CHAPTER 5.

MORPHOGENETIC AND EVOLUTIONARY COMPUTATIONAL DESIGN

This is the start for the applicable study chapters, which presents the definition of morphogenetic and evolutionary computation presenting their application in architecture within biological design principles.

Keywords:

MORPHOGENETICS DESIGN, MORPHOGENESIS, COMPUTATION, DIGITAL MORPHOGENESIS, EVOLUTIONARY COMPUTATION, COMPUTATIONAL DESIGN, MORPHOECOLOGY, BIOTECHNOLOGY, BIOMATERIAL, GENETIC BIOLOGICAL PRINCIPLES.

CHAPTER FIVE

MORPHOGENETIC AND EVOLUTIONARY COMPUTATIONAL DESIGN

CHAPTER STRUCTURE: APPLICABLE STUDY SECTION

5.1. INTRODUCTION

> "As digital architecture is undergoing a paradigm shift; the computer no longer represent form, it generates form. This new paradigm is named as Digital Morphogenesis." (Leach, 2009)

This research chapter aims to establish a new morphogenetic evolutionary design system, based on a dynamic fusion of different biological architectural design processes, such as self-organization, emergence etc. which focus on taking the design matter in hand within a natural approach, in order to eliminate the general architectural disadvantage of approaching to a design problem with specific pattern designs. (Leach, 2009)

As it was defined in the previous chapter by the researcher that evolutionary design through genetics can be defined to deal with natural growth mechanisms applied to architectural design processes which implement a genetic algorithm as part of a digital tool to be used in the creative design process. This evolutionary process is evaluated by means of environmental parameters, passive qualities and the designer's individual requirements. A morphogenetic computational process is put forward, based on a metamorphosis strategy" we will be introduced to the morphogenetic and computational part in this chapter.

This chapter presents a definition of morphogenesis in both biology and architecture. Another set of definitions is also presented that serves as a theoretical framework for further study analysis. The same biological principles selected in the previous chapter are discussed again within the context of computational design applications.

5.2. MORPHOGENESIS DEFINITIONS

S. Roudavski (2009) explains morphogenesis in biology, highlighting the general advantages of studying it as follows.

Definitions

The original usage was in the field of biology and the first recorded instances occur in the second half of the 19th century. Morphogenesis literal translation goes to the Greek words morphê (shape) and genesis (origin). Which means 'shape origin'. An earlier, now rare, term was morphogeny, with the foreign-language equivalents being morph genie (German, 1874) or morph genie (French, 1862). Geology was the next field to adopt the term in the 20th century.

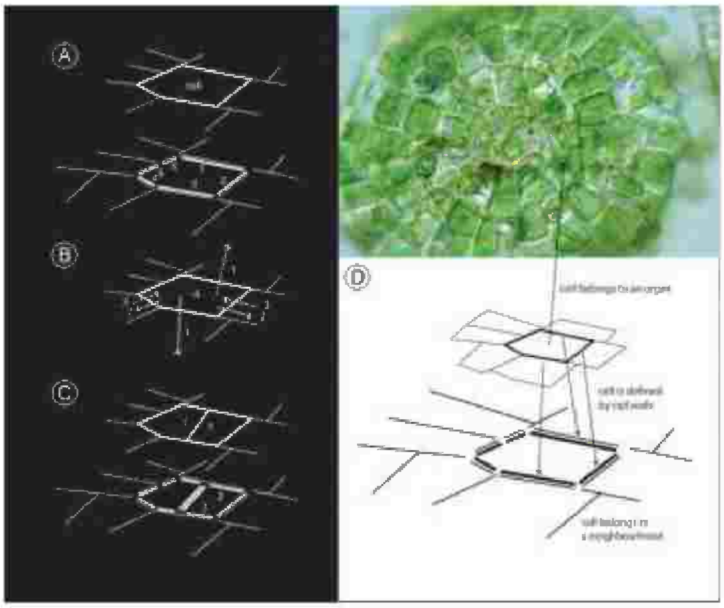

Figure (5- 1): Cellular architecture of plants can be conceptually subdivided into several scale levels represented in this diagram by horizontal planes. This conceptual subdivision helps to formalize the structure and functioning of plants.
Source: (Roudavsk, 2009)

Morphogenesis is a concept used in a number of disciplines including biology, geology, crystallography, engineering, urban studies, art and architecture. This variety of usages reflects multiple understandings ranging from strictly formal to poetic.

5.2.2. In Biology

In biology the word morphogenesis ‘is often used in a broad sense to refer to many aspects of development, but when used strictly it should mean the molding of cells and tissues into definite shapes. Furthermore, in biology the word “morphogenesis” can be used to refer either to the structural changes observed in tissues as an embryo develops or to The underlying mechanisms responsible for the structural changes. Both understandings can be of interest and inspiration for architects, despite the fact that a literal importation of biological structures or processes into architectural design is usually not feasible, meaningful or desirable.

Morphogenesis is one of several processes typical for living organisms. Apart from morphogenesis, these processes include growth, repair, adaptation and aging. Transferring knowledge of these processes into designing might be also productive, especially in relationship to architectural structures with dynamic capacities.

5.2.3. In Biological science.

In the biological sciences, the study of forms and their categorization, or morphology, was the first instrumental set of zoology, predating the evolutionary theory. More recently, Morphogenesis is a concept used in a number of disciplines including biology, geology, crystallography, engineering, urban studies, art and architecture. This variety of usages reflects multiple understandings ranging from strictly formal to poetic. The original usage was in the field of biology and the first recorded instances occur in the second half of the 19th century. Geology was the next field to adopt the term in the 20th century. . (Roudavsk, 2009)

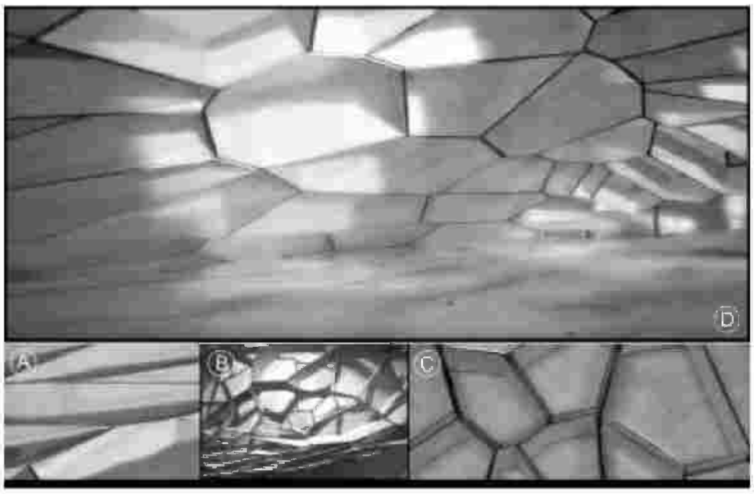

Figure (5- 2): Procedural production of the parasite's structure, the image of Parasite project (A) Visual, non-repeating striation produced by cell-walls seen in perspective resembles complex patterns produced by natural phenomena. (B) A fragment showing a detail of the cellular structure and its capabilities for local curvature and cell-wall variations. (C and D) Cells arranged to be assembled into a patch. Similarly to the cells in plants (see Figure 7), The Parasite’s cells were assemblies of walls.)
Source: (Roudavsk, 2009)

5.2.4. In Architecture

In architecture, morphogenesis (digital morphogenesis) or computational morphogenesis) is understood as a group of methods that employ digital media not as representational tools for visualization but as generative tools for the derivation of form, adaptation and its transformation often in an aspiration to express contextual processes in built form.
Also Leach N. and Roudavski presented morphogenesis in architecture in another way as following:

Leach's (2009) view is that It's a “bottom-up,” “form-finding” process. Which describes the origin and development of an organism’s form and structure, In digital morphogenesis the environmental constraints are all the systems that act upon architecture? Digital morphogenesis derives forms, using algorithms that generate the biological process of form-finding.

Roudavski (2009) explains the concept of morphogenesis in architecture as it is linked to a number of concepts including emergence, self-organization and form-finding. Among the benefits derived from redundancy and differentiation and the capability to sustain multiple simultaneous functions.

A morphogenetic evolutionary computational method in architectural design requires the development of novel design methods that integrate both the modeling of behavior and the constraints of materialization processes. This approach presents aspects of the profound changes to the architectural design process entailed by a transition from Computer Aided Design towards Computational Design. It will present the research on computational design tools and demonstrate their application in research based on the abstraction of biological and genetic principles for the development of environmentally responsive structures. Complex, non-uniform structures are expected to become increasingly common in architecture in response to the growing utilization of algorithmic modeling, fabrication and mass-customization. (Researcher, 2014)

5.3. ADVANTAGES OF STUDYING BIOLOGICAL MORPHOGENESIS

As Roudavski (2009); Leach (2009), Analysis that a better understanding of biological morphogenesis can usefully inform architectural designing because:
- As organism's growth is described as a bottom-up process because an organism's form emerges from environmental constraints rather than blueprints this acts the same in morphogenetic architectural design process
-Architectural designing aims to resolve challenges that have often already been resolved by nature
- Architectural designing increasingly seeks to incorporate concepts and techniques, such as growth or adaptation that have parallels in nature
- Architecture and biology share a common language because both attempt to model growth and adaptation (or morphogenesis).

5.4. DIGITAL MORPHOGENESIS

5.4.1. General definition

Digital morphogenesis is a process of shape development enabled by computation. While this concept is applicable in many areas, the term "digital morphogenesis" is used primarily in architecture.

5.4.2. In architecture

In architecture digital morphogenesis is a group of methods that employ digital media for form-making and adaptation rather than for representation, often in an aspiration to express or respond to contextual processes. "In this inclusive understanding, digital morphogenesis in architecture bears a largely analogous or metaphoric relationship to the processes of morphogenesis in nature, sharing with it the reliance on gradual development but not necessarily adopting or referring to the actual mechanisms of growth or adaptation. Recent discourse on digital morphogenesis in architecture links it to a number of concepts including emergence, self-organization and form-finding.

5.5. GENERAL CONCEPTS

Within the context of this research, a set of relevant concepts are presented and explained since they are important for the understanding and comprehension of the forthcoming theoretical framework and case-studies.

5.5.1. Computational design

Computational approaches to design have traditionally treated design as a knowledge intensive activity utilizing as much knowledge as possible. This assumes that such knowledge can be captured, represented and utilized in knowledge-based systems. Such knowledge-based systems have been useful in many areas of the design process but there still exist difficulties with the area of design synthesis. This is especially so when the design solutions are not known a priori. Thus using a knowledge-lean approach, such as the evolutionary approach, in the design domain may lead to a design mechanism useful for producing unexpected but meaningful design solutions. This would especially be useful where little experiential knowledge exists to suggest such meaningful solutions. (Miranda, Derix, 2009)

5.5.2. Morphogenetic Computation

Morphogenetic Computation is form-generating processes are based on genetic engines that are derived from the mathematical equivalent of the Darwinian model of evolution, and from the biological science of evolutionary development that combines processes of embryological growth and evolutionary development of the species. Evolutionary computation offers the potential of relating pattern and process, form and behavior, with special and cultural parameters. (Hensel, 2006)

This approach is part of the contemporary reconfiguration of the understanding of nature‘, a change from metaphor to model, from nature 'as a source of shapes to be copied to nature' as a series of interrelated dynamic processes that can be simulated and adapted for the design and production of architecture. During the short history of so-called digital architecture, the notion of morphogenesis has almost become a cliché owing to excessive referencing to all kinds of design processes that operate most often merely on a metaphorical level. (Hensel, Menges, 2004)

This thesis presents current research on morphogenesis that attempts to investigate the principles underlying natural morphogenesis and step by step transferring them into an integral computational process. Within this context, computational morphogenesis can be described as a process of perpetual differentiation. The increasing morphological and functional difference of elements enabling the system‘s per-formative capacity unfolds from their divergent development directions triggered by a heterogeneous environment and multiple functional criteria.

5.5.3. Evolutionary computation

Evolutionary computation is a subfield of artificial intelligence (more particularly computational intelligence) that involves combinatorial optimization problems. Evolutionary computation uses interactive progress, such as growth or development in a population. This population is then selected in a guided random search using parallel processing to achieve the desired end. Such processes are often inspired by biological mechanisms of evolution.

Evolutionary Computation (EC) is a modern search technique which uses computational models of processes of evolution and selection. Strong resemblance to biological processes as well as their initial applications for modeling complex adaptive systems influenced the terminology used by EC researchers. (Miranda, Derix, 2009)

5.5.4. Natural and Computational Morphogenesis

Natural morphogenesis, the process of growth and evolutionary development, generates systems that derive complex articulation, specific gestalt and per-formative capacity through the interaction of system intrinsic material characteristics as well as external stimuli of environmental forces and influences. Thus formation and materialization are always inherently and inseparably related in natural morphogenesis. Such integral processes of unfolding material gestalt are particularly striking as architecture as a material practice, by contrast, is still mainly based on design approaches that are characterized by a hierarchical relationship that priorities the definition and generation of form over its subsequent materialization. This suggests that the latent potential of the technology at stake may unfold from an alternative approach to design, one that derives morphological complexity and per-formative capacity without differentiating between form generation and materialization processes.

5.5.5. Computational Morphogenesis and Material systems

Nowadays designers develop and employ computational techniques and digital fabrication technologies to unfold innate material capacity and specific latent gestalt they all commence from extensive investigations and tests of what we define as material systems. Material systems are considered not so much as derivatives of standardized building systems and elements but rather as generative drivers and biological design principles in the design process. Extending the concept of material systems by embedding their material characteristics, geometric behaviour, manufacturing constraints and assembly logics within an integral computational model promotes an understanding of form, material, structure and behaviour not as separateelements, but rather as complex interrelations forming computational morphogenesis. See figure This initially requires disentangling a number of aspects that later on form part of the integral computational set up in which the system evolves.

Figure (5- 3): Prototype structure of strip morphologies project
Source: (Hensel, Menges, 2008)

5.5.6. Growth and Evolutionary Process

Basically the way the system modulates the environment, the system's performative capacity unfolds from feedback cycles of manipulation and evaluation. These processes of driving the development of the system through continual differentiation of its instances can be envisioned in different ways. The most immediate possibility is the direct, top-down intervention of the designer in the parametric manipulation and related assessment cycle. More coherent with the overall concept though are processes based on similar principles as natural morphogenesis. In this respect two kind's of development processes are of interest here: the growth of the individual instance and the evolution of the system across generations of populations of individual instances. In order to facilitate the former there are different computational growth models that can be implemented, which are all based on two critical factors: on the one hand, the internal dataset or growth rules, the genotyp, and on the other hand the variable gestalt that results from the interaction of the genotype with the environment, the phenotyp. The critical task for the designer is defining the genotype through the aforementioned system-intrinsic constraints. The generation of phenotypic system instances, enabled through seed configurations and repeatedly applied genotypic rewriting rules, happens in direct interaction with the environment. One critical aspect to be considered here, and captured in the computational process, is the profound influence of goal oriented physiological regulation mechanisms, as for example homeostasis, on the growth process.
Each derived instance then forms part of a population and is evaluated with the aforementioned analytical tools. Driven by fitness criteria evolutionary computation, for example through the implementation of genetic algorithms, can then be employed to evolve various generations based on the confluent dynamics of mutation, variation, selection and inheritance.

5.5.7. Morph-Ecology

Biology is the science of life; it is concerned with the living. For this reason, architecture must go beyond using biology as merely a source of convenient metaphors. Ecology is the study of the relationship between organisms and their environment. This definition also suits the discipline of architecture surprisingly well: in our view one of the central tasks of architecture is to provide opportunities for habitation through specific material and energetic interventions in the physical environment. (Hensel, Menges, 2008)

Correlating morphogenesis and ecology, a new framework has been developed for architectural design that is firmly rooted within a biological paradigm and thus connected with issues of higher-level functionality and performance capacity. Enhanced context sensitivity lies at the base of this approach. This approach is referred to as 'Morpho-Ecology'. (Hensel, Menges, 2008)

It argues for an ecological model for architecture that promotes an active modulation of environmental conditions across ranges and over time through morphological differentiation. This approach promises both a new spatial paradigm for architectural design and advanced sustainability that links the performance capacity of material systems with environmental modulation and the resulting provisions and opportunities for inhabitation. (Hensel, Menges, 2008)

5.6. THEORETICAL FRAMEWORK

The theoretical & methodological frameworks relevant to this approach concern themselves with intense differentiation of material and energetic interventions that are evolved from:

- Their specific behavioral tendencies in given environment
- Their mutual feedback relationship
- Passive modulation strategies that are sustainable
- Speculation on the resultant relationship between spatial and social arrangements and habitation patterns and potentials

Morphogenesis is concerned with the processes that control the organized spacial distribution of cells which arises during the embryonic development of an organism, producing the characteristic forms of organs, tissues, and overall body anatomy. This approach takes up the concept of morphogenesis relating to the way the development of material systems is informed by inquiries into scale and size-specific behavior and related per-formative capacities. This involves the exposure of the system at each stage of development to a series of extrinsic influences and stimuli provided by a given environment. (Menges, Hensel, 2007)
This approach commences from the unfolding of per-formative capacities inherent in material systems in relation to the specific environment they are embedded within, as well as an intensively empirical mode based on physical and computational form generation analysis methods. Compared with current practice it presents a radically different take on the relation between formal expression and per-formative capacity of the built environment, as well as a fundamental revision of prevailing approaches to sustainability (Menges, Hensel, 2008)

5.6.1. Performance

An alternative understanding of performance, one that is based on multi-parameter effectiveness rather than single-parameter optimization and efficiency, must from the start of the design process include both the logics of how material constructions are made and the way they will interact with environmental stimuli. Computation in analytical and generative modes has a key role in both aspects. The underlying logics of computational processes, particularly when combined with computer-controlled manufacturing processes, provide a much higher level of design synthesis. (Menges , Hensel, 2008)

5.6.2. Form-Generation:

Particularly related is the underlying impoverished notion of form-generation, which refers to various digitally driven processes resulting in shapes that remain detached from material and construction logics. In foregrounding the geometry of the eventual outcome as the key feature, these techniques are quintessentially not dissimilar to more conventional and long-established representational techniques for explicit scalar geometric descriptions. As these notional systems are insufficient in integrating means of materialization, production and construction, they cannot support the evaluation of per-formative effects, and so these crucial aspects remain invariably pursued as top-down engineered material solutions. (Menges , Hensel, 2008)

This suggests that the talent, but as yet unused, potential of computational design and manufacturing technology may unfold from an alternative approach to design, one that derives morphological complexity and per-formative capacity without differentiating between form-generation and materialization processes (Menges , Hensel, 2008)
The morpho-ecological approach aims for a more integral design approach to correlate object, environment and subject into a synergetic dynamic relationship. (Menges , Hensel, 2008)

5.7. INTRODUCING 4 HUMANIST CONCEPTS THROUGH GENETICS AND BIODIGITAL DESIGN:

Digital architecture can be divided into four main areas to become humanist through genetics and bio digital concepts (generative evolutionary architecture):

These 4 main areas of design which will be stated are the new products of digital design in this third century where the morphogenetic area is our main part for study as morphogenetic is the main studying computational section for exploring and defining Bio digital and Genetic architecture. (Feuerstein, 2002)

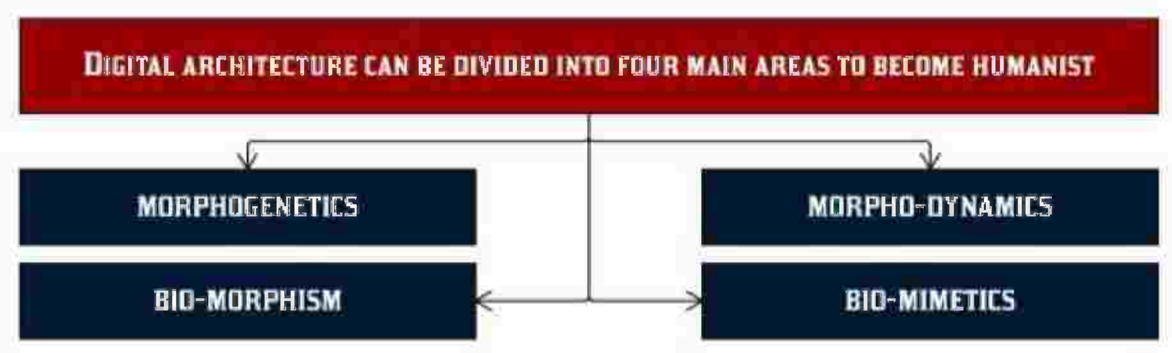

Figure (5- 4): Four divisions of humanist architecture
Source: Researcher 2014

5.7.1. Morphogenetic

- The hermeneutics of genetic and bio-digital architecture for inputting as data and design bases

- Algorithmic architecture that is based on fractal systems, Linden-Mayer systems and genetic algorithms for generating recursively defined geometrical objects

- The monad-ology of genetic and bio digital architecture that accepts sym-bogenesis as the action plan for "possible" worlds and design evolution. (Sym-biogenesis: is the merging of two separate organisms to form a single new organism).

5.7.2. Morph dynamics

There is no genetic code; it merges definite form into blob, particles, fluid etc.

5.7.3. Bio-morphism

Imitated forms, no internal understanding of biology

5.7.4. Biomimetic

Biological systems are being imitated using the benefits of computation processes. Biomimetic, for example, the flower is viewed, attempts to analyze it, learn its characteristics, then reproduce it in architecture, but Genetic architecture deals with abstract systems. It is based on a simple logical idea; the genetic architecture of progress takes place through the development process so that the end result may be even not look like something that came from nature. Genetic architecture evolves through the system the logic of simple algorithms to generate complex results. This approach is inside, it means creating from within, rather than take an example from outside. This can be the difference between genetics and biomimetic architecture.

5.8. ALGORITHMIC OPERATIONS IN MORPHOGENETIC EVOLUTIONARY COMPUTATIONAL DESIGN:

5.8.1. Hybridization (Morphing-BIO-Morphing)

Terzidis (2006) defines hybridizations as a "procedure in which an object changes its form gradually in order to obtain another form" He also added that "Morphing is a gradual transition that results in marked change in the form's appearance, character, condition, or function"

The operation of Morphing includes the selection of two objects and the assignment of a number of in between transitional steps. The essence of such a transformation isn't so much in the destination form but rather in " the intermediate phases" these transformations pass through, as well as in the "extra potations", which go beyond the final form. It is the transitional continuity of a form that progresses through a series of "evolutionary stages".

Jaenes and Jonathan's project serves as an important metaphor for the hybridized cultural and topographical qualities of Hong Kong, represented through a set of beautifully narrated digital poetic drawings and models. See figure 5-5; 5-6

Their early studies and final design is a semi-living translation clinic surgically nestled in the topographical conditions of the mid-level hill gardens and grows behind a modernistic old hospital façade. The biological design approach allows sophisticated control over the morphing of natural and artificial architectural elements, encoding hidden agendas within its volumes and circulations. Its technological green building envelope farms pharmaceutical ingredients, blending and disguising private programs, but also providing a public garden within the ecology of the hilly city. (Bong, Alotto, 2009)

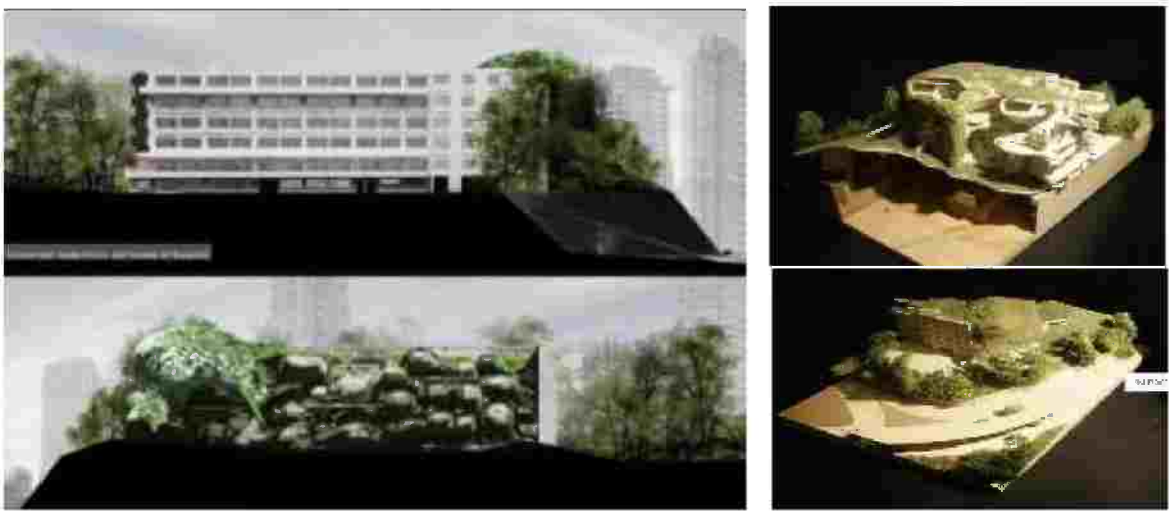

Figure (5- 5): Bio metamorphic Architecture: Organ Transplantation Clinic And Laboratory
Source: Bong, Alotto, 2009

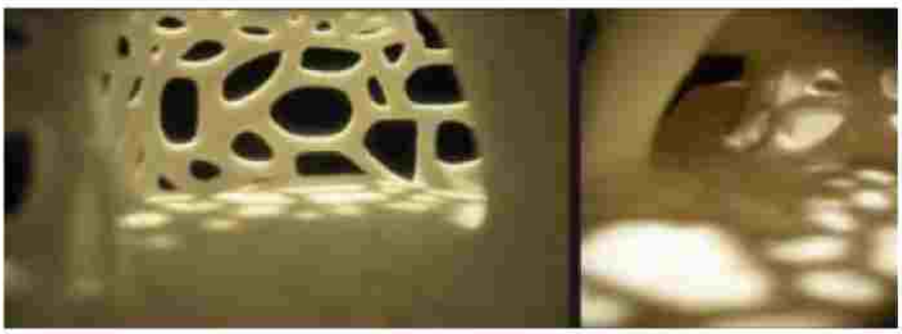

Figure (5- 6): Interior natural light rays - Bio metamorphic Architecture: Organ Transplantation Clinic And Laboratory
Source: Bong, Alotto, 2009

5.8.2. Cellular Automata

> *"Contrary to Mies van derRohe's remark that architecture is the art of putting two bricks together the emerging concept is that architecture is the art of putting two bits together, at least bits that are programmed to self-replicate, self-organized and self-synthesize into evermore new constellations of emergent relations and aggregations"* (Chu, 2006)

This cellular automata is used in morphogenetic and evolutionary architecture and applies biological genetic concepts. The first time a cellular automaton was introduced in 1940's in Los Anglos when Stainslaw Ulam studied the growth of crystals, using a simple "lattice network" as his model. In 1970 the concept of the cellular automata was brought to the attention of a wide audience through the introduction of a simple ecological model, called "game of life", by the British mathematician John Horton Conway. "Life" combined all the notions of cellular automata into a model that simulated the key elements of reproduction in the simplest possible way. (Stamoua, 2006)

The use of cellular Automata in architecture ranges from vernacular settlements and social interaction to material behavior and air circulation of bio-digital and genetic concepts. This is also used in the examination of the exploration of the simulation of urban growth using complex systems theory and cellular automata (Stamoua, 2006)

A project as an example is the construction of a Proto-cellular Housing that is based on the logic of self-replication and mutation as well as on the potential for self-organization into an emergent or end morphology of architecture. As such, it aspires to be a conceptual model for the construction of cellular architecture.

The closest analogy is that of a housing project, albeit one that is situated in between a theoretical / abstract model of the aggregation of cells or cluster of cells and an architectural model of a housing project, which typically contains a high degree of redundancy built into it. See figure 5-7. One of these challenges for genetic architecture, which obsessively deploys self-similar elements that are driven by genetic codes, is how the engagement of difference and repetition at the formal level can generate novelty at the level of architectural morphology. (Chu, 2009)

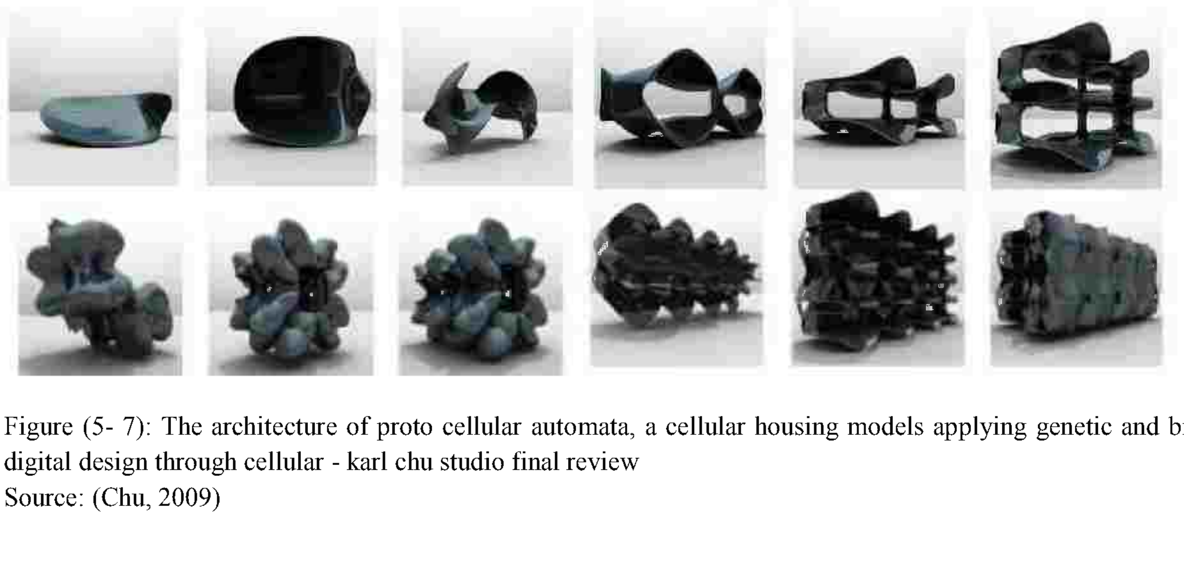

Figure (5- 7): The architecture of proto cellular automata, a cellular housing models applying genetic and bio-digital design through cellular - karl chu studio final review
Source: (Chu, 2009)

5.8.3. Stochastic search

Stochastic search methods are a form of heuristic search that use the following generic algorithms to generate morphogenetic and evolutionary computational designs: first, construct a set of random candidate solutions. Second, keep searching unit some condition is reached. (Terzidis, 2006)

Stochastic search as a process in which building elements are placed at random locations in space that are then evaluated against a 'set of constraints' to be accepted if there is a "satisfying fit". The random search space can be adjusted to match the 'zoning envelope' according to genetic stratigies and 'the constrains' can match structural, circulation or programmatic requirments. (Cardoso, 2006); (Terzidis, 2006)

According to a genetic concept or biodigital growth material, an example for stochastic search, Cardoso (2006) took a program and site for a residential tower amd documents a rule building process and implementation of these rules in stochastic search program written in MELscript. He also showed that how adjustments made in the set of rules after evaluating describe the architectural program affected the search space and consequently the resulting form. See figure 5-8

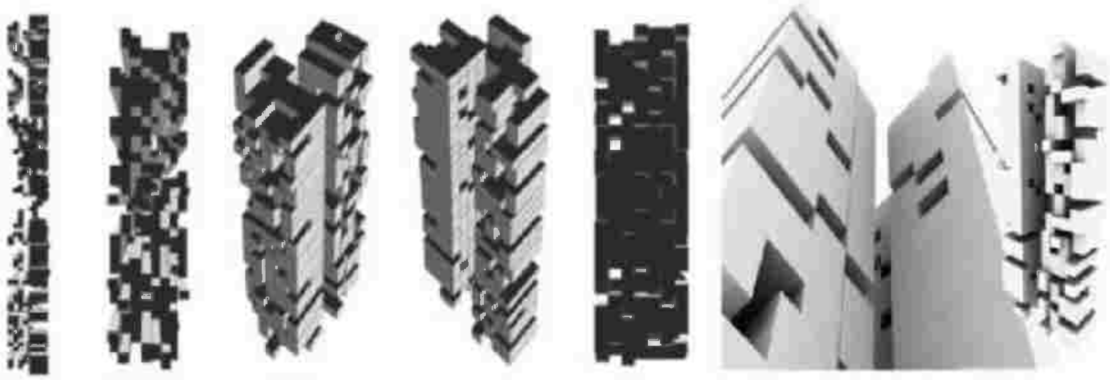

Figure (5- 8): Cardoso's Resi;timg towers after changing the parameters
Source : (Cardoso, 2006)

Another example with the same nature is this particlar problem a simple program of 200 residential units (50 1-bed 900 sq. ft, 100 2-bed 1200 sq.ft and 50 3-bed 1600 sq. ft) was to be placed within a 70 X 70 ft. site. This is a class project by julie kaufman and brain price for course. See figure 5-9

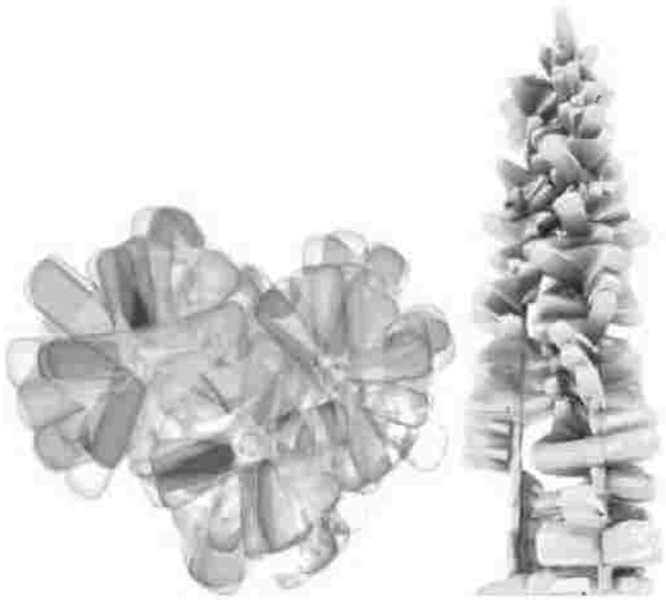

Figure (5- 9): Views for the residential tower from above and down.
Source: Terzidis, 2006

5.9. METHODOLOGICAL FRAME WORK OF MORPHOGENETIC AND EVOLUTION APPLICATION

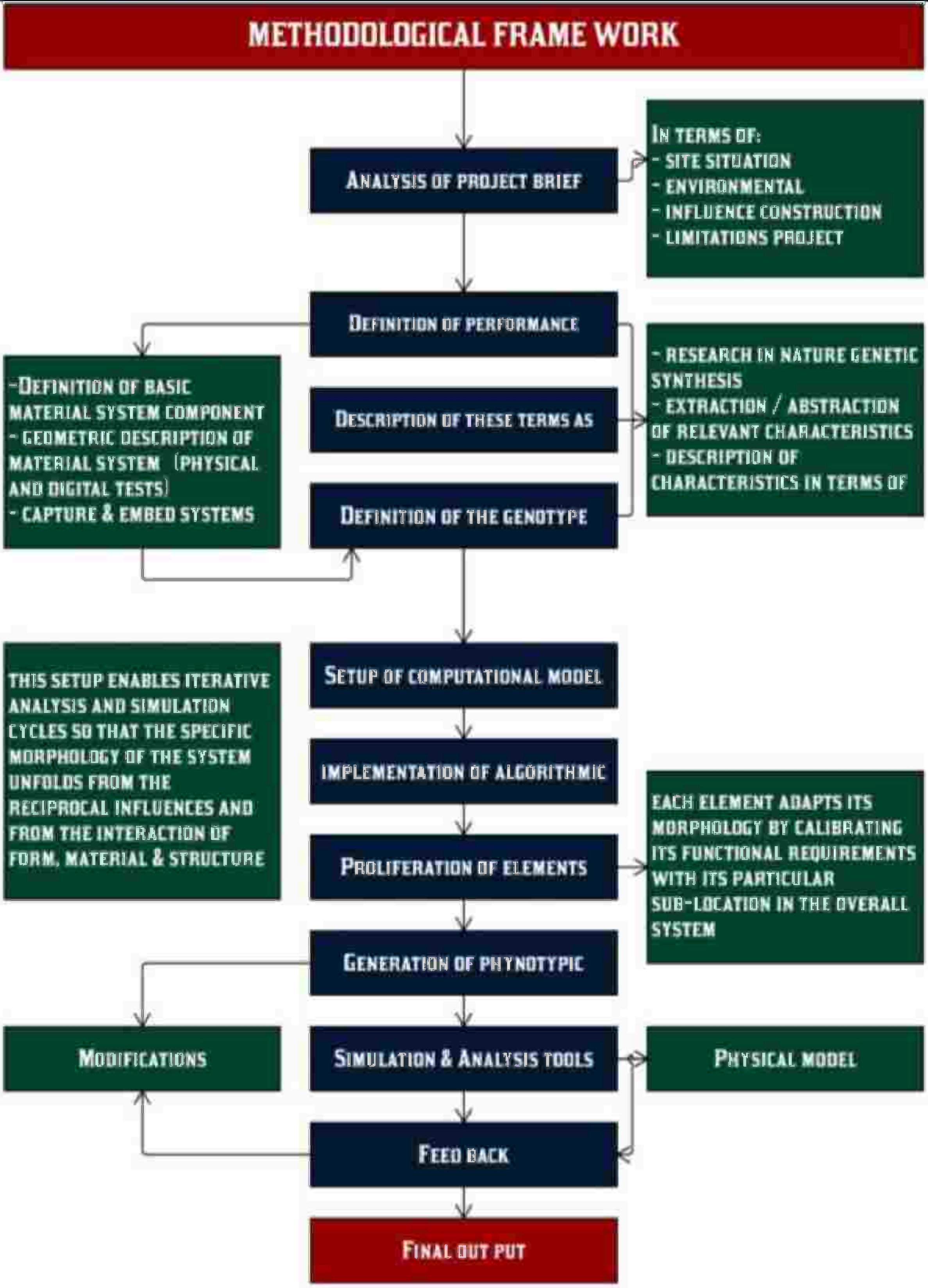

Figure (5- 10): Diagram summarizing the presented methodological framework
Source: Researcher 2014

5.9.1. General example applying previous methodological framework

General example applying the main methodological frame work/steps of a biological and genetic example of a morphogenetic and evolutionary computational design

ANALYSIS OF PROJECT BRIEF: Influence Construction / Limitations Project

Michael Weinstock, Achim Menges and Michael Hensel (2004), presents the case for considering high-rise buildings as surface structures. Where they stated that there is a need to rethink the design of high-rise buildings, to find as approach that integrates structure and behavior into material systems that are adapted to vertical urbanism. They discuss the need for flexure and stiff.

DEFINITION OF PERFORMANCE – DESCRIPTION OF THESE TERMS AS

Cylindrical morphologies and helices

Geometry is essential in natural and computational morphogenesis. It provides the set of boundary constraints that inform the global configuration of a developed form as well as the local rules and organizing principles for self-organization during morphogenesis.

There are natural structures that have a cylindrical morphology, that display a robust and flexible structural performance that is provided mainly within the skin without any internal ribs or columns. These structures achieve a wide range of performance and functions through the organization of their components - fibers and matrix - in 3-d assemblies, despite the fact that fibers have low compressive strength and are prone to buckling. Cylinders are generally particularly prone to buckling. Natural evolution has provided several successful strategies for surface structures, including shape-optimized morphologies and the arrangement of components in complex hierarchies to provide multiple load-path vectors. The initial research into generic patterns in natural systems suggested that the helix be selected for this evolutionary experiment. (Weinstock, Menges, Hensel, 2004)

Spiral helix occurs in dynamic configurations at all scales in the physical world. They appear in enormous energy systems such as spiral galaxies that have central regions thousands of light years across. Helices are immediately visible in geophysical systems such as the atmosphere or oceans, in the dynamic vortices of hurricanes, tornadoes, storms and whirlpools. In living forms spiral helices are found in, for example, the arrangement of protein molecules in DNA and the geometry of pine cones, sunflowers and the florets of broccoli. Xylem vessels in plants are the slender tubes that transport water and solutes up from the roots into the stem and leaves. Spiral bands of lignin reinforce xylems, and the spiral geometry allows the tubes to elongate and grow. In many plants the arrangement of the leaves around the stem corresponds with the Fibonacci number sequence, which appears to maximize the space available for each leaf to receive the optimal degree of sunlight. (Weinstock, Menges, Hensel, 2004)

DEFINITION AND DEVELOPMENT OF THE GENOTYPE

Development of the genotype:

The evolutionary process began with the 'seed" or primary input, of the simplest industrial component - the section of a steel tube 150 millimeters in diameter. This was swept along a helix to the bounding limits of the mathematical 'environment', which was defined by the planning constrains and dimensions of a competition site for a tall building. The single, helical tubular member was 'bundled' by generating copies rotated around the originating center. This established a 60-meter double helix of 10 tubular members deployed in two bundles, which was further evolved by generating a counter-rotated inner layer. In the next generation four bundles were selected, each with its outer and inner group in counter rotations. In successive generations inner and outer layers of members were deployed in the earth quadrants between the bundles. The structure in this stage of evolution has 80 members arranged in two concentric contiguous layers. Forces were applied to the global geometry, producing a population of variant forms, and from these a single form with the base and top flared, and the waist slightly narrower, was selected.

The development of the genotype continued by relaxing the geometrical rule of parallel construction planes for the inner and outer layer of helices, This resulted in more complex geometrical relations between the planes with non-uniform distances between them. The curved planes of the helices became strongly differentiated, sometimes quite far apart, sometimes touching and occasionally penetrating each other. A reciprocal development within the planes changed the initial arrangement of equal distances between individual helical members, so that varied distances between individuals appeared, and finally intersections between individuals. A higher level of structural organization emerged, in which microstructures intersect, wrap around each other, bundle and unbundle. The complexity suggests a new spatial organization and structural capacities may be enabled by the phenotype. Floor plates, for example, may be more three dimensionally articulated and less symmetrical than in conventional tower structural than in conventional tower structure, and may even be volumetric.

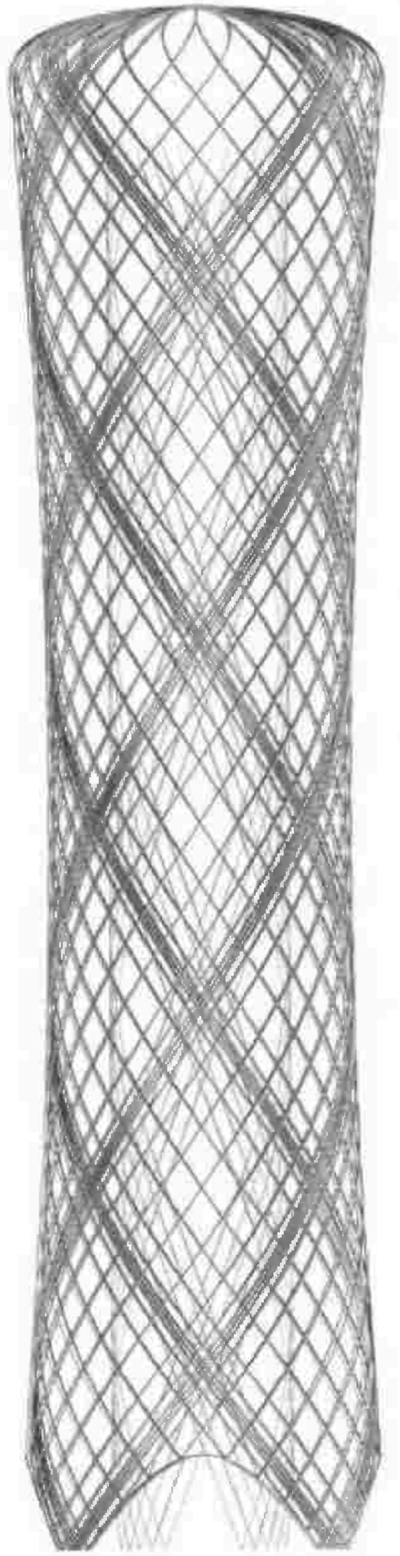

Figure (5- 11): Evolved Double Helix Structure
Source:(Weinstock, Menges, Hensel, 2004)

IMPLIMANTATION OF ALGORITHM - PROLIFERATION OF ELEMENTS

Fitness through flexure

As in figure 5-12: Two notions dominate the traditional approach of engineering to the design of structure: stiffness and efficiency. Stiffness implies that structural members are optimized so that they do not easily bend, and members are arranged into whole structures that are rigid and inflexible. Efficiency characterizes the preferred mode of achieving structural stiffness with a minimum amount of material from which it is made must be minimized, and elastic deformation of the structure under load is carefully calculated. (Weinstock, Menges, Hensel, 2004)

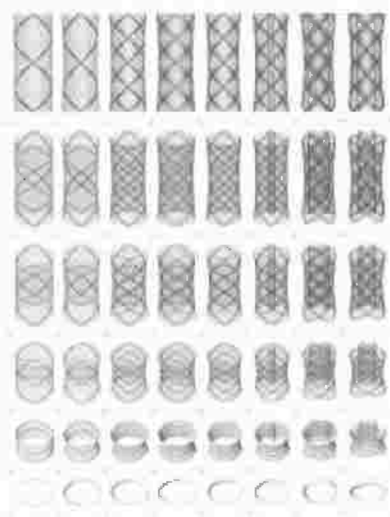

Figure (5- 12): Helix Evolution
Source: (Weinstock, Menges, Hensel, 2004)

GENERATION AND DEVELOPMENT OF PHENOTYPE

Development of phenotype

The development of the phenotype is driven by exposure of the geometry to environment forces, a process that encourages twins multiples, and aggregations of forms that increase structural capacity by sharing and distribution of loads – not speciation but variation within one population of geometries. The building envelope was developed from a digital study and finite element analysis of the tessellated surface geometry of a custard apple. The skin of the fruit must maintain its structural integrity, resisting the pressure of the swelling material inside. The panels all have the same form but size is varied and tessellation results in a surprisingly low number of variations required for the complex double curvatures.

The building envelope is considered as an integral system of structure and environmental regulator-panels that are adaptive in geometry and performance. The differentiation of the geometry of the panels follows a similar logic to the differentiations of the helices – all have the same form and geometric logic but the size is varied through a limited number of parametric changes allow the form of the panel to adapt to the changing curvature and varying density of the helical structure through a simple algorithm. The organization of the structural interface, the connection between the helices and panel regions, is local. This maintains coherence between the different geometric hierarchies and has the capacity to adjust to global changes in geometry. (Weinstock, Menges, Hensel, 2004)

SIMULATION AND ANALYSIS

The skin achieves its kinetic capacities through differential pressure in a capillary system of pneumatic actuator cells that are distributed between the inner, center and outer membranes. Differential pressure in capillary layers triggers the change from convex to concave geometry by the differential expansion and contraction of layers. Synchronized changes from convex to concave geometry in a panel allow the regulation of light reflection between the inner and outer membrane, and the insulating volume of the enclosed air space. (Weinstock, Menges, Hensel, 2004)

Alternating the changes to the geometry of the lower and upper half of a panel regulates the fresh air ventilation and directs light transmission. Differential pressure between pneumatic chambers allows from movement of the interfacing membrane. Patterns of photovoltaic cells printed on the membranes collect from a secondary solar energy gain, which can be collected from the entire surface and used to feed the micro-compressor that produces the air pressure of the pneumatic actuator cells in each half panel. All the energy necessary to maintain the air pressure ant to operate the regulator valves of the pneumatic panels is sourced, stored and managed locally by very simple microprocessors, microprocessors and high-capacity accumulators. There is no need to draw on a central energy supply, which increases the reliability and efficiency of the system and lower production and maintenance costs. (Weinstock, Menges, Hensel, 2004)
Environmental data from interior and exterior is collected by local sensors and processed locally. The activity of individual panels is entirely local and is a response to local stimuli. Direct operation by users is local, affecting an individual panel or a surface region of the building. The self-learning capacity of the simple panel processing units also happens locally. Each panel is independently responsive, capable of modulating the passage of light, heat and air through it in both directions, and managing its own energy economy. No remote central processing is used for instruction: sensing and activation are embedded functions in each individual panel, and multiple links between them provide the means for a distributed intelligence from which a complex global performance emerges. The exterior appearance will be constantly changing, with small variation in angles and transparencies producing an animated and subtle surface. (Weinstock, Menges, Hensel, 2004)

FINAL OUTPUT

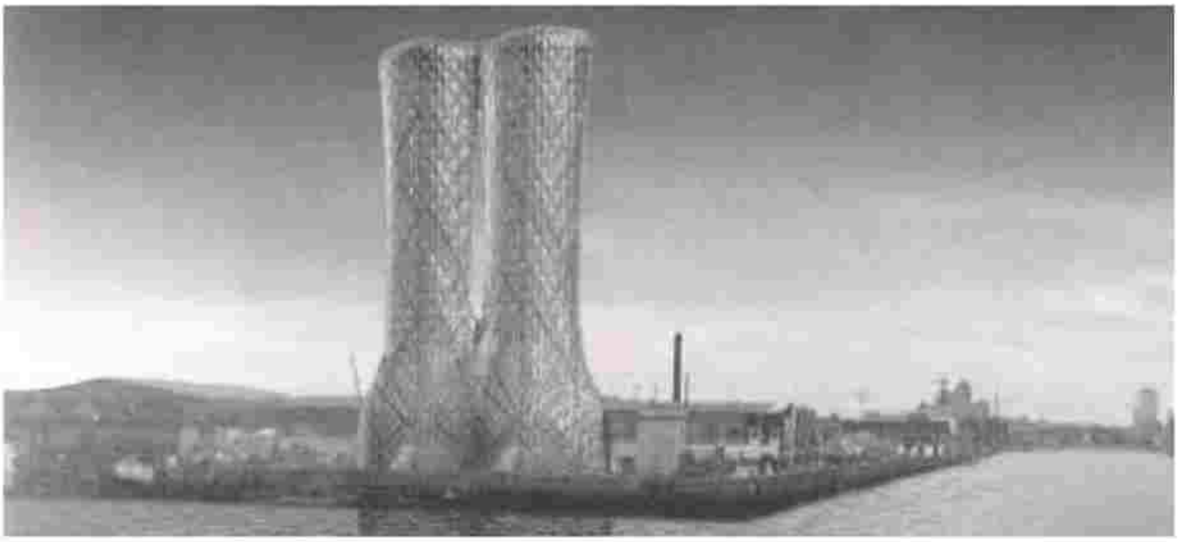

Figure (5- 13): double helix tower project on site
Source: (Weinstock, Menges, Hensel, 2004)

Adapting these strategies of design for tall buildings will make a radical change to their performance. The total amount of material involved will not be excessively increased, for whilst there will be many more members, each individual member will be very much smaller in section. (Weinstock, Menges, Hensel, 2004)

5.10. SELECTED BIOLOGICAL DESIGN PRINCIPLES THROGH MORPHOGENESIS

The previously selected biological principles stated in chapter three are presented here once again within the context of such an application design approach. They represent some of the most important features and characteristics of morphogenetic evolutionary computational design, and will serve as analysis criteria for generative genetic and bio-digital evolutionary design. The selection of these principles was due to the available research and literature on this topic.

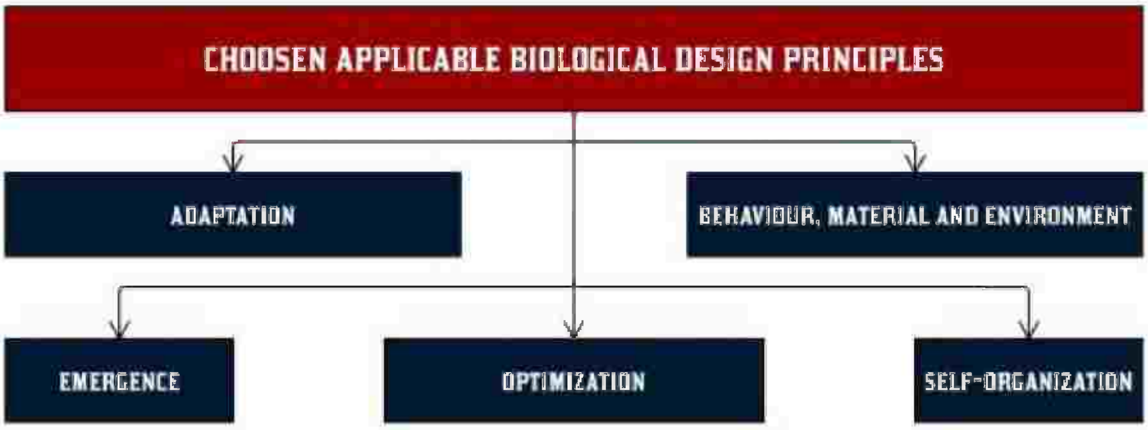

Figure (5- 14): Chosen applicable biological principles
Source: Researcher 2014

5.10.1. Adaptation

As in chapter 4 in 4.11.1 the most important principle of adaptation is small random variation in the design, repeated over time. It is this stochastic process that produces robust systems that persist through time. In mathematical terms, stochastic is often used in opposition to the deterministic. Deterministic processes always produce the same output from a given starting condition; stochastic processes will never repeat an identical output. It follows that developing processes that include small random mutations over many iterations is a significant evolutionary ‘strategy for design, architecture and engineering, and one that will preclude the standardization of components and members. See figure 5-15

Adapting geometry to changing circumstances throughout the design process can be a time consuming and costly ordeal or, on the other hand, can be anticipated and tools designed that facilitate the possibility of significant changes right up to the manufacturing stage. Whenever the design requirements and constraints and performance profiles of a design change, it is important that the design can absorb such changes through a modifiable geometric modeling setup capable of retaining geometric relations while being substantially modified. (Hensel, 2006)

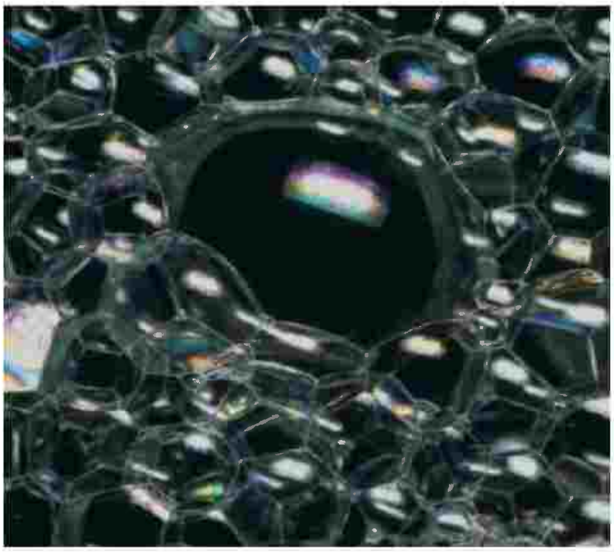

Figure (5- 15): Scanning electron micrograph of polyurethane foam, showing the porous structure of differentiated open and partially closed cells. Magnification x 20 when printed at 10 centimeters wide
Source: (Hensel, 2006)

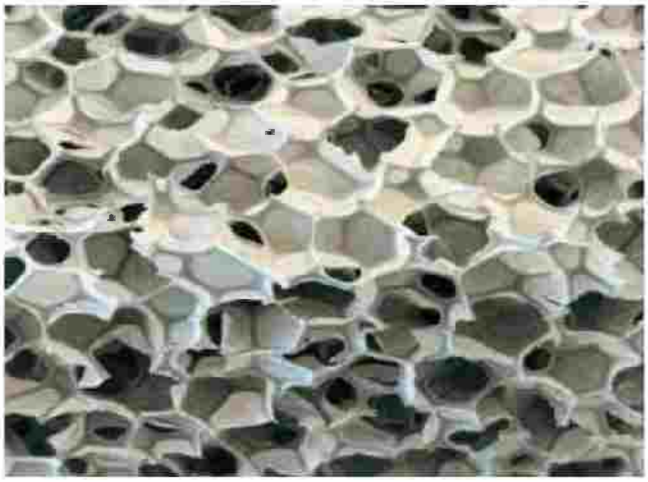

Figure (5- 16): A naturally produced foam of soap bubbles, demonstrating the differentiation of polyhedral cells in an intricate geometry of foam architecture, including the basic Plateau rules for the intersection of three films.
Source: (Hensel, 2006)

5.10.2. Behavior material and environment

As in chapter 4 no: 4.11.2 and in figure 5-17 the notion of the form behavior and material system constitutes one central aspect of the research presented in this thesis. While it may initially seem obvious to consider material systems more or less as the equivalent of construction systems and tectonics, material systems are conceived within this context as a more profound and integral concept. In this way, material system does not refer to the material constituents of a building alone, but rather describes, in a system-theoretical sense, the complex reciprocity between materiality, form, structure and space, and the related processes of production and assembly, and the multitude of per-formative effects that emanate from the interaction with environmental influences and forces. (Hensel, Menges, Weinstock, 2010)

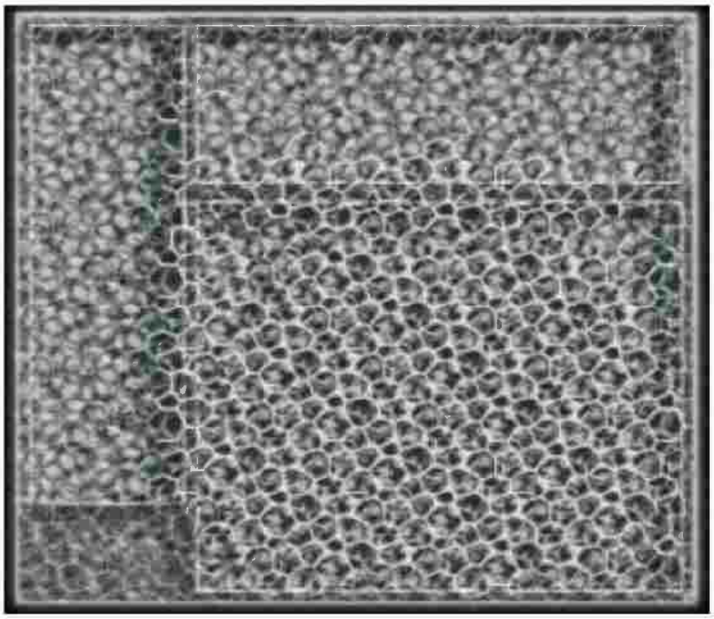

Figure (5- 17): Water cube digital structural model. The mathematics of foam geometries are used to produce the structural array, ensuring a rational optimized and buildable structural geometry.
Source: Hensel, Menges, Weinstock, 2010

The emphasis on process and acceleration of the evolution of an architectural environment is also very important, in which the relation of form and space to program acknowledges the dynamic patterns of human habitation, environment is understood as a dynamic composition of habitat-specific conditions and inhabitant-specific itineraries, a gradient field of per-formative micro and macro milieus. Together, these milieus produce an ecosystem, a dynamic relationship between environmental, topographical and structural intensity and human activities. (Menges, 2004)

Form and behavior emerge from the processes of complex systems. Processes produce, elaborate and maintain the form of natural systems, and those processes include dynamic exchanges with the environment. There are generic patterns in the process of self-generation of forms, and in forms themselves. Geometry has both a local and a global role in the interrelated dynamics of pattern and form in self-organized morphogenesis. (Hensel, Menges, Weinstock, 2010)

Forms maintain their continuity and integrity by changing aspects of their behavior and by their iteration over many generations. Forms exist in varied populations, and where communication between forms is effective, collective structured behavior and intelligence emerges. Form and behavior are intricately linked. The form of an organism affects its behavior in the environment, and a particular behavior will produce different result in different environments. Behavior is nonlinear and context specific. (Hensel, Menges, Weinstock, 2010)

5.10.3 Emergence

As in chapter 4 emergence design principle was introduced in partition 4.11.3 The phenomenon of *emergence was* discovered in the 1970s, it offers a new precision to the study of evolution, complexity and it appears to be strangely applicable to a huge range of disciplines and scales, from the micro-biological to the macro-economic. It forces us to reconsider the pervasive atomic, collage-based view of the world, which is concerned with parts, even parts in seemingly complex arrangements.

An emergent organization exhibits behaviors or has properties which are not predictable by observing any of the behaviors or properties of its constituent parts. That is, the emergent whole always exceeds its parts qualitatively. The beautiful coherence and dynamics of a swarm of bees can never be traced back to the behavior of a single bee. Within the realm of architectural practice, an emergent network is more than an arrangement of expertise or an overlapping of spheres of influence. It is a collective which exhibits emergent behavioral patterns that are unpredictable by examining the behavioral patterns of its parts. (Wiscombe, 2006)

Emergence refers in fact to a very particular scientific phenomenon: the indivisibility and irreversibility of wholes- be they structures, organizations, behaviors, or properties. In particular, emergence refers to the universal way in which small parts of systems, driven by very simple behaviors, will tend toward coherent organizations with their own distinctly different behaviors. (Wiscombe, 2005)

5.10.4. Self-organization

Self-organization is a process whereby pattern at the global level of a system emerges solely from interactions among the lower level components of the system. The rules specifying the interactions among the systems components are executed using only local information, without reference to the global pattern. Examples of self-organization include a wide range of pattern formation process in both physical and biological systems: sand grains assembling into rippled dunes, chemical reactants forming swirling spiral patterns and many other concepts in nature. (Camazine , Deneuboug, Franks, 2001)

These patterns are used here not only to a particular arrangement of subjects in space, but also to structure and organize in time. (Camazine , Deneuboug, Franks, 2001)

"Predominately masonry" façade, an example which its façade design began through a material exploration of their module: a single brick and mortar. This investigation of the physical constraints of the material generated two simple parameters for working with the material. 1. The size and shape of the brick. 2. Minimum amount of surface area required by the mortar to hold a brick into the panel. These two parameters were used for several different brick types, which were tested for the amount of projection they could provide from the panel. Environmental and programmatic requirements were addressed at the scale of the panel.

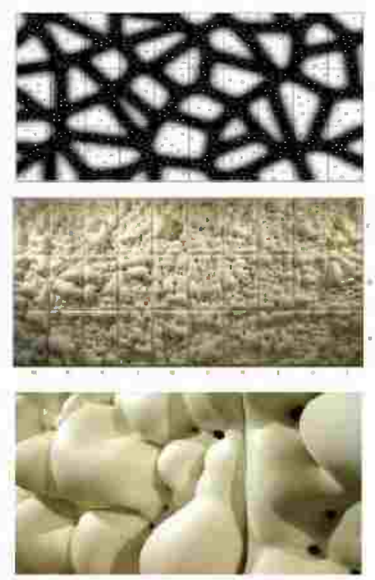

Figure (5- 18): Initial gray scale image, corresponding P_Wall, and a close-up showing the amount of variation achieved in the wall.
Source: (Weinstock, 2008)

This investigation leads to a digital model of a single panel that had the physical constraints of the brick module built in.

The digital model of the panel revealed that a modification to the original brick module would be advantageous, and the brick's width was cut in half. The physical properties of the half-brick module allowed for acceptable projection, but did not inform how the bricks should be coursed or which undulating surface geometry would work best at the scale of a panel or the facade. (Weinstock, 2008)See figure 5-18

This competition entry for a library in Prague aspires to create a building with "gradually eroding exclusive programmatic and hard threshold alignments in favor of heterogeneous spatial arrangements and environmental gradients." The underlying organization is that of a tree: the national archive is housed in the solid trunk; branches hold up the cantilevered stacks and create a semi-transparent "canopy".

The smallest module for the facade of the library is one steel "branch" section. The internal parameters for each module are 1. Length of steel member 2. Width/height of steel member 3. Angle of connection to neighboring members. It considered the modulation of thermal, airflow and luminous conditioning of the different areas. (Weinstock, 2008) See figure 5-19

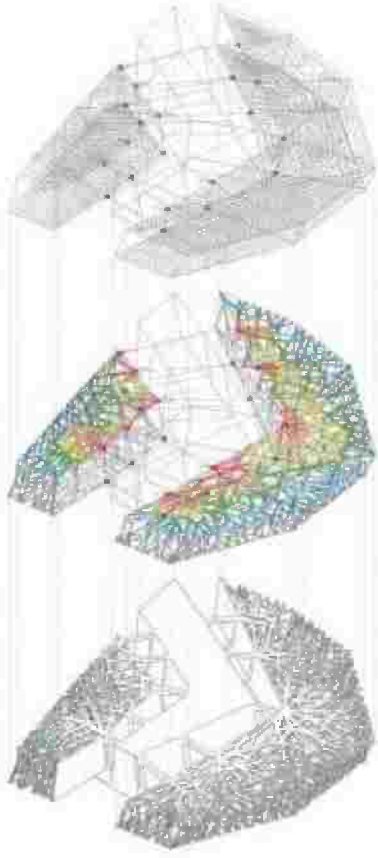

Figure (5-19): OCEAN North, New 1. Stresses are analyzed 2. Tree modules are created using algorithm 3. Steel branch modules are sized based on Stresses. Source: Weinstock, 2008)

5.10.5. Optimization

Optimization is the act of rendering optimal; "the simultaneous optimization of growth and profitability"; "in an optimization problem we seek values of the variables that lead to an optimal value of the function that is to be optimized"; "to promote the optimization and diversification of agricultural products". It is a biological principle used as a tool in architecture for form and design making. It is a subfield of engineering that uses optimization methods to study, aid, and solve architectural design problems, such as optimal floor plan layout design, optimal circulation paths between rooms, and structural optimization which is mostly used.

A method for shape generation (morphogenesis) and structural optimization of a reinforced concrete roof shell, based on the application of a genetic algorithm, is presented. See figure 5-17. The use of a NURBS representation of the roof allows modifying the shape by changing the position of control points or interpolating points, so that the coordinates of these points can be assumed as design variables. The structural optimization, based on reducing the maximum vertical displacement of the structure under the self-weight, improves the structural behavior of about ten times in 75 generations, modifying selectively the parts of the structure showing the worse behavior. See figure 5-17 (Sassone, 2006) ; (Pugnale, Sassone, 2011)

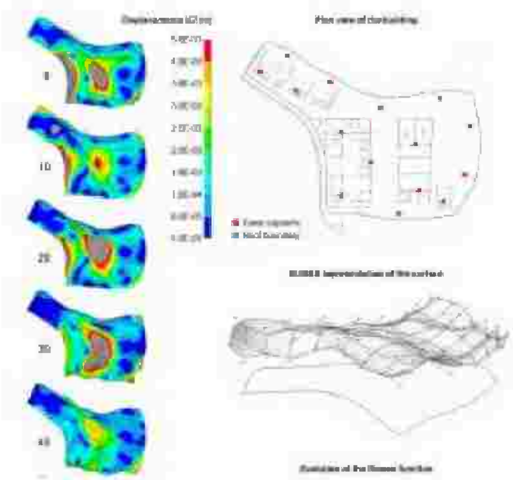

Figure (5- 20): Kahamigahara crematorium, Gifu, Japan – Left: map of vertical displacements every 10 generations
Source: (Pugnale, Sassone, 2011)

Another example of a 150 mm non design frame was established around the design space to ensure usability of the optimized structure. The initial optimization objective was to minimize deformation energy within a design constraint on the volume fraction of 40% of the total volume. Within this model, we conducted a series of comparative studies of the impact of certain alterations in the configuration of the resulting topology, in order to test the difference in performance of the derived designs. See figure 5-21 (Dombernowsky, Sondergaard, 2009)
Presented in the scheme below are the variables:

- Distribution of load
- Minimum size of basic elements
- Constraint on displacement

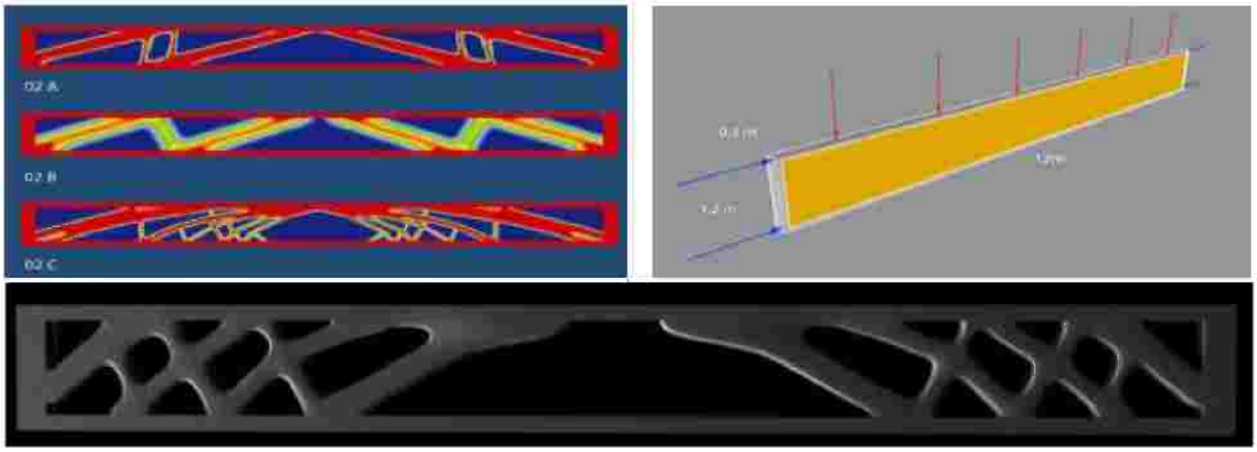

Figure (5- 21): (A) - Comparative scheme of optimization results. (B) - Final design incorporating both displacement and minimum member size constraints
Source: (Dombernowsky, Sondergaard, 2009)

5.11. EXAMPLES OF MORPHOGENETIC AND EVOLUTIONARY COMPUTATIONAL DESIGN (SINGLE / MULTI BIOLOGICAL PRINCIPLES)

Figure (5- 22): Examples of morphogenetic and evolutionary computational designs and their classifications
Source: Researcher 2014

5.11.1. SINGLE BIOLOGICAL DESIGN PRINCIPLES

5.11.1.1. Emergent Generative design structure - Genetic stairs

The emergent genetic stair is designed as the centerpiece of a much larger apartment renovation for art collectors on Manhattan's Upper West Side, this stainless steel stair represents the culmination of a fully integrated generative design process which exploits advanced digital design techniques from the earliest conceptual stages, through per formative analysis and onwards to fabrication.

Figure (5- 23): Generative design of a structure for genetic stairs
Source: (Caliper, 2013)

In the search for a final form that inhabits the fecund territory between exuberance and rationality, custom code was developed to marry the generative potential of 3D architectural modeling with the analytic power of structural design software. In an entirely automated evolutionary process, populations of stairs were created in compliance with strict fabrication constraints and then rated for structural performance. Following genetic principles, new generations were produced in which individuals showed stronger and stronger properties until a final design was deemed structurally adequate to connect two floors with no intermediary supports while making three ninety degree turns. Materially, the stair embodies a restrained palette of polished stainless steel, white translucent Corian and low-iron glass. See figure 5-23 (Caliper, 2013)

Figure (5- 24): The stair is an almost minimal composition of white translucent treads, stainless steel fittings and low-iron glass.
Source: http://www.caliperstudio.com/

5.11.1.2. Form behavior and Adaptation: Lamp, "battery" with bioluminescent bacteria that live originally in abyssal fish

Genetic research about bioluminescence for architectural applications: Bio-lamp, "battery" with bioluminescent bacteria that live originally in abyssal fish. In 2008, for first time in architecture history, without electrical installation, a whole home was systematically illuminated with bioluminescence. Searching efficiency this phase also introduces in other non-bioluminescent bacteria and plants the genes group responsible for bioluminescence in previously mentioned bacteria. See figure 5-25 (Estevez, 2009)

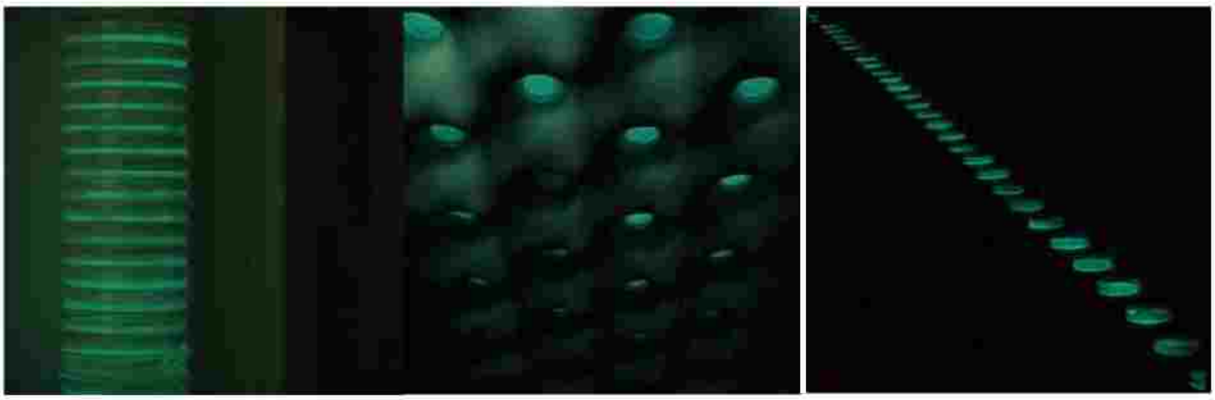

Figure (5- 25): Lamp, "battery" with bioluminescent bacteria that live originally in abyssal fish- real application
Source: (Estevez, 2009)

5.11.1.3. Form finding and emerging of design: Embryological House

The Embryological House was inspired by the evolutionary biology and the science of turbulence and made possible by the computer's ability to generate warped or fluid forms. The result of three-dimensional curves defined by mathematical formulae rather than of straight lines specified by fixed, two-dimensional coordinates. The Embryological House represents a new approach to fabrication and growth. Historically, a modern house would be thought of as a kit-of-parts. (Lynn, 2000)
Each part is distinct and discreet, and you customize the house through the addition or subtraction of parts from the kit. The embryological house is supposed to trace the evolution pattern of the human embryo see figure B and the mutation patterns where none was considered ideal. The mutation system and the possible iterations that could be generated in varied sequences see figure C. Embryological House concludes with “A New Style of Life," a science-fiction story describing the domestic life of an occupant who has been consumed by his Embryological House, as in swallowed. The interference between its digital and biological systems gives rise to a house that is animal-like in structure–and behavior. (Lynn, 2000)

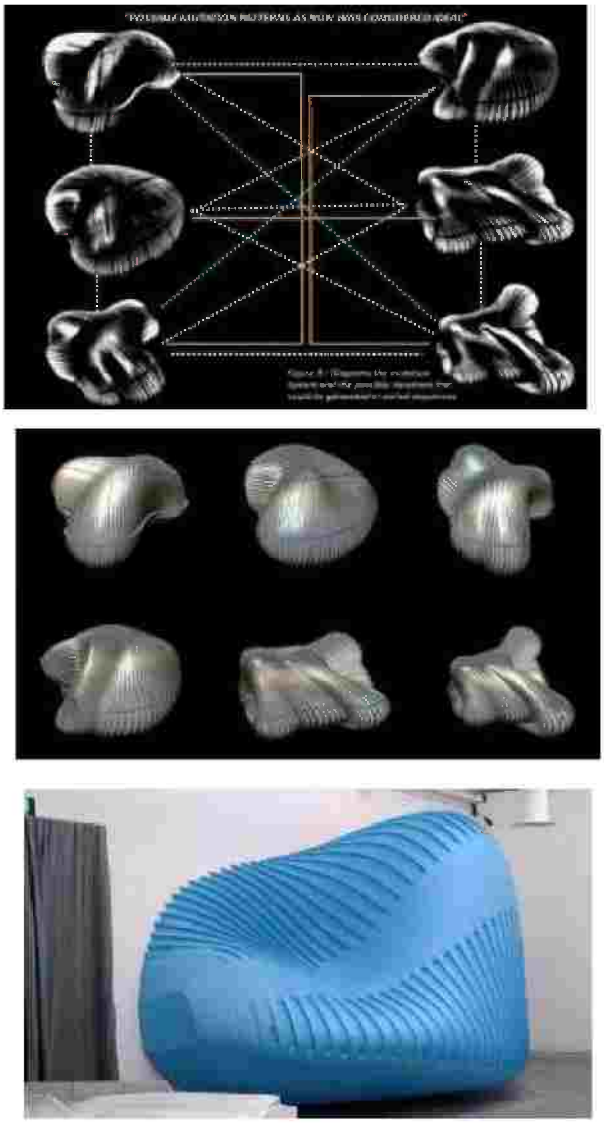

Figure (5- 26): Greg Lynn: Embryological Houses model
Source: (Lynn, 2000)

5.11.1.4. Arch kludge – Evolution of form

One of the applied parametric and genetic algorithm evolutionary design is the ArchiKludge, it is a project by Pablo Carranza that explores the evolutionary design of architecture. It is a simple and rare example of a genetic algorithm being used in the parametric and genetic evolutionary design of architecture. (Carranza, 2003)

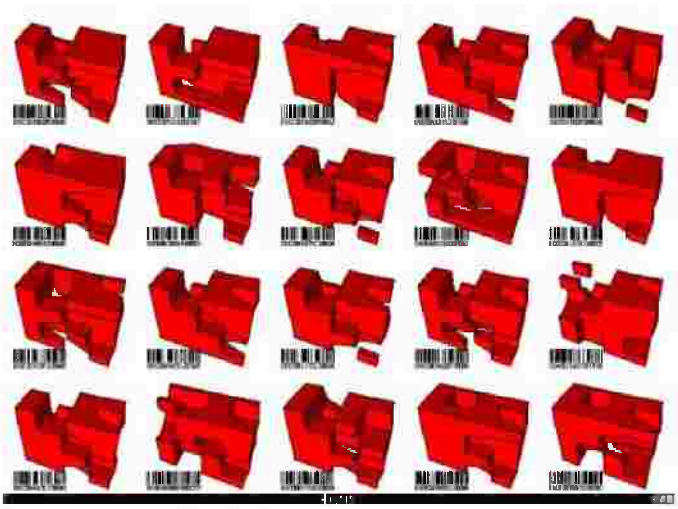

Figure (5- 27): arch kludge algorithmic populations and solutions of the chosen genetic algorithm criteria
Source: (Carranza, 2003)

The genetic algorithm used by ArchiKludge belongs to a family of algorithm known as search algorithm. These algorithms have been developed by computer scientists to search for solutions to problems, and recently architects like Pablo Carranza have appropriated them for use in digital morphogenesis. The way the genetic algorithm finds architectural solutions in ArchiKludge is as follows:

1. **Initialization and evaluation:** The population is made up of individuals and each individual is an architectural solution. The individuals all have genomes associated with them. In ArchiKludge the genome is a string of 64 numbers. Each number is connected to a cube in a 4*4*4 structure, when the number is set to 1 a room is created in this location, when it is set to 0, there is a void.
2. **Selection:** All the individuals are measured to find the best. In ArchiKludge the individuals score is a sum of the average distance between connected rooms.
3. **Reproduce:** The best individuals are breed together to form a new generation. Typically what happens is two parents are selected and a child is made from half of each parent's genome.
4. **Solution selected:** ArchiKludge continues indefinitely, but presumably an individual could be selected as the final design. (Carranza, 2003)

The process used in ArchiKludge is made to look more complex through a fairly slick interface. Notably the cubes have been pushed and pulled a little bit to make the buildings look more interesting than the cubes the program is really designing. How individuals are measured is also cleaver because it produces unconventional buildings with voids, where as if the measurement was gross area it would quickly become a solid cube (Carranza, 2003)

5.11.1.5. Genetic performing materials: Perform interactive urban material an Algae Canopy, which produces a small forest's worth of oxygen

This is an example for how can biology and architecture come together to create new and compelling forms and functions. Responsive "genetic" architecture, the latest development is this fascinating Urban Algae Canopy Module which features bio-digitally activated, micro-algal cultivation that is responsive to various environmental factors like weather changes, light patterns. The canopy will change dynamically, thanks to various sensors that will react to environmental variables to control the interior flow of water and carbon dioxide, which act as a growing medium for the algae within. (Mok, 2014)

Figure (5- 28): (A) Ecologic Studio- bio-digital model
Source: (Mok, 2014)

Figure (5- 29)(B): Ecologic Studio- bio-digital model
Source: (Mok, 2014)

This canopy will react to people kinetic movements and factors like sun by growing more algae on sunnier days to create more shade, or vice versa, all of it in real-time. Most importantly, it will be capable of producing the same amount of oxygen as four hectares of woodland, and 330 pounds (150 kilograms) of biomass per day, 60 percent of which will be natural vegetal proteins... Imagine cities covered with these algal canopies this could be the future of how a new, responsive and biologically-based architecture could help solve the problems of food scarcity, deforestation and energy, all in one. (Mok, 2014)

5.11.1.6. Construction system based on the self-organizing properties: AUTO-MORPHIC AND GENETIC STRAND TOWER

The Auto-morphic and Genetic Strand Tower introduces an environmentally sensitive 21stcentury construction system based on the self-organizing properties of extreme fiber networks. It draws on many sources ranging from tissue engineering and textile technology to organic templating. The tower instantiates agency at the level of individual fibers and fiber groups that organize recursively to create extreme networks of unprecedented complexity, this emergent strand morphology was generated using software developed and coded through an interactive templating and scripting process. The underlying principle of fiber agency and affiliation demonstrates the potential of coding structures for an exact construction. The ultra-light nested fiber structure builds strength and resilience through a massive redundancy of elements that challenges conventional models of structural and environmental performance.

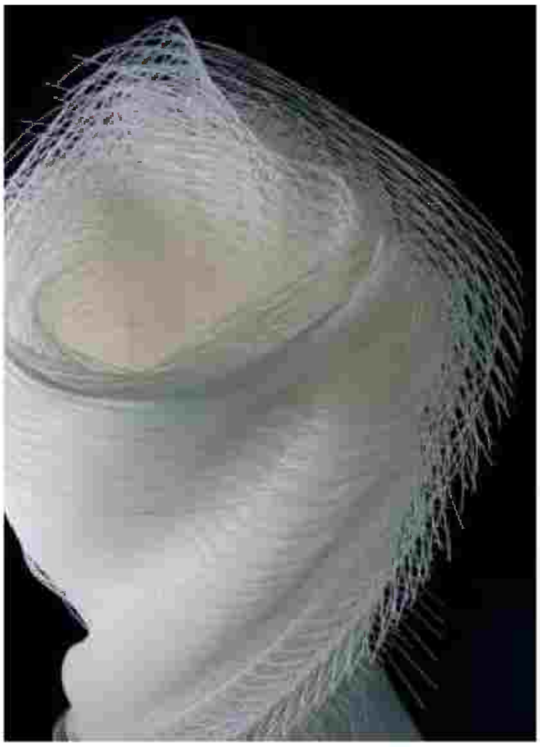

Figure (5- 30): Auto-morphic and Genetic strand tower
Source: Testa, Weiser, White, 2009

The tower is built on site using an innovative auto-morphic construction technique developed specifically for the project, whereby robotically spun basalt fiber groups form nested structural and spatial layers. In effect the project consists of fiber strands that are robotically spun into place like candy floss. In this way the tower manifests in real time the concurrent development of material properties, spatial patterns, and design technology and fabrication techniques. (Testa, Weiser, White, 2009)

Figure (5- 31): Robotically spun basalt fiber groups form nested structural and spatial layers
Source: Testa, Weiser, White, 2009

5.11.1.7. Behavior material, form emergence and optimization: Underground Station Roof- Piazza Garibaldi- Naples

Computational processes enable generating and evaluating a large number of possible structural articulations. During the design study for an underground station roof at Piazza Garibaldi in Naples, entire populations of structures was evolved and individuals were selected through predefined architectural and structural fitness criteria. (Perrault, 2008)

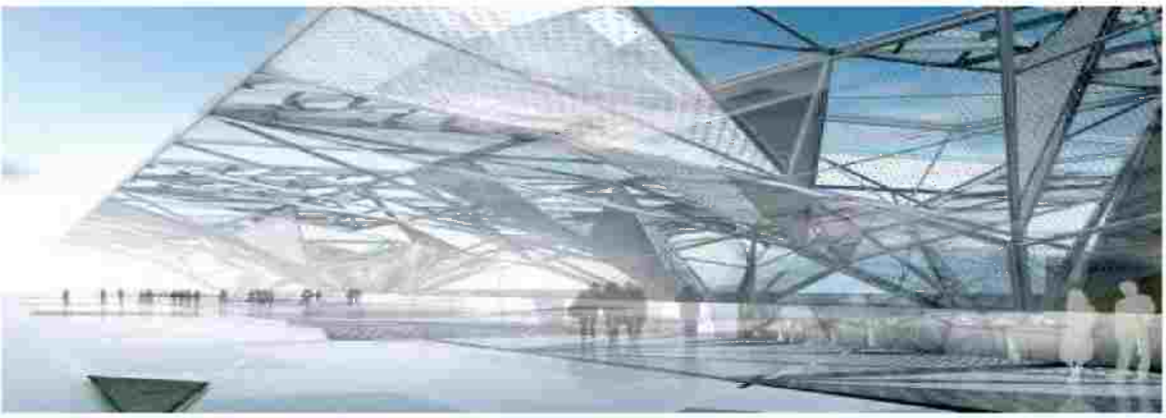

Figure (5- 32): Differentiated branching structure, Dominique Perrault, Underground station roof, Piazza Garibaldi, Naples, Italy
Source: (Perrault, 2008)

These processes evolved articulations in response to specific criteria without relapsing into a priori defined typologies. A design study was conducted on improving the performance of the folded roof structure through genetic algorithms. Topologically the roof structure can be described as a two dimensional plane based on a system of self-similar triangles folded in the third dimension. Each node is assigned a random z-coordinate within defined thresholds. A tube-like column folded out of the roof reaches the ground and acts as a support structure. To achieve cantilevering capacity and a minimum of node displacement just by folding the triangulated plane, the behavior of the entire structure was simulated in RStab software. By encoding the z-coordinates of all nodes into a genome and using a genetic algorithm that allowed for crossover and mutation, the performance of the structure could be significantly improved over the run of 200 generations with 40 individuals each. As a fitness criteria, the displacement of the nodes under self-weight was calculated by the analysis software, the worst node defining the inverse fitness for each individual. (Perrault, 2008)

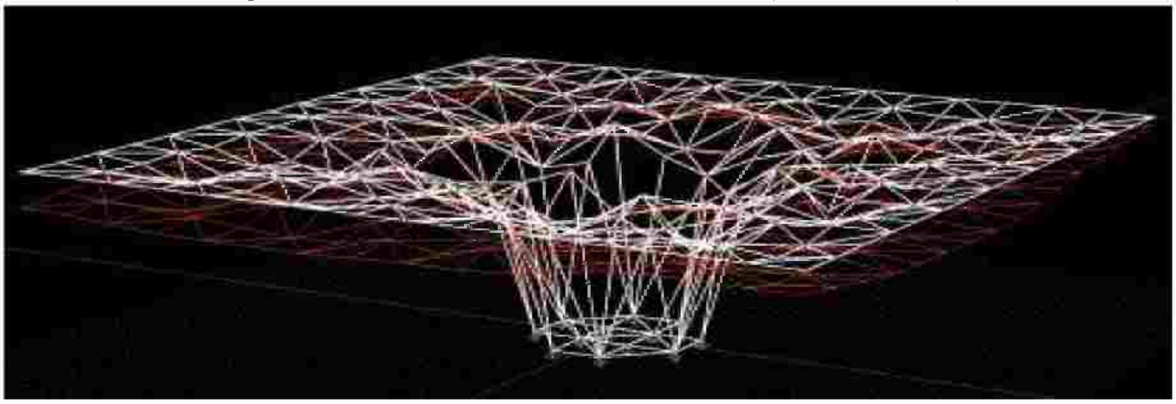

Figure (5- 33): Analysis of the specific load-bearing behavior of each individual branching structure derived through the evolutionary process.
Source: (Perrault, 2008)

5.11.2. MULTI BIOLOGICAL DESIGN PRINCIPLES

5.11.2.1. A Morphogenetic Library in Florence by Tommaso Casucci

The approach demonstrated in this library uses Evolutionary morphogenetic Computation (EMC) to enhance and modify structural form based on biological micro structures. This is based on the concept of "form first, structure first, material first". Precisely, this project stresses the "hierarchical nature of the design process with form being driving both structural and material strategies. This building is perforated allowing for a best diffusion of natural light and ventilation within the building in response to environmental constraints urban contexts, bioclimatic issues. (Oxman, 2010) ; (Tommaso, 2011)

A) - Adaptation:

The skin seems to be bodily adapted to climate control and to environmental pressures. Computational design processes and advances in digital fabrication technologies allow architects to think about form-finding and space-making. The forms are modified to conform to new boundary conditions associated with architectural structures. The process is based on a Genetic Algorithm (GA) which visually exposes for the designer a range of good performing adapted solutions within the design space.

The application of the GA is combined with parametric software, in this case Generative Components (GC).
The program described here as Para Gen (Parametric Genetic Algorithm), uses a Finite Element Analysis (FEA) to determine the morphogenetic structural performance of the forms. (Oxman, 2010) ; (Tommaso, 2011)

Figure (5- 34): Outer 3d morphogenetic evolutionary computational bio-digital and bioclimatic skin
Source: (Oxman, 2010)

B) Optimization

This allows the designer to manipulate and optimize a parametrically defined model based on predefined criteria and parameters. The opportunities and limitations of this design process are explored and evaluated based on an experimental case study using topologies based on radiolarian skeletons. The design procedure described includes user interaction in the exploration of solutions that perform well both for the explicitly defined programmatic criteria (structural) as well as for the implicit criteria provided by the designer (visual aesthetic). (Oxman, 2010) ; (Tommaso, 2011))

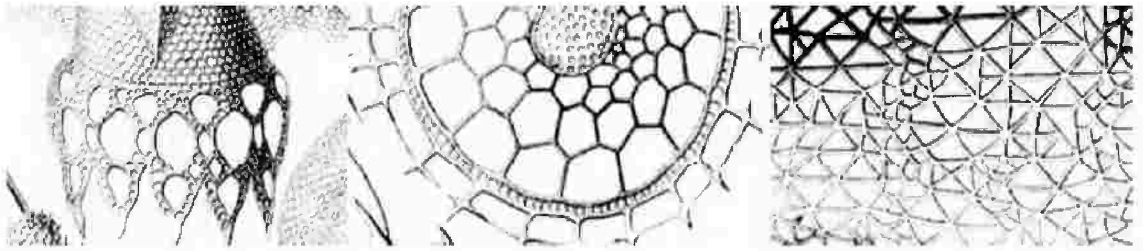

Figure (5- 35): Various tessellations of radiolarian skeletons
Source: (Oxman, 2010)

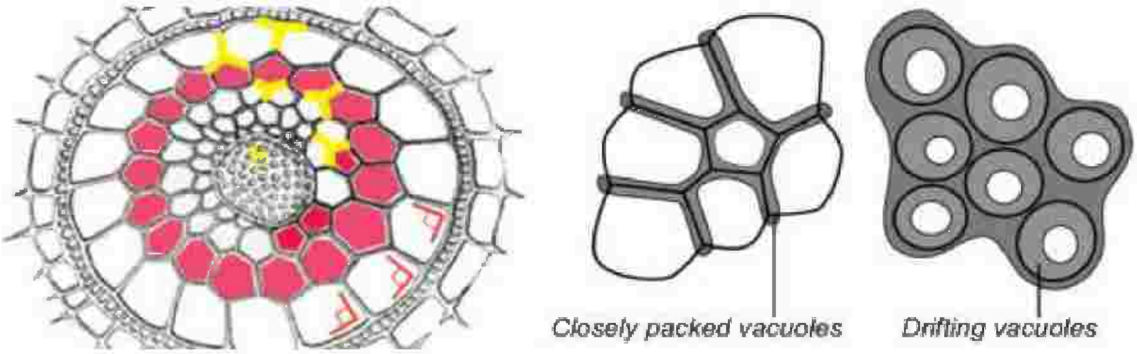

Figure (5- 36): Left: Geometrical characteristics of radiolarian skeletons. Right: Formation of radiolarian skeletons
Source: (Oxman, 2010)

C) Emergence

This free-form-shaped building appears to be in perpetual emergence such as an organic system. The shape seems to be directly linked to the influences of external forces surroundings, environmental constraints. It has been structured by site analysis data. (Oxman, 2010) ; (Tommaso, 2011)

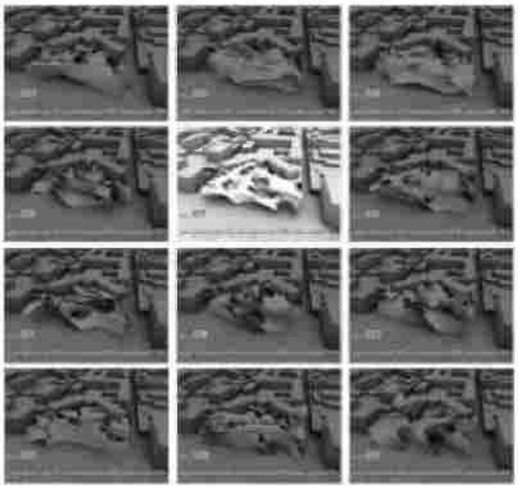

Figure (5- 37): Site analysis and generating best possible design.
Source: (Oxman, 2010)

D) Behavior material and environment

Such a building requires the usage of tools, techniques and technologies in service of site such as the School of Architecture site. The skin seems to be bodily adapted to climate control and to environmental pressures as the diagram below shows. Morphogenetic evolutionary Computational design processes and advances in digital fabrication technologies through bio digital inputs which allow architects to think about form-finding and space-making. (Oxman, 2010) ; (Tommaso, 2011)

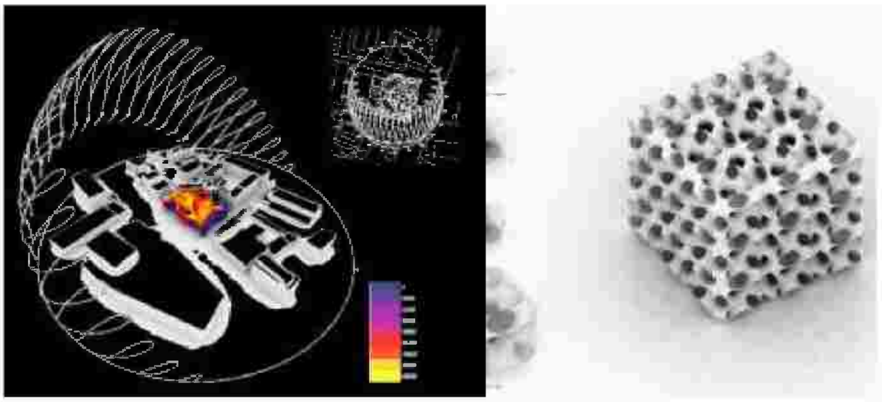

Figure (5- 38): (A) - Bioclimatic thermal chart through environmental computational program (B) - Simulation of the building. The building's evolution responding to various constraints, Shape, structure and materials are linked to the influences of internal and external forces acting on the building.
Source: (Oxman, 2010)

Surface porosity is based on triply periodic minimal genetic surfaces structures to define a per-formative interface of bioclimatic regulation where irradiation values on the surface are used to module light perception in the interior spaces of the library. Hence this perforated morphogenetic structure. (Oxman, 2010) ; (Tommaso, 2011)

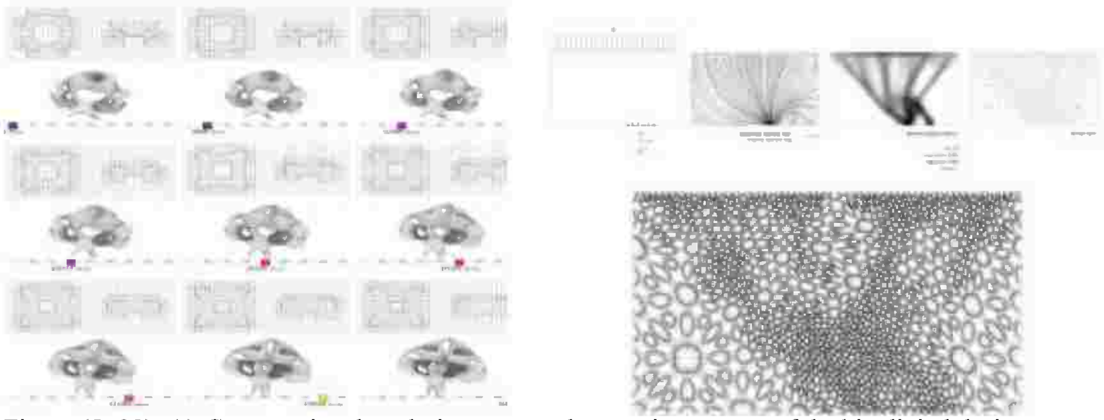

Figure (5- 39): A)-Computational evolutionary morphogenetic progress of the bio digital design process B) - Originally appeared on site; it's the envelope of a genetic structured skin
Source: (Oxman, 2010)

5.11.2.2. Glittering metallic pavilion morphs - Generative envelopes responding to environmental changes:

Glittering metallic pavilion morphs its self to adapt to climatic and environmental changes through adjusting its bio-digital and genetic characteristics of its material. This is applied after many steps of computation and simulations to find a suitable form to add the material to it. (Mok, 2012)

A) Adaptation

Evolutionary genetic studies now is currently working on integrating the use of thermo-bimetals in building components, like glazing, and "breathing" bricks, inspired by the biological capabilities of insect spiracles and trachea systems to adapt the reduction of energy-intensive, mechanical systems of artificial cooling (Mok, 2012)

B) Self-organization

It is receiving to further implement the research in "re-skinning" an Airstream trailer with this material. It's a powerful demonstration of how existing materials could be used differently improving the environmental energy intense. (Mok, 2012)

Figure (5-40): The structure acts like a sun-shading canopy that automatically opens and closes itself according to changes in temperature and light, and could be also applied to venting applications
Source: (Mok, 2012)

C) Behavior, material and environment

The difference in expansion coefficients, when the temperature changes the metals expand at different rates, curling up or down, giving the appearance of a reactive skin. (Mok, 2012)

Material system

20-foot tall installation made out of a commonly-found composite material that allows it to morph in response to temperature changes. It's made out of 14,000 pieces of bimetallic material called "thermo bimetal", usually found in the coils of a house thermostat. This composite metal is made up of two or more layers which have different expansion coefficients. See figure 5-39 (Mok, 2012)

D) Emergence

A functional full scale prototype consisting of more than 14000 geometrically variant components was constructed and tested. Once exposed to changes in relative environment, the special coiling metal composite patches swell or shrink and thus facilitate the opening and closure of each local component resulting in different degrees of porosity across the surface, which is both a structure and responsive skin.

This high level of integration and interaction of form, structure and material performance enables a direct response to environmental influences without the need for additional electronic or mechanical control. (Mok, 2012)

5.11.2.3. Strawberry bar Morphogenetic Design Experiment

The main aim of this morphogenetic experiment was extending the evolutionary dynamics of reproduction, mutation, competition and selection as design strategies. The potentials and limits from initial form-generation to the actual manufacturing process were explored by shifting the investigation towards per formative patterns that evolve as species across populations and successive generations whilst maintaining structural capacity and geometric characteristics.

Form Generation, Behavior and Emergent of Morphogenetic Evolutionary Design

These simple geometric relations were defined as a generic 3D cutting-pattern, provided the base data for the subsequent process that simultaneously grew three sub-populations of surfaces. Two subpopulations evolved the definition points of the shorter and the longer surface, and one that defined the spatial datum. According to the logic of the pneumatic base component specific fitness criteria for each sub-population of the geometry-defining surfaces were established, which influenced the global undulation and surface subdivision in relation to parametric variables such as the scale factor of growth, branch length and branch angles. (Menges, 2004)

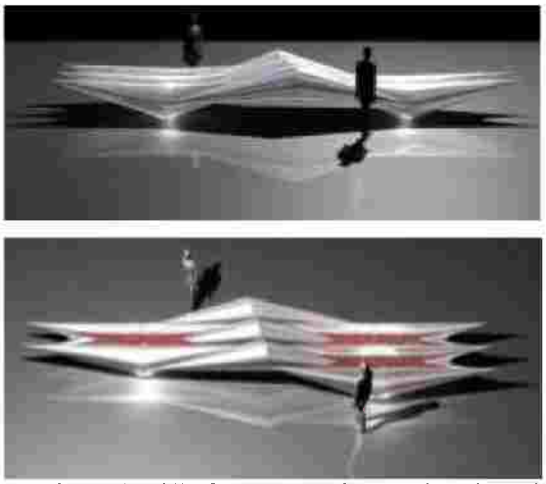

Figure (5- 41): form generations and evaluated morphogenetic design for a strawberry bar
Source: (Bentley, O'Relliy, 2001)

The evolving points of local maximum distances between the shorter and the longer surface in relation to the datum surface established the definition points of the pneumatic system. Rather than breeding just one surface, this method instigated a feedback loop by continuously using the bounding box of the most recently evolved surface as the environment in which the next surface would be grown. This method maintained the inherent logic of the pneumatic component in a larger system but dissolved the distinction between environmental constraints and individual response. (Bentley, O'Relliy, 2001)
Another feedback loop utilized digital form-finding in a dedicated membrane engineering software, and additional physical test-modeling further informed the evolutionary process and its evaluation. (Bentley, O'Relliy, 2001)

After running the evolutionary process over 600 generations 144 species were identified and catalogued according to specific patterns of relevant geometric features. Considering the interrelated evolution of the geometry-defining surfaces the criteria for evaluation was the relative fitness amongst the emergent species rather than the absolute fitness ranking of any particular individuals.

As the structural behavior of the pneumatic system primarily relied on specific geometric relations such as alignment and proportional distances of definition points, the species of individuals that shared these geometric features was selected. Then the individual of the chosen species that grew in the last and most developed generation was picked. The genotype of this individual incorporated the genomes of three geometry-defining surfaces, establishing a degree of phenotypic plasticity that allowed the resulting pneumatic system to adjust to the constraints of a digital cutting pattern and computer-aided manufacturing process.

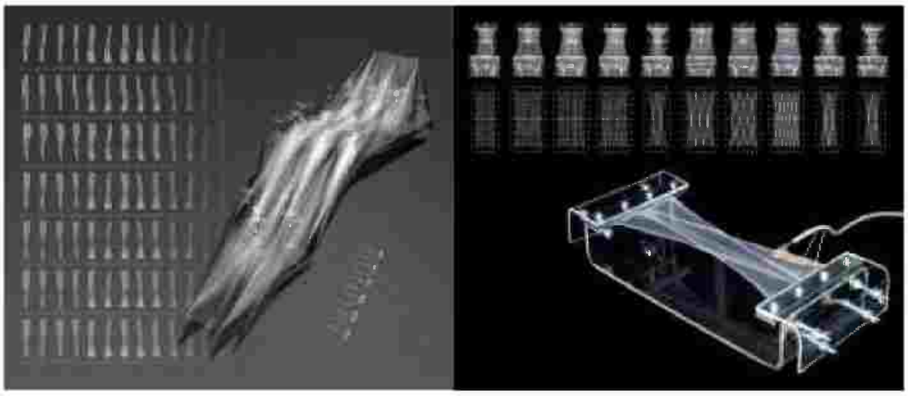

Figure (5- 42): form generations and evaluated morphogenetic design for a strawberry bar
Source: (Bentley, O'Relliy, 2001)

5.12. SUMMARY

Computational morphogenesis helps to develop a design approach that allows for a much higher level of integration of form generation, materialization and construction as what has been achieved thus far. Due to the nature of basic research the projects and related material systems presented here remain in a proto-architectural state still awaiting their context specific architectural implementation. Nevertheless they challenge the nature and hierarchies of currently established design processes and promote an alternative approach.
One that enables architects to exploit the resources of computational design far beyond the creation of exotic shapes subsequently rationalized for constructability and superimposed functions. Rather, it promotes the unfolding of per-formative capacities and spatial qualities inherent in the material systems constructed while at the same time encouraging a fundamental revision of still prevailing functionalist and mechanical approaches towards sustainable design.
The advanced material and morphogenetic digital design techniques and technologies presented in this research call for a higher level methodological integration, which poses a major challenge for the next generation of multidisciplinary architectural research and projects. This collaborative task encompasses the striving for an integrated set of design methods, generative and analytical tools and enabling technologies that facilitate and instrumentalize evolutionary design, and evaluation of differentiated material systems towards a high per-formative and sustainable built environment.

This chapter has considered existing understandings of morphogenesis and evolutionary computation in architectural design and biology by discussing examples of bio-digital and genetic generative evolutionary designs, computationally-generated structures; one of an architectural installation and several others constructed to represent morphogenesis in nature, where in the next chapter a morphogenetic and evolutionary case sturdy through computational design program will be presented.