is the process of change in all forms of life over generations, while evolutionary biology is the study of how evolution occurs. Life evolves by means of mutations (changes in an organism's hereditary information), genetic drift (random change in the genetic variation of a population from generation to generation), and natural selection (the non-random and gradual process of natural variation by which observable traits (such as eye color) become more or less common in a population). Another important term is that of "ecological inheritance" which is defined by the regular and repeated activities of organisms in their environment.[8] This generates a legacy of effects that modify and feed back into the selection regime of subsequent generations.[9]An individual organism's phenotype results from both its genotype and the influence from the environment it has lived in. A substantial part of the variation in phenotypes in a population is caused by the differences between their genotypes. Amos Hardwood stated that "The modern evolutionary synthesis defines evolution as the change over time in this genetic variation. Variation disappears when a new allele reaches the point of fixation – when it either disappears from the population or replaces the ancestral allele entirely."[10]

The first to actively develop a mechanized system or a methodology that would follow some of the principles of evolutionary theory was Lawrence Fogel. In 1964, while at UCLA, Fogel completed his doctoral work *On the Organization of Intellect*, which would later evolve into one of his most famous publications, *Artificial Intelligence through Simulated Evolution*, published in 1966 by John Wiley & Sons. With this publication, Fogel essentially discarded what he called primitive neural networks or experience-based techniques for problem solving while he emphasized the implementation of alternative systems more open to adaptive behaviors and their relationship to specific changing environments.

> "And what are goals made of? They are made of the factors that contribute to self-preservation, the invariance of identity of the entity as it sees itself. Only those creatures that can effectively model themselves can alter their sub-goals in support of their own survival. To survive, the self image must be in close correspondence with the reality of themselves and their environment." – Lawrence Fogel[11]

Clearly his intention was to accentuate methodological efforts in evolutionary computation, which he derived from one of four different motivations: improving optimization, robust adaptation, machine intelligence, and facilitating a greater understanding of biology. Fogel's methodology was further explored by John Holland who also examined the potential of genetic algorithms in order to mimic natural processes of evolution as well as the intrinsic morphological relationship among classes of organisms (phylogenesis). Holland's work focused on studies of tessellated structures (cellular automata) conducted at the University of Michigan during the late 70s where he ultimately introduced a formalized framework known as the Holland's Schema Theorem, which predicted the qualitative nature of the next generation produced by the genetic algorithm.[12]

FROM GENERATIVE ALGORITHMS TO ADAPTIVE ECOLOGIES

> "In Adaptive Ecologies what is called architecture is barely distinguishable from the behavior making up the natural world all around it – a world, that is, where bodies, organisms, systems and even disciplines share one thing above all else in common: their own malleability."
> – Brett Steele[13]

Considering the ever-increasing role of computational tools on the practice of architecture, it is interesting to look at David Rutten's work and consequent development of Galapagos, an evolutionary solver and genetic algorithm nested into Grasshopper™. Galapagos essentially provides a fascinating application of biological principles of mutations, selection and inheritance; all those factors can then be associated to particular 3D models generated in Rhino via Grasshopper™ and Galapagos, creating a workflow that is constantly responding to changes of inherited mathematical values.[14]

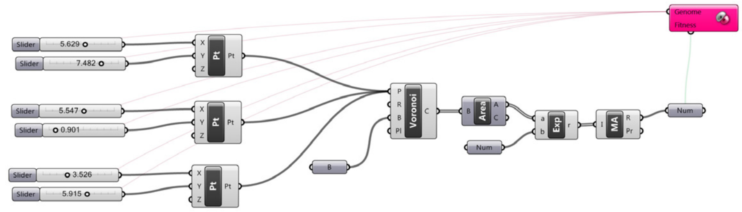
Moreover, if we look at the work and pedagogy implemented at the Architectural Association over the last ten years and recently consolidated into *Adaptive Ecologies*, a book edited by Theodore Spyropoulos, it is rather apparent how the development of a machinic process characterized by algorithmic definitions has maximized the intricacy and coherence of formal and spatial outputs. Undoubtedly, the study of complex self-organizing systems, which are at the basis of this algorithmic praxis, requires a definite methodological hybridity, which involves the interaction of traditional digital architectural modifiers and generic population-based metaheuristic algorithms characterized by strategies that guide the search for optimal form. This process of morphogenetic variance rejects the implementation of traditional planning design strategies such as functional zoning or socio-economic growth management, while it promotes the application of non-linear and systemic approaches that address the dynamic complexity typical of urban apparatuses The ultimate goal is to assembly a symbiotic urban system that processes human feedback while it generates morphogenetic solutions intrinsically related to the dynamic quality of the hosting ecosystem.[16]

In order to clarify this methodology, my paper examines some the principal theoretical premises of a design studio that investigated issues of urban resiliency in the weather-beaten Louisiana Gulf Coast.[17] In this particular case, the redesign of specific urban areas had to consider particular generative models characterized by visual-scripting feedback, which in exchange provided the possibility for solutions that showed a certain morphogenetic adaptability to regional and climatic changes. While investigating issues relative to costal developments and global climatic changes, it became clear how particular subtropical ecosystems have undergone minor systemic modifications due to extreme weather conditions while maintaining their originating patterns of self-organization. Pedagogically speaking, students had to examine the application of algorithmic solvers such as Galapagos, an evolutionary component built-in Grasshopper™, which generated optimized urban forms relative to the parametric inputs selected. Weather systems were reduced to mathematical variables in order to create patterns of climatic behaviors, which were ultimately used as numerical inputs. Indeed computational systems applied to architecture tend to provide, theoretically, a better long-term survival in constantly changing urban environments and responsiveness to unpredictable climatic conditions. Those parameters - storm surge, wind, humidity, and rainfall - were used as inputs connected to computational components characterized by self-organizing formal outputs typical of the regional ecosystem.

FROM GENERATIVE ALGORITHMS TO ADAPTIVE ECOLOGIES

> “The simplest of all computing machines, finite state automata, can perform a computation by changing from one state to another in a well–defined sequence without having to store intermediate results.”
> – Manuel De Landa[18]

Parametric-associative platforms, understood as computing machines, have the ability to facilitate and simulate the evolution of design processes based on algorithmically organized urban components while producing new emergent solutions. In order to create responsive scenarios underlined by what De Landa calls the emergence of synthetic reason, students began by analyzing how certain ecological patterns, generated by extreme climatic conditions, emerge and consolidate themselves among specific territorial formations. Consequently, upon their recognition, those formations where manipulated via non-linear algorithmic models and adaptive scripting to produce more responsive urban interventions.



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This investigative praxis originates from the idea that architectural form and its ultimate material manifestation emerges from the meshwork assemblage of energy and matter, which can be simulated through the use of visual scripting language or components (Figure 2). The definition of machinic assemblages has been already clarified by Gilles Deleuze and Felix Guattari, who defined them as the morphogenetic processes that generate new structures while operating in total autonomy.[19] The main ideological premises of this definition are found in the heterogeneity of those elements actively engaged in the process where sets of relationships among different systems generate the final machinic premises that allow specific morphogenetic formations to arise.[20]

This systemic process was accomplished via data mining, while urban feedback was collected, analyzed and algorithmically parsed in Grasshopper™. As a result, definitions were generated to redesign parts of the ecosystem under investigation. Thus, a series of evolutionary projections of the site were articulated by proposing speculative scenarios that could become proposals for future urban growth though morphogenetic selection, accentuating the importance of field correlations existing between urban fabric, public spaces, infrastructural systems, and that quantitative mathematical data used to express the system's responsive fitness. In this particular case, the idea of fitness was generated by the relationship between the average value of storm surges collected over the last 10 years and the topographic altimetry of the site analyzed. This methodology was also applied to construct a system of data/patterns, which through the recognition of specific processes of natural occupation relative to areas subjected to drastic climatic agents would convey meaning through the mathematical and logical resemblance of site-specific bio-ecological analogues. This does not necessarily create an expected or predetermined form, but it generates an optimized model by way of finding satisfactory solutions.[21]

Interestingly enough, specific territorial formations, those typical of subtropical climates, provided some interesting biological models, which emerge and are also normally affected by extreme weather conditions such as hurricanes, or tropical storms. Those models are intrinsically characterized by precise patterns that theoretically enable prediction; moreover, pattern formations, often characterized by a sometimes-microscopic structure, follow a clear mathematical logic of arrangement, which accordingly represents the best probability for urban survival. By following this methodological process, it can be stated form does not always arise from complexity, but it is contingent to those modalities of difference and repetition that elucidate pattern-making processes.

> "Everything which happens and everything which appears is correlated with orders of differences: differences of level, temperature, pressure, tension, potential, difference of intensity." – Gilles Deleuze[22]

Figure 2: Visual scripting language using Grasshopper

Thus, those modalities are not exclusively formal or representational; instead, they are evaluated for particular relational inequalities by which form has been methodologically communicated. Fundamentally, this methodology of complexity suggests the adoption of a methodical analysis and understanding of morpho-tectonic changes/variations that might explain the emergence of particular models of architectural production and assembly. This is only possible if we can recognize those discrepancies by which the phenomenon unfolds.

CONCLUSIONS

At the end of this pedagogical process characterized by specific theoretical processes of computational praxis, it has been interesting to observe how different categories of algorithmic simulation can produce spatial solutions characterized by the interaction of mathematico-logical and specific climatic agents. While theoretical at most, the methodology developed in my studio promoted the implementation of systemic models of architectural and urban production based on the assimilation and tabulation of large numerical data assembled via visual scripting language.

As explained by David Rotten, the implementation of a process based on evolutionary solvers presents a few shortcomings: from a disciplinary point of view, they exclude any traditional architectural connotation, which might preclude its operative understanding as a pure architectural artifact. Solvers work via scripting and coding, which are important technical aspects that are not always addressed in architecture schools. Secondarily, evolutionary solvers appear to be very slow; in fact, the production of particular morphogenetic solutions is directly related to the numerical information embedded into specific sliders, and how those sliders are eventually connected to specific geometries or actions (Figure 3).

Regarding the question of fitness. In order to perform, Galapagos has to be activated by connecting selected sliders to the genome input, and by providing an evaluation system that defines the fitness required. Rotten defines fitness "a stumbling block" as it is very difficult to evaluate how fit something needs to be to evolve and adapt. Yet, fitness, as utilized in my academic module, was indeed understood as the ultimate compromise between the machinic presence of the algorithm and the user's capacity to recognize particular valuable solutions. In the end, the interaction between numerical agents used to generate urban plans was in correspondence with a certain formal sensibility, which provided some morphological integration with a given site. Again, fitness can be everything and anything, and its evaluation is always destabilized, so to speak, by one's common sensibility to certain design aspects and how those might fit specific ecological parameters.

Eventually, some of the solutions evaluated in my module uncovered some qualities such as authenticity, hybridity, connectivity, porosity, and vulnerability, which ended up creating an urban approach more open to the systemic integration of architecture and nature.[23] Indeed, evolutionary computation can produce novel techniques that address systemic and ecological issues that are not normally prioritized by traditional design methods. To generate the best probability for urban survival, we ought to discard methodologies based on linear approaches, while considering alternatives that address variance and systemic interface. Computational strategies seemed to offer an

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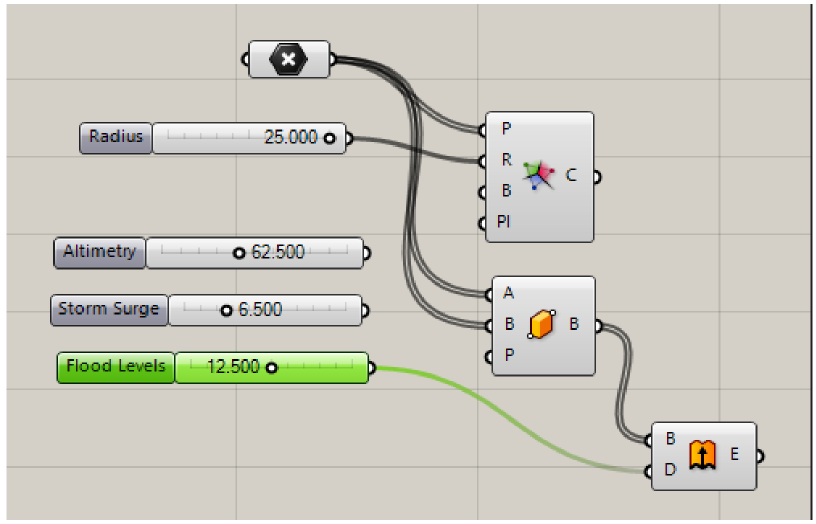

Figure 3: Association between numerical sliders and specific generative components

approach more open to complexity, transformations, and new types of scalar exchanges that cause the plan to evolve; computational strategies also offer a methodological process that appears to be based on the comprehensiveness of evolutionary strategies as a way to generate intricacy and urban adaptability. An interactive methodology that offers a comprehensive look at both architectural and ecological principles certainly hypothesize a framework that considers new situations and new scenarios, logically layered and sequentially intertwined. It is about finding the best solution for ecological survival. Architecturally speaking, it is either interact or die.

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