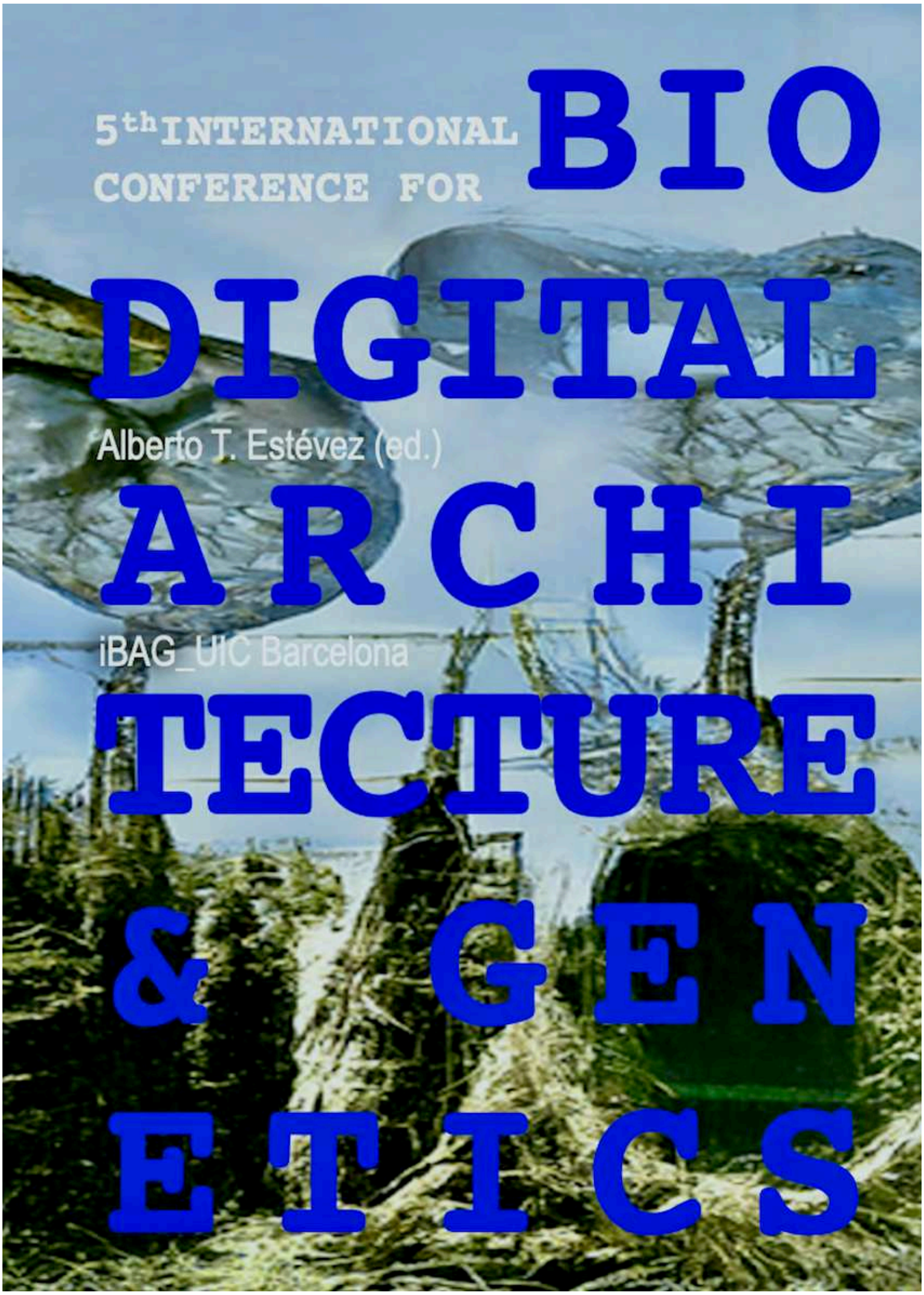

5th INTERNATIONAL CONFERENCE FOR

BIO DIGITAL ARCHI TECTURE & GEN ETICS

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Melih Kamaoğlu

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From Logic to Materiality

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Abstract.

Throughout history, nature has inspired architectural theories, philosophies, and designs. Architects have looked at nature for inspiration, solutions and creativity for design processes. Developments in philosophy, science and technology have triggered various conceptions of nature, which have an undeniable impact on architectural design thinking. Until the introduction of evolution theory, the common belief was that organisms do not change through successive generations. Soon after Charles Darwin formulated a scientific framework, scientists started to accept the evolutionary process in nature. After evolutionary processes began to be explained from genes to population scale due to the advancements in genetics, the Neo-Darwinian understanding of evolution theory was born. Then, the developments in computer science have allowed us to generate computational models of evolution through digital computation. After the 1990s, architects have used the Neo-Darwinian computational evolution models in architectural design processes for variation, optimization and randomness purposes.

This paper critically reviews the impact of Neo-Darwinian evolution theory in digital architecture by mainly focusing on the design theories of John Frazer, Achim Menges, Michael Weinstock and Michael Hensel. The paper discusses the potentials and limitations of digital Neo-Darwinism in architecture regarding the relationship between nature and computation. It demonstrates how digital Neo-Darwinism in architecture changed attention from universal models of evolution to unique behaviors of matter and environment. Computational evolutionary models are useful when the design problems can be described quantitatively. Also, the searching power of computation is quite admirable in generating various alternative design outcomes depending on initial evolutionary parameters. However, once digital simulation of evolutionary processes is used in architectural design, it only provides a reductive connection to nature. For this reason, digital Neo-Darwinism in architecture utilized abstract and pattern-recognized interpretation of evolutionary processes from materiality to environmental and population scale.

Keywords. *Neo-Darwinism, digital computation, digital architecture, logic, materiality*

Introduction

Humans always questioned the reality of nature to survive and understand their place in the universe. Nature has been understood as a model for architects, demonstrating various types of intelligence and creativity. For this reason, a thorough interrelationship has existed between how humans make sense of nature and design buildings. Various disciplines such as biology, mathematics, physics, and philosophy have advanced such a connection between nature and architecture. Evolution theory is one of the important scientific discoveries that destroyed the idea of static, unchanging and non-transformable nature and promoted a process-based understanding of the physical world. In time, the modern synthesis of evolution, called Neo-Darwinism, was formulated by combining selection theory and Mendelian genetics. Then, the advancements in computer science made it possible to create mathematical models of Neo-Darwinian evolution from gene to population scale. After the 1990s, architects started utilizing the Neo-Darwinian evolution model in architectural design processes through digital computation procedures.

This paper is a critical review evaluating the reflections of Neo-Darwinism in digital architecture, focusing on the design theories of John Frazer, Achim Menges, Michael Weinstock and Michael Hensel. The paper discusses the potentials and limitations of digital Neo-Darwinism in architecture regarding the relationship between nature and computation. It demonstrates how digital Neo-Darwinism in digital architecture portrayed a change in attention from universal models of evolution to unique behaviors of the matter and environment. Computational evolutionary models are useful when the design problems can be described quantitatively. Also, the searching power of computation is quite admirable in generating various alternative design outcomes depending on initial evolutionary parameters. However, once digital simulation of evolutionary processes is used in architectural design, it only provides a reductive connection to nature. For this reason, I argue that digital Neo-Darwinism in architecture utilized abstract and pattern-recognized interpretation of evolutionary processes from materiality to environmental and population scale.

The rest of the paper is structured as follows. Firstly, I will explain the history of evolution theory from Darwin to modern synthesis around the 1930s and extended synthesis today. Then, I will evaluate the relationship between computation theory and evolution theory by mainly focusing on cellular automata and evolutionary algorithms. Afterwards, I will discuss two examples of Neo-Darwinism in digital architecture through the theories of "evolutionary architecture" (John Frazer) and "morphogenetic design" (Michael Weinstock, Achim Menges, Michael Hensel). Here, I will demonstrate how digital Neo-Darwinism in architecture portrayed a change in attention from universal models of evolution to unique behaviors of matter and environment. Finally, I will conclude the paper by showing how digital Neo-Darwinism in architecture started with a purely abstract and descriptive understanding of evolutionary processes and later embraced the digital materiality of the physical world through the embodiment of pattern-recognized information in architectural design.

Evolution Theory and Neo-Darwinism

The concept of biological evolution, as we understand it today, essentially started to be discussed only in the last two centuries. Several ideas proposed during the 18th century and at the beginning of the 19th century informed Darwin's early understanding of nature. Darwin initially believed in adaptation as an absolute response to the environment and transmutation as the source creating variations. After understanding the importance of growing populations and finite food sources, Darwin started to formulate his theory of natural selection, initially as a designed law in nature (Herbert, 1971). However, after Darwin started to stop referring to teleological explanations and embraced the idea of relative adaptation, the concept of chance became essential in his evolutionary theory. Regarding the relation of variations with divergence, Darwin applied the branching concept of morphological processes to the evolutionary history of life and claimed that most diverged forms have more chance to be selected (Ospovat, 1981). Therefore, Darwin proposed a theory of evolution essentially depending on a play between forces of natural selection and variation mechanisms.

In his book, On The Origin of Species, published in 1859, Darwin proposed descent with modification depending on five main elements (Futuyma & Kirkpatrick, 2017). The first is that characteristics of organisms change through time and create variation through inheritance. The second one is the idea of common descent. According to Darwin, all species diverged from common ancestors and the history of life can be understood as a branching tree of life. The third element was gradual evolution, meaning that evolution proceeds through small steps, not jumps. The fourth idea was related to populational change against the concept of transforming individuals. And the last argument was natural selection, which was probably Darwin's most original contribution to biology (separately proposed by Alfred Russel Wallace) and the ultimate source of evolutionary change in his theory. A combination of these ideas constitutes Darwin's theory of evolution and Darwinism.

The fact of evolution as a descent from common ancestors was widely accepted by scientists shortly after Darwin's revolutionary work. However, the scientific community acknowledged natural selection as the cause of evolutionary change around the 1930s. Darwin failed to explain how variations emerge and pass to offspring because he knew nothing about genetics and mutation. Gregor Mendel proposed that discrete units pass from parents to offspring, explaining why variations can be preserved in the populations. In the meantime, the ultimate mechanism of genetic variation, "mutation", was discovered, describing how hereditary material changes. Also, the "recombination" mechanism referring to the exchange of DNA pieces between chromosomes started to be understood. Therefore, around the 1940s, the modern synthesis of evolution theory was developed, combining natural selection with mutation, recombination and mendelian genetics (Huxley, 2010). Even though some elements have been updated and explained further, the modern synthesis provided a fundamental framework of evolutionary biology which is still valid today.

Mayr (1982) considered evolutionary synthesis as the most influential action maturing what Darwin proposed in 1859. The modern synthesis, also called Neo-Darwinism, provided consensus on how macroevolution takes place through the accumulation of microevolution (Freeman & Herron, 2014). According to this proposition, evolution occurs through natural selection acting on genetic variations (Huxley, 1954). Individuals differ because of variation mechanisms like mutation and recombination. Then, individuals pass their genetic materials to their offspring. Some individuals are always more favorable regarding surviving and reproducing in the populations. As a result, these individuals become more successfully adapted to their environments and increase the frequency of their genes within the population. With enough time and small steps, this evolutionary process would inevitably create divergence and speciation within the populations (Futuyma & Kirkpatrick, 2017). Therefore, the history of evolution emerges as a branching tree of life connecting all organisms through common ancestors.

The modern synthesis was missing the integration of developmental biology into evolution theory. Developmental biology analyses how the structure, shape and size of organisms change from genes to organs. Neo-Darwinian understanding of evolution understood as an approximate cause neglect the possibility of goal-directedness and the inheritance of acquired traits during individual's lifetime (Jablonka & Lamb, 2020). Thanks to the advancements in molecular genetics since the 1980s, developmental biology has become an essential research field supplementing evolutionary biology. Therefore, the extended evolutionary synthesis was conceptualized depending on observations collected from evolutionary developmental biology, developmental plasticity, inclusive inheritance and niche construction (Laland et al., 2015). This new perspective was not a denial of Neo-Darwinian evolution but locating it within a broader set of principles of evolution which acknowledge the biased developmental impacts on natural selection and variation (Chiu, 2022). Therefore, extended evolutionary synthesis proposed a new account that puts the developmental agencies of organisms at the center of the equation.

Neo-Darwinism and Computation

The introduction of evolution theory has not only affected biology but also found substantial reflections in the development of computation theory and practices. Since the 1940s, computer scientists have developed evolution strategies to solve various engineering problems and simulate complex natural behaviors. The computational equivalents of evolutionary processes provided abstracted and universal models of nature to understand the complexity emerging from cells to the population level. Evolutionary algorithms and cellular automata have been the most prominent research fields for the simulation of life. Cellular automata theory portrayed how complex systems and behaviors can emerge through the cooperation of simple components, which operates depending on simple rules. As a reflection of Neo-Darwinism, genetic algorithms showed how such emerged complexity can evolve in time depending on various mechanisms. Therefore, the Neo-Darwinian understanding of evolution and the development of cellular automata theory provided an effective framework for imitating nature inside the computer.

Cellular automata theory deals with the idea of universal computation and building new automata through the reproduction of existing ones. A simple cellular automata model consists of a vast collection of identical and associated cells. The main idea is to understand the working principles in natural systems by reducing their complexity into dynamical interactions of simple cells. The former theorist of cellular automation was John von Neumann, who proposed an analogy between organizations of natural and artificial systems through universal rules of the system (Von Neumann, 1966). His model consists of cells with twenty-nine potential states and four closest neighbors. The evolution of the state of a cell depends on the previous states of this cell and its neighbors. In time, groups of active and associated cells emerge depending on functional relations between whole cells (Shannon, 1958). Therefore, the system creates complex patterns depending on the organization of simple cells.

After Neumann's ground-breaking work, Codd (1968) developed a cellular automata model consisting of cells with 8-state and 5-neighbours. Codd claimed that his model could perform universal computation with some special self-reproduction behavior that cannot be found in Neumann's model. Later, John Horton Conway introduced cellular automata named Game of Life, consisting of cells with two states (dead or alive) and eight neighbors. The game starts with a simple cell, then changes depending on genetic rules related to deaths, survivals and births, aiming to make the process unpredictable (Gardner, 1970). The most controversial argument regarding cellular automata was presented by Stephen Wolfram. The main objective was the utilization of cellular automata to develop a universal mathematical system for representing emerging complexities in nature (Wolfram, 1984). Wolfram instrumentalized cellular automata to develop models for the simulation of specific systems and to create universal principles suitable for divergent systems (Wolfram, 2002). Such an idea attempted to crack nature's complex working principles through the localized interaction of simple boxes.

The role of genetic and evolutionary mechanisms in nature has rarely been part of the investigation in cellular automata studies. When it comes to true reflections of Neo-Darwinism in computation, the development of evolutionary computation discipline comes to the front. Evolutionary computation works depending on the Neo-Darwinian model of organic evolution. These algorithms model the evolution of populations by utilizing recombination, mutation and selection mechanisms. Then, the algorithm search through evolved populations and uses the fitness function to find better candidate solutions. The history of evolutionary algorithms can be evaluated through four main types: evolutionary programming, evolution strategies, genetic programming and genetic algorithm (Bentley, 1999). Although there are minor differences regarding data representation, sources of variation and selection procedures, all evolutionary algorithms work depending on the logic of selection of produced variations.

Genetic algorithms are the most commonly used computational equivalence of Neo-Darwinian evolution today. John Holland established the foundations of genetic algorithms in his work, illustrating the process of adaptation through computation procedures (Holland, 1975). Holland was interested in constructing adaptive computation procedures to solve various problems and simulate Neo-Darwinian evolution mechanisms (Mitchell, 1998). Such an ambition to reveal working principles of adaptation was derived from his enthusiasm for initial mathematical examinations of adaptation and developments in cellular automata theories showing that simple principles can create complexity and resilience (Fogel, 1998). Consequently, Holland proposed a mathematical framework abstracting and generalizing Neo-Darwinian principles of evolution, including mutation, crossover and natural selection. Holland also developed the concept of schema, providing a universal template to apply the working logic of genes. Compared to earlier attempts of evolution simulations, Holland probably introduced the most elaborate and comprehensive articulation of evolution and adaption through the computer language.

Genetic algorithms are used to imitate the working principles of evolution and genetic mechanisms. Unlike other evolutionary computation models, this type of algorithm necessitates the representation of the problem as a finite state string defined over a finite alphabet. It is a search algorithm that differs from other optimization and search strategies in four main ways: performing with coded parameters of the problem, parallel searching of populations, using payoff values of individuals for selection and using probabilistic principles instead of deterministic ones (Goldberg, 1989). Genetic algorithms have four main mechanisms: recombination, mutation and selection (Bäck, 1996). The recombination mechanism is used in the form of crossover to combine useful parts of strings from various parents for the development of high fitness. The mutation operator is utilized to change single parts of individuals and reintroduce some potentially lost strings into the population. The selection mechanism allows individuals with higher fitness values to survive and pass their properties to the next generation. Together, these operators construct working principles of basic genetic algorithms representing Neo-Darwinian evolution.

Digital Neo-Darwinism in Architecture

Neo-Darwinian understanding of evolution has found substantial reflections in digital architecture theories and practices since the beginning of the 1990s. Carpo (2012) investigated some of these endeavors under the concept of "Digital Darwinism" and explained how it led to the end of authorship and allowed collaboration of many hands in architecture. However, digital Darwinism is an insufficient concept to encompass all methodologies and theoretical backgrounds of design models instrumentalizing evolutionary processes. Instead of Darwinism, architects have used the Neo-Darwinian model of evolution regarding the nature of variations, mutations and natural selection. Also, genetic algorithms, as the most influential tool for architects, were a genuine reflection of Neo-Darwinism. For this reason, I instrumentalize the notion of "Digital Neo-Darwinism" to cover various design theories of architects utilizing the logic of survivals of fittest among the variations through form-finding and random search experiments.

The early experiments of digital Neo-Darwinism in architecture were related simulation of evolutionary processes through digital computation procedures. These studies were restricted to abstract and universal design models simplifying evolutionary processes into logical descriptions of 0s and 1s. Communication with the physical world was only through the medium of digital computation, meaning that only global principles of evolutionary processes were adapted into the design models as a hierarchical system. Later, architects started to combine the materiality of the physical world with universal models of evolution by allowing the agency of the matter to talk and be part of form-finding processes. The main difference was using the behavior of materials as a fitness function to determine the design solution among variations instead of applying subjective selection criteria. Therefore, digital Neo-Darwinism in architecture portrayed a change in attention from universal models of evolution to unique behaviors of the matter. In other words, from logic to materiality.

The first representation of the Neo-Darwinian understanding of evolution through digital computation in architecture was John Frazer and his colleagues' thirty years of work collected in the book "An Evolutionary Architecture", published in 1995. Understanding the virtual domain as an additional dimension to the physical world, Frazer accepted architecture as part of cyberspace, where the computer has been utilized to create evolutionary and dynamic environments (Frazer, 1995a). In his book, Neo-Darwinian evolution was utilized for form-generation experiments through digital simulation of environment and architectural models. In order to test the evolution of architectural forms, design notions were defined through generative rules, represented by code scripts in an analogy with genetic language. Evolved architectural forms were analyzed depending on their performance against the environment which acts as selection criteria (Frazer, 1995b). Unlike nature, the evolution of forms and environment was monitored faster, and unpredictable design solutions emerged depending on Neo-Darwinian evolutionary mechanisms.

The general design model proposed by Frazer consisted of genetic code, development rules, outline of the code into the form, defining an environment and selection criteria. Among the design experiments in the book, one of the most interesting attempts was the project "Universal Constructor" regarding the connection between physical and digital. In Universal Constructor, identical cubes were arranged in three dimensions in reference to Von Neumann's theory of automata capable of universal computation (Frazer, 1995b). The system comprised identical cubes with a computer program for investigating environmental feedback, passing messages and displaying results. By adding cubes to the system, it was possible to create environmental feedback. Then, Universal Constructor would analyze this feedback and create its response as a representation of a dynamic model. In 1992, the Universal Interactor project was developed to investigate further the impact of the environment through antennae, transmitting and receiving information. Therefore, a feedback loop was built between the physical environment and architectural models. However, in both models, the data coming from environment had to be simplified and abstracted into a computer language.

In 1995, a special version of these evolutionary systems called "The Interactivator" was constructed. The evolutionary design procedure in this system was designated by using a classifier system developed by Goldberg (1989), which consists of an environmental system, developmental section, analysis module, genetic algorithm and graphic output procedure (Frazer, 1995b). Three computers working were used for this model. The central computer dealt with the evolution of genetic code and the visualization of cell structures. The second computer operated the communication with the environment. The third computer produced images and animation of evolving forms (Bettum, 1995). The proposed system was based on evolution of cellular automata families where each cell represents DNA information through binary code. The cells were multiplied and divided depending on their genetic code and data introduced from the environment. Crossover and mutation mechanisms were used to create variations of genetic code among the population. Depending on the relationship between genetic code, cellular structures and environment, successful genetic codes were selected in an analogy to natural selection (Frazer & Janssen, 2003). Therefore, a genuine embodiment of Neo-Darwinian evolution was utilized in digital architecture through digital computation.

After the beginning of the 2000s, this mathematics and logic-based Neo-Darwinian understanding of evolution in digital architecture started to be challenged. Architects began to integrate material, environmental and industrial production constraints into the evolutionary process of architectural form. The precedents of this new perspective, "Morphogenetic Design", were Michael Weinstock, Achim Menges, and Michael Hensel. In this material and performance-based approach, the Darwinian evolutionary process was combined with morphogenesis which mainly focuses on the developmental process of individuals. The material agency and structural characteristics of architectural form were intertwined with context-specific environmental conditions for dynamic and performance-based architectural design procedures (Hensel & Menges, 2006b;

Hensel et al., 2004). Therefore, the material agency was used to create variations and act as a constraint for the development of the architectural form (Menges, 2006). In this design proposition, the form, material and structure were considered united for form-generation procedures. Such interaction was built through multi-level feedback between geometry, material behavior and environment.

Evolutionary mechanisms that create random variation (mutation, crossover, etc.) provide flexibility against changing environmental conditions among natural populations. Likewise, the morphogenetic design used random characteristics of evolutionary processes to explore divergent design alternatives and introduce robustness into the design model, which allows resilience against changing circumstances (Weinstock, 2006). Beyond optimization purposes, where design objectives must be expressed quantitatively, the population-based understanding of Neo-Darwinism was also used to explore potential design space (Menges, 2012). Instead of a priori selection criteria leading to predefined solutions, the flexible selection criteria emerged as a temporary control parameter and changed depending on environmental simulations and material behavior (Hensel, 2004). Such a design process needed the designer to develop a flexible computational model that can evolve depending on additional parameters introduced by digital simulation of material behavior and environment, together with assembly logic (Hensel & Menges, 2008). Therefore, both developments of individual forms and their population-level evolution were integrated into the architectural design process.

The synthesis between materiality and digital in morphogenetic design was organized through four main stages (Hensel & Menges, 2006a). Initially, the agency and features of materials were integrated into dynamic parametric modelling as geometric compositions. Then, these parametric geometries were informed with manufacturing and assembly constraints to ensure that changing architectural forms can be constructed anytime, when needed. Afterwards, developmental and evolutionary algorithms were used to create various alternative design models with increasing complexities. Finally, these evolved models were tested against multiple performance criteria to determine one or more successful answers. This summarized process is a form-finding experiment that creates an environment and context-specific architectural design. However, realize that all environmental and material feedback to the parametric model goes through the medium of digital computation, which can only measure and embed pattern-recognized information. Although morphogenetic design led designers to think beyond abstract and universal models of Neo-Darwinism and allow the agency of materiality to perform on design models, the nature of such feedback is still limited within critical and technical boundaries of digital simulation.

Conclusion: From Logic to Materiality

Digital Neo-Darwinism in architecture started with a purely abstract and universal understanding of evolutionary processes and later embraced the digital materiality of the physical world. John Frazer's design models adapted a generalized model of the evolutionary process based on the modern synthesis of evolution theory. Although the impact of the environment on the development of design models was investigated, this connection was quite reductive, ignoring or simplifying the materiality of evolving form and environmental conditions. The selection process of variational forms barely depended on objective performance criteria. Evolution as a design methodology was mainly used to explore the diversity of architectural forms or optimize design parameters through external selection procedures. For this reason, the association of architectural models with components and characteristics of the physical world remained quite limited.

The morphogenetic design combined growth and developmental processes with population-level evolution for form-finding experiments. It incorporated material agency, environmental conditions and industrial production logic into the evolutionary process of architectural form. Architectural design was informed by the behavior of matter, digital simulations of the physical environment and manufacturing logic. While variation mechanisms of evolution increased the resilience of the design model, selection mechanisms ensured the selection of architectural geometries that can respond to feedback from the physical world. However, architecture's communication with nature remained somewhat simplified as all data introduced from the physical world had to be abstracted and integrated into the design model as pattern-recognized data. Therefore, the materiality of nature was embedded into the architectural design within the limits of digital computation.

Simulation of evolutionary processes in nature through digital computation produces a descriptive, mathematical and logical representation of the physical world. Inevitably, utilization of computational depiction of evolution in architectural design is limited to design experiments with evolving geometries, whether informed by digital materiality or subjective judgements of the designer. This constraint of digital computation should be overcome to set up direct and real-time feedback between architectural design and nature. Such achievement will likely depend on the development of digital computation and finding new methodologies of computing natural processes. Once we find a way to compute with the whole complexity of nature, digital Neo-Darwinism in architecture can go beyond digital logic and materiality.

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