Architecture Research 2014, 4(1B): 1-12
DOI: 10.5923/s.arch.201402.01

Towards a Different Architecture in Cooperation with Nanotechnology and Genetic Science: New Approaches for the Present and the Future

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Abstract Technological advancements and scientific researches, especially in nanotechnology and genetic engineering in the latter part of the 20th century, encourage new approaches for the architecture of the future at present. There have been many studies on genetic algorithms, nano-materials, nanostructures and "searching a new architecture" with the help of interdisciplinary relationships between architecture and nanotechnology and genetics. This study categorizes contemporary works in this field into three main approaches: the form-finding strategies helped by genetic algorithms, the hybrid designs with nano-materials or nano-sensors and the living architectures. Thus, the aim of this paper is to introduce new architectural approaches generated with the interdisciplinary domains of genetics and nanotechnology and to discuss them in the context of the future of architecture.

Keywords Architecture of the Future, Genetic Architecture, Nanotechnology, Living Spaces

1. Introduction

The Information Age, which is regarded as the third grand social revolution of mankind [1], began with the rapid development of microelectronics and computer technology and also spread over all scientific fields. Technological advancements and scientific researches, especially in nanotechnology and genetic engineering in the latter part of the 20th century, encourage new approaches for the architecture of the future at present. There have been many studies on genetic algorithms, nanomaterials, nanostructures and "searching a new architecture" with the help of interdisciplinary relationships between architecture and nanotechnology and genetics from the 1990s to today [2].

The science of **genetics** substantially developed over a short time by analyzing the genetic code of humans when the Human Genome Project was completed in 2000. From the developments within genetic science, a nano revolution occurred in the 21st century. **Nanotechnology** is the science of manipulating matter on an atomic and molecular scale, deals with structures measuring 100 nanometers or smaller, and involves developing materials or devices within that size.

When the dimensions of materials are reduced to a nanometer criterion, quantum behaviors supersede the declared traditional behaviors, and physical properties begin to change. Electronic properties such as electric conductivity are changed conspicuously with the adherence of foreign particles to the existent nanomodel. When the foreign atom is a transition element, the nanomodel adheres to and can gain magnetic properties. For example, even though a diamond crystal constructed by carbon atoms is not normally a good conductor, the one-dimensional carbon atom chain can be rendered a fairly good conductor by means of nanotechnology [3]. Thus, if we could manipulate the molecular structure of matter on an atomic scale, either we would have new and moldable materials or the real genetic codes would take the place of digital codes and would be reshaped by the designer the user needs in the future.

As we have seen, genetics and nanotechnology, which are the most transformative technologies we have ever faced, have the potential to radically alter our built environments and our lives. Both of them take their power from nature. Their main characteristics are based on the laws of nature. Thus, we can mention new architectural approaches built on genetics and nanotechnology, which are related to nature, natural principles, and life.

However, the basis of these approaches goes back to computer technology and computational techniques that developed after 1960. Computer software called CAD/CAM technologies, which transfer the designs to drawings, making use of 3-D digital modeling and rendering, enable new design forms. These forms have complex types of geometry determined by mathematical functions and parametric algorithms and have a new vectoral geometry, which is not

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Published online at http://journal.sapub.org/arch

Euclidian. Different forms which haven't been designed can be produced from different mathematical functions [4].

Emerging computational design techniques enhance the interdisciplinary relationship between architecture and the sciences of mathematics, geometry, electronics, genetics and biology. Thus, new design practices were generated by transferring various notions or techniques from scientific fields to architecture, such as NURBS curves, spatial bubbles (Blobs) or pits (Blebs) or twisted surfaces (Folds), genetic algorithms and parameters, evolutional approaches, animation techniques, artificial intelligence, robotics, etc. We can see that the mentioned approachments are variously termed in the media: evolutionary architecture, genetic architecture, parametric design, algorithmic design, biomorphogenic architecture, recombinant architecture, cyberspace architecture, hypersurface architecture, non-linear architecture, etc.

At the present time, the use of nanotechnology and genetic technologies in architecture has generated various materials, equipment, forms, and design theories. When the potential of biological science was associated with a complete transformation of computer technology, firstly, the resulting architectural outcomes were included morphological aspects. Engineers can describe the genetic codes of DNA in a mathematical process -with the help of genetic algorithms- and recode it for new requirements in the virtual platform. Hence, the new nature-inspired organic forms could be digitally derived and some of them produced. Some other architects model genetic or evolutionary processes in designs and produce new forms that show natural characteristics. In addition, innovative nanomaterials and nanosensors already give designers a renewed palette. As George Elvin said, "Advances in biomaterials and biocomposites converge with advances in nanotechnology, and an increase in their application to construction seems certain to emerge in the future" [5]. Nanostructures' materials represent an interesting development in the construction sector, showing higher-level performances and a lower consumption of energy resources when compared to traditional cement-based products [6].

On the other hand, there are few studies on the possibility of a building that is self-generated by its own DNA like an organism, growing, surviving and even dying though using the opportunities of genetics and nanotechnology.

Most architects consider this effort as a utilitarian experience which might be a way for them to develop eco-friendly and livable architecture derived from the nature for a sustainable environment. According to them, it is not only a romantic concept of "back to the nature" or searching for different, attractive forms; it is about reducing dependence on environmental resources, improving our decadent ecosystem, and the desire for a sustainable world.

The studies on the relationship between architecture and nanotechnology or genetics continue in both universities or research centers and in freelance architectural offices, such as the Institute for Genetic Architecture at the GSAPP in Columbia University, New York, and architectural studio METAXY; Biodigital Architecture Program at ESARQ, Universitat Internacional de Catalunya, Barcelona; master's program of University of the Alexandria; and the architectural offices of Greg Lynn, John Frazer, Marcus Novak, and others.

It has been reviewed from the literature that there is a complexity about both the theoretical and practical fields. Each architect generates their own experiences; conceptual terms and production techniques are varied. It is hard to classify or label the present approachments academically. On the one hand, they based on a common scientific foundation and are derived from interrelated scientific areas such as genetics, biology, nanotechnology, microelectronics, computational techniques, etc. On the other hand, the outcomes of these approachments are different from each other in practice. For example, the words of genetics and genetic algorithms sound the same, but in fact, there is a serious difference between real DNA and computational DNA. In this respect, it is hard to determine a design product and settle in a class. For many designs –those mentioned in this paper too- it is undecided whether these are yet genetic architecture or, rather, still architecture about genetics. It is hard to easily separate which design has real "aliveness", which is only computational versus biological or nature-mimetic, which is utopian or virtual, which is actual or applicable to the real world. Definitions are changeable from person to person, and the questions of "According to what?" and "According to whom?" are subsequently conjured up.

There is also not a clear and comprehensive classification in the literature. This study could be considered as a classification dissertation. However, it is not possible to mention sharp borders in between the categories; they are intertwined. Three main approaches are described in contemporary architecture at the intersection of genetics or nanotechnology:

- The form-finding strategies helped by genetic algorithms
- The hybrid designs with nanomaterials or nanosensors
- The living architectures

The first of these focuses on the form finding which uses the digital computational techniques in computers. The second of these discusses the developments in materials and the effects of nanotechnology on architecture. And the last one deals with the interrogative works that question the possibility of a really living building with a hope and concern for the future. Some works in this classification are only utopic and stay in the virtual environment, but some of them are produced in real life. Consequently, the aim of this paper is to introduce new architectural approaches generated with the interdisciplinary domains of genetics and nanotechnology and to discuss them in the context of the future of architecture. The selected works -spaces or buildings- are generated through genetics or nanotechnology in a virtual or real environment.

2. Form-finding Strategies with the Help of Genetic Algorithms

The new hospital shall offer an environment specifically designed with patients in mind. The new hospital shall use natural light, therapeutic colours and distinguishable finishes to assist way finding and provide a restful, relaxing environment. The rooms shall have daylight and views to ensure patients are in touch with the outside world, even in the basement areas. Consideration shall be made to ensure high levels of infection control in the clinical rooms and reception areas including anti-bacterial finish; and ledges and protrusions shall be kept to a minimum. In the architectural field, the major impact of cooperation with biotechnologies, including genetics, genomics and transgenic engineering, is on the architectural imagination. So, most of the studies on genetics and architecture have served to provide form-finding strategies. Genetic science first met architecture in a virtual platform. The genetic body -of all organics, human, animal, plant- contains multiple and creative animated forms, figurative principles and evolutionary systems that can be given architectural expansion [7].

Hence, a different form -generating process that is based on biological evolution came to the fore by moving genetic technology to the computer with new software. This software uses the genetic algorithm method, which is inspired by Darwin's theory of evolution. Genetic algorithm, suggested by John Holland in the 1970's, is a search and optimization method based on canonical selection rules. This method works according to probability rules, synchronously searches all of the population, and reaches the optimum solution for a complex problem in a short time [8].

Genetic algorithms used in the software that generates design forms in the architectural area last 10 years. Biological evolution processes, such as the crossover of genes, reproduction, mutation and natural selection run in software codes. The best genomes are perpetually selected and transferred to the next generations. At the end of the process, new forms that are members of same family and have little differences are generated [9]. Architects can see the outcomes of designs and operate them as requested.

The British architect John Frazer, both an educator and the writer of the book *The Evolutionary Architecture,* is among the earliest researchers to investigate generative design systems using genetic algorithms. His research suggests nature's evolutionary model as the generative process for architectural morphology: ***Interactivator*** (1995) (Figure 1). In this context, a seed in a computer model transfers its genetic codes to the other seeds by cell division and then disperses to all models. According to the fitness value which is calculated for the computer medium, successful genes in genetic algorithms are selected as in nature. Then these genes are exposed to crossover and mutation operations, and different architectural forms are produced in a working process of the model. The goal of this approach is to create artificial life due to evolutionary processes and to simulate nature's behavior in a built environment [10].

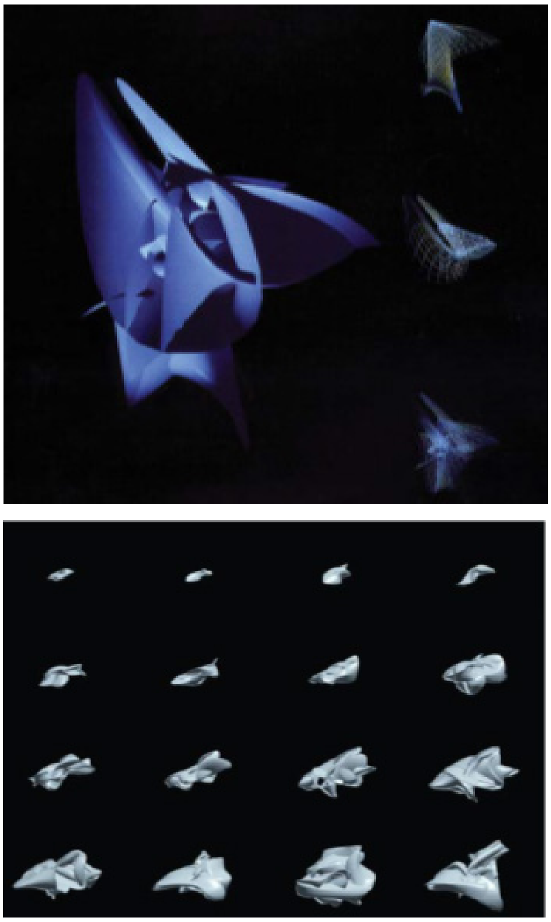

Figure 1. Derivation in the Interactivator model (Frazer, 1995)

Greg Lynn is one of the architects studying genetic architecture. The project on ***embryological houses*** of Greg Lynn suggests six prototype parental houses which have different genetic characteristics from one another. Thousands of different houses can be produced by means of mutation and natural selection from these prototypes. The production principles are equal with nature's in this process: gene transfer from parents to their children, natural selection, and adoption of the genes from the gene pool. The maximum and minimum limits of each component are determined. The interaction of these components gives mutants of endless potentiality. Despite the fact that all child houses have the same number of aluminum spines, steel beams and panel components, each prototype has a different character and property. The structure of the design, produced as an example for an exhibition in MoMA, constitutes a double-facade cover and steel beams with a circular section. The first cover is a semi-transparent screen constructed using aluminum and glass panels, and the second is the shading layer [11]. Embryological houses suggest diversity, continuity, flexibility, and propriety for users (Figure 2).

Another project of Lynn, ***UN Plug Office***, proposes a building with an external facade that can change and constitute its own living units according to various effects, instead of the usual spatial organization consisting of walls and floors. It is covered with sunlight-sensitive receptors, photovoltaic cells, vacuum tubes, canals, and cables. It works like a network (Figure 5).

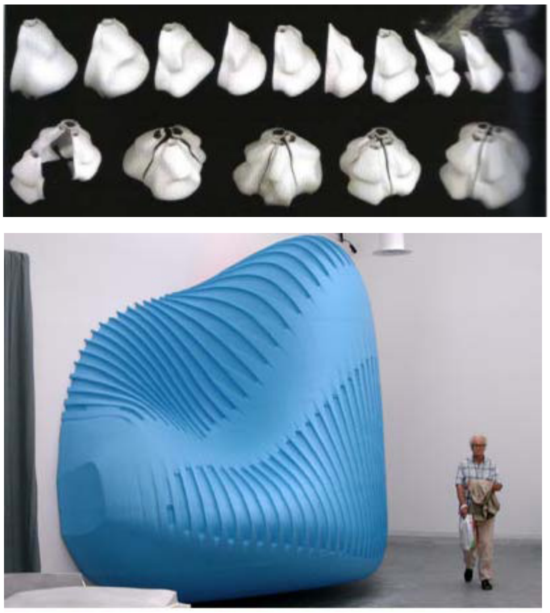

Figure 2. [Above] Generating forms for Embryological houses / [Down] 3-D Embryological house prototype (www.glform.com)

Karl S. Chu, a leading figure in this area, is known for coining the term "genetic space" and establishing the theoretical underpinnings of genetic architecture. He views the formal principles as more essential than material actualization. Chu generated the ***Planetary Automata***, which was designed for the Gen(H)ome exhibition in 2007. He suggests spherical mathematical entities –planets- by using genetic algorithms. He describes, "*Each planet is generated by a rule in one-dimensional cellular automata. There are a total of 256 possible rules, and, correspondingly, a total of 256 planets, which together constitute a monad: the sum total of possible worlds contained with the universe of one-dimensional cellular automata.*" [12].

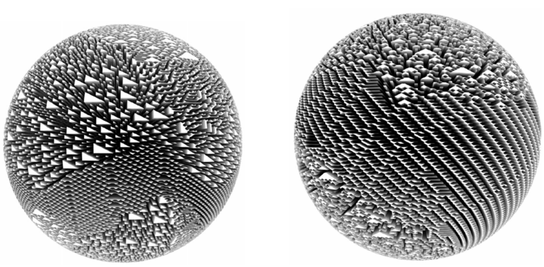

Figure 3. Different planets of Planetary Automata (Gregory Chaitin, http://www.futurefeeder.com/wp-content/6chuCorr.pdf)

Each planet is an abstraction of the concept of possible worlds based on 1-D cellular automata. At the deepest level, CA is one of the simplest forms of generative engine and constitutes a computational monad, which has 256 rules in itself. Each monad has a self-replicating and self-organizing system capable of constituting itself into a cohesive whole. Its internal generative principle transmits and propagates heredity information. Each sphere represents a proto-architectural universe that is potentially infinite in terms of variability and density with regard to its composition [13] (Figure 3).

Dennis Dollens, who is the founder of the Genetic Architecture Program of ESARQ, suggests ***Digital Botanic Architecture*** by adopting the growth principles of plant structures to digital models. The idea is to interlace nature and architecture, enabling the design of hybridized, biological structures. Dollens intends to create s new bio-aesthetics by understanding biological principles with growth algorithms, parametric design, CNC fabrication, animations, and also new architectural skins, panels, floors, and skeletal systems. He uses Xfrog, ParaCloud, Generative Components, and Rhino to develop branching tree structures. The software is generally employed to computationally "grow" lifelike digital trees, shrubs, and flowers for special effects in film. It has the ability to produce forms based on botanic attributes. Selected attributes of living organisms for example, branching, leafing, or spiraling of an oak or an elm are imparted to the program for it to generate original structures based on the organically-derived algorithms. Dollens viewed this architecture as a part of a process observation for ordering design forms infused with botanical properties. This search, linking design and nature, involves tracking ways to visualize and model algorithmically from plants and trees [14] (Figure 6).

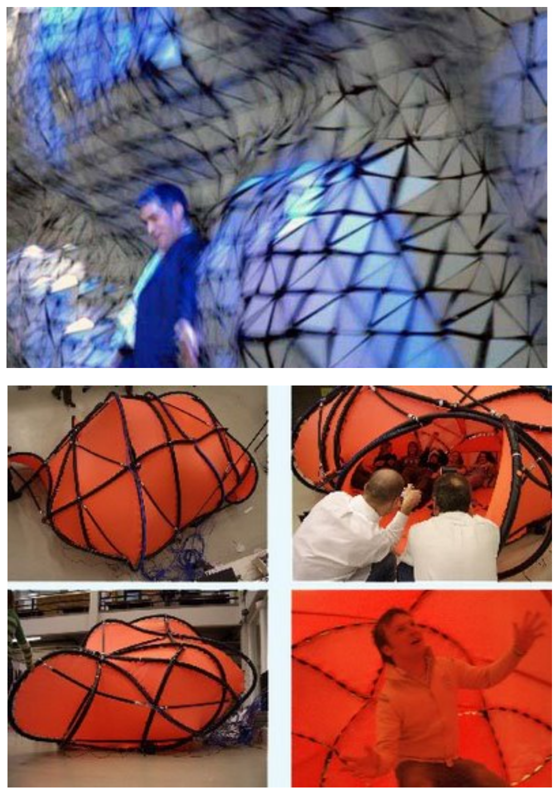

Figure 4. [Above] Aegis Hyposurface / [Downt] Muscle Body project

The architectural objectives of the ***Bionic Pavilion***, designed by the 3Deluxe architecture office, consist of natural principles such as dynamism, communication, metabolism, sense perceptions, and operations of intelligence. The biological construction of plants is taken with regard to its aesthetics and construction and adapted to architecture. The dome-shaped roof in front of the Pavilion's great screen is fitted with solar cells or photo-voltaic equipment for sun-powered energy production. The folding structure of the roof has been constructed from simple repeated triangles and pentagons. This structure is generated by different genetic programs [15]. Other architects and their works must also be mentioned in regard to these form-generating strategies -namely Lars Spuybroek, Rem Koolhaas, Marcus Novak, Bernard Cache, Mark Goulthorpe and Kas Oosterhuis [16].

A few experiments from these studies are constructed with the help of using information technologies as an element of space. Infrastructural systems, sounds, images, text, simulations, projections and screens and sensors have been integrated into space. Attractive spaces that can interact with users, respond to external stimulations, or be changed by environmental effects have been designed.

Water Pavilion designed by Lars Spuybroek, Aegis Hyposurface designed by Decoi, and Muscle Body desgined by Kas Oosterhuis are exemplified as initiator works. Aegis Hyposurface, which was designed by Decoi, and has mathematically generated patterns, is an interactive surface responding to the changes in the surrounding environment (Figure 4). Stimuli are picked up by sensors responsive to video, sound, light, heat, and movement and are used to activate the wall surface. The movements of the visitors in the environment are reflected by the deformation and the changing color of the surface. The rubber squids that connect the bi-polar metallic facets are moved using 'telescopic fingers' which reach a speed of up to 60 km/h and have a stroke of 50 cm [17]. Similarly, the "Muscle Body" project of Oosterhuis can respond differently with sensors that are sensitive to human movements (Figure 4).

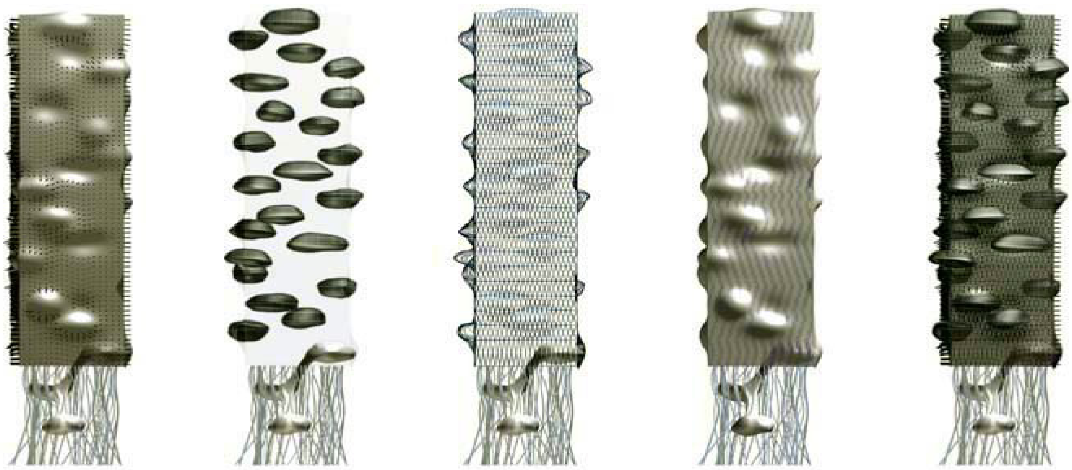

Figure 5. UN Plug Office (www.glfor m.com)

Figure 6. The eTree structure, covered by a monocoque facade and chainmail-like components, can take on environmental performance duties such as filtering and ventilation

Consequently, architecture profited through the transformation of scientific paradigms and realized different and reformist form-finding ways. Using genetic algorithms, architects provide and derive new forms on computers, selecting and operating them. But what is questionable is whether these are a new architecture or whether technology is just a tool for actualizing some forms. Most of these works are only in virtual areas or are produced with conventional techniques and materials. They are derived from biogenetics but not the epitome of nature. Although they are important and innovative works, it is hard to say that these are exactly path-breaking, yet familiar architecture. In addition, we also observe that generating extraordinary forms is considered in the media as a trend by architects and also consumers. It is almost a mediatic situation. The gap between the design process and the practice of architecture and also the practicability of these forms is not paid enough attention.

3. Hybrid Spaces in Cooperation with Nanotechnology and Architecture

Contemporary architecture has more opportunities than just creating genetic algorithms for form finding. It can adopt material investigations for generative design approaches. The works in this title are generally helped by nanotechnology.

Many nanomaterials are already available, and also, nanoparticles could integrate into conventional materials to attain multifunctional nanocomposites and have new properties. Nanostructured materials are constituted as traditional materials -steel, cement, glass, polymers- admixed in a mass or surface with nanomaterials (nanocomposites) or modified in its chemical and physical structure at the nanoscale level (nanoengineering) [18]. In the near term, the nanocomposite reinforcement of steel, concrete, glass, and plastics will dramatically improve the performance, durability, and strength-to-weight ratio of these materials. For example, a nanocomposite steel that is three times stronger than conventional steel, is already on the market.

Many intelligent materials are also researched based on the development of nanotechnology such as shape-memory alloys, which return to the original shape at a particular temperature after stretching; piezo-electric materials, which can be widened and narrowed by voltage; composite materials, which have properties of two or more materials; and also some materials which can copy themselves, change their transparency and colors, and transmit information, sound, and light to each other through sensors [19]. Furthermore, it is claimed that in the future, external surfaces of buildings would be changeable according to computer instructions; would change between liquid, solid, and gas states of matter; and would sometimes be dull and solid or sometimes be transparent and liquid [6].

An example of this is Aerogel that has a density of three times that of air but has considerable strength and insulation capabilities [20]. Aerogel, currently used in solar collectors, is a solid, but it is so transparent that it looks like a hologram. Another is carbon nanotubes, which have a significant potential for use in the future. They could bring unprecedented strength and flexibility to our buildings with their power. It is said to be 100 times stronger than steel because of its “molecular perfection” [21]. In addition, carbon atoms can act as a switchable conduit, a light source, a generator of energy, and even a conveyor of matter by bonding with other forms of matter. Carbon nanotubes—sheets of graphite just one atom thick, formed into a cylinder—are not only 50 times stronger than steel and 10 times lighter, but they are transparent and electrically conductive to boot. Nanotubes are already the building blocks for hundreds of applications and are used to reinforce concrete and deliver medication to individual cells [22] (Figure 7).

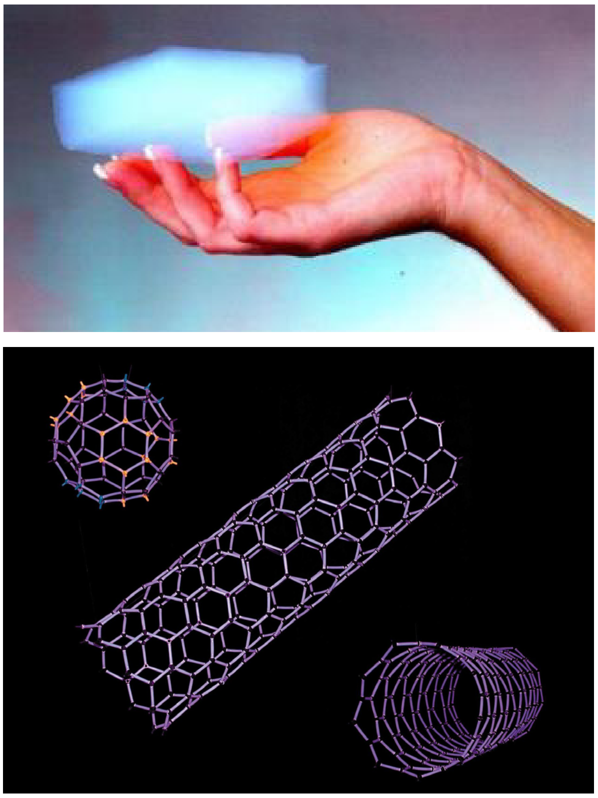

Figure 7. [Above] Aerogel (http://stardust.jpl.nasa.gov/images/technology/aerogelhand.jpg), [Down] Carbon nanotubes (http://www.nanoscience.ch/nccr/nanoscience/pictures/gallery_01/gallery_01_03)

The Nanohouse Initiative is a collaborative design between scientists, engineers, architects, designers and builders. It is a new type of ultra-energy-efficient house exploiting the new materials being developed by nanotechnology. The Nano House Initiative was designed in 2002 by Carl Masens at the Institute for Nanoscale Technology and was visualized and implemented by architect James Muir. It has the latest technology in which windows clean themselves, tiles might resist the build-up of soap scum, and timber surfaces resist UV damage [23] (Figure 8).

Francesco Gatti, Francesco Lipari, Aurgho Jyoti and Summer Nie, researchers at the Beckman Institute, University of Illinois, have developed ***a skin system*** as cladding material for a building by using nanotechnology. The skin transforms the building into an intelligent structure with automated adaptive systems to suit variable situations. Heat loss in summer will be ensured by the process of perspiration of the skin producing a cooling effect on the building. Similarly, heat storage in winter is ensured by the generation of hair like structures on the skin, which prevent the loss of heat by insulation. The change of color is also instrumental in heat insulation systems.

Figure 8. Nanohouse (http://www2.arch.uiuc.edu/elvin/nanohouse.htm)

By developing a natural and living epidermis created by studying the DNA of different types of organisms and animals, designers aim not only for a "roof" or "facade" protection but also expect it would react and change itself according to the climate in different seasons of the year. The skin could be added to an existing building like a mask due to the elastic property of the skin. It could also change typology according to the latitude and climate in which the building is located. A typological animal chart helps decide the system for such a transition. A building located in a cold region could use a skin made with the DNA of a sea lion, for its thick fat coat, mixed with the DNA of a bear, for its protective dense fur [24] (Figure 9).

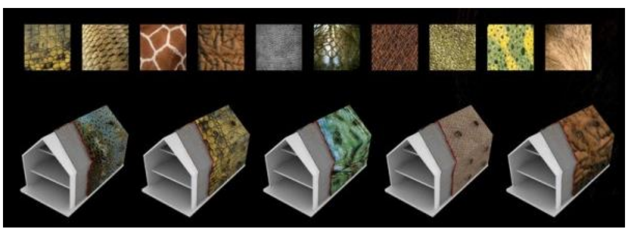

Figure 9. Nano Skin System

The Shimizu TRY 2004 Mega City Pyramid is a proposed project for Tokyo Bay in Japan by the architects Dante Bin and David Dimitric. The structure would be 12 times higher than the Great Pyramid of Giza, and if built, it would be the largest man-made structure on Earth. It is a conceptual city in the air, including wind and sunlight, to serve as a home and workplace for about one million people. A megatruss structure, which also serves as a platform for infrastructure facilities, is designed to meet the needs of residents and the surrounding environment at the same time. The 2000 meter-high structure is based on a combination of regular octahedral units [25]. The structure cannot be built with currently available materials due to their weight, but carbon nanotubes could realize it (Figure 10).

Figure 10. Megapyramid

The Nano Towers were proposed as the new headquarters of the DuBiotech Research Park in Dubai by Allard Architecture. This mixed-use development offers 160.000 square meters of office space, laboratories, a hotel and residential and associated support facilities in a 262 meter-high tower. The canopy at ground level provides sunshade while creating a conceptual ground plane from which the towers grow. The repetitive grid of the exoskeletal structure has non-curved beams of equal length. The structure was inspired by a nano-scale carbon tube. It has junctions where the geometry shifts from vertical to horizontal, and this creates multiple opportunities for dividing the interior space along mullion lines [26] (Figure 11)

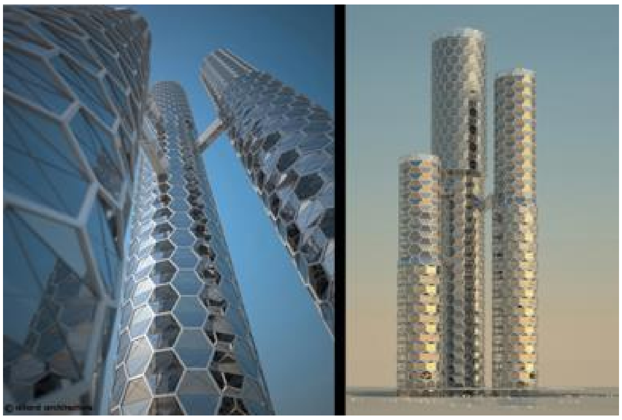

Figure 11. Nano Towers

Nano Vent Skin, designed by Agustin Otegu, uses nano-scale wind turbines. This concept wall consists of different kinds of microorganisms that work together to absorb and transform natural energy from the environment. These bio-engineered organisms could convert sunlight and wind power into renewable energy and they could absorb CO_2 from the air. These microorganisms have not been genetically altered. They work as a trained colony where each member has a specific task in this symbiotic process. The outer skin absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside the nano-wires, which are then sent to storage units at the end of each panel. Each turbine on the panel generates energy by chemical reactions and also works as a filter absorbing CO_2 from the environment while wind passes through it. NVS works like the human skin. When we suffer a cut, our brain sends signals and resources to this specific region to get it restored. Every panel has a sensor on each corner. When one of the turbines has a failure or breaks, a signal is sent through the nano-wires to the central system, and building materials (microorganisms) are sent through the central tube in order to regenerate this area with a self-assembly process. A scale model was developed in order to test the wind tribunes [27] (Figure 12).

Figure 12. Nano Vent Skin

One may suppose that their aesthetic appearances are simple, rational, exaggerated technologist, or even sometimes naïve. But all of them suggest hybrid spaces that gather organic and inorganic life. Although they appear much more pragmatic and feasible than digital form generating, there is a controversial question: "does being incorporated with organic substances and living materials make the buildings 'alive'?". For instance, B. Bratton considers these studies as just a replacement of traditional materials with new artificial biomaterials in the formation of traditional forms, spaces, and programs [7]. On the other hand, there is not much specific research in biomaterials for construction of architectural environments. Because the research is mostly focused on medicine and agriculture, which relates with the fundamental needs of humanity and are hoping to have the fastest benefits. So the deficiency in this area waits for interdisciplinary research.

4. Shaping a Living Architecture

We know that architecture has adopted many concepts from the nature throughout history, for example, Ancient Egyptian columns, modeled on palm trees and lotus plants; the Geodesic Dome of Fuller, generated by his researches on plants and human neural systems; the Living Pod of Archigram; the IMAX Theater of Santiago Calatrava, shaped like an eye, and other designs of Calatrava inspired by birds or structures of trees; the Sydney Opera House of Utzon, inspired by seashells. All of these, inspired by natural forms, have organic characteristics and are named in literature as analogical or biomimetic design [28].

But the architecture that has recently been suggested is different from them. Genetic architecture, suggested by a group of architects, is based on the philosophical notion of genesis [31]. Its aim is not exactly to imitate nature or designs in the nature, but plasticize with nature and, moreover, design nature. The architects try to achieve an architectural approachment which is a real and living piece of natural life by making use of the opportunities in genetic principles and nanotechnology. Nature is not only a source of inspiration but also raw material for them. Accordingly, the works in this category are born out of the desire to design self-growing, living buildings operating by their own DNA.

John M. Johansen, in the late 1960s, envisioned the building as an organism whose structure is determined by genetic processes. Buildings, in his imagination are self-organizing, self-regulating structures with the capabilities of self-diagnosis and self-healing and have a central nervous system. The ***Molecular Structure House*** and the ***Multi-Storey Apartment Building*** designed by Mohamad Alkhayer and John M.Johansen for the year 2200 are already utopic but impressive futuristic designs. Everything would start by placing a "seed" of artificial DNA, the molecular modeled code designed by the architect, in the ground and into a vessel filled with special liquid chemicals. The order of the processes are as follows: taproots, which would compose the basis of the building, followed by the upper building, inside-outside horizontal skeleton, grid system, inside-outside walls, and platforms or flats, with gaps and mechanical systems then being completed via molecular divisions in nine days (Figure 13).

The construction starts with an excavation for placing large vessels he calls "assembly vats." The second day, the vats and ingredients are delivered and placed on the site by pumping. Then "The Code" comes on day 3. He describes the code as a representation of a very old combination of architectural drawings, specifications, and strategies of construction management. The code is placed in the vat. The fourth day is when molecular growth begins. A vascular system develops, with roots germinating from the mixture in the vat and reaching the ground level. The roots (also beams of the ground floor) then start forming a superstructure by weaving a ground-floor platform by extending themselves across each other. The structure grows during the fifth day by extending its vertical ribs and forming necessary lattices of the structure. He also mentions that a neural network joins the structure at this phase. During the sixth day, the boundaries of the molecular-engineered house start functioning, mimicking membranes of living cells. When membranes receive electric currents, molecules disengage, and exterior membranes open while letting inhabitants permeate the house. The seventh day is for the growth of interior finishes that are simply called “body support”. The next day brings us an artificial organic shelter which Johansen refers to as a cocoon. Day 9 is the grand opening: he house is a flexible, self-sufficient molecularly engineered living space which can be rearranged or demolished and recycled [30].

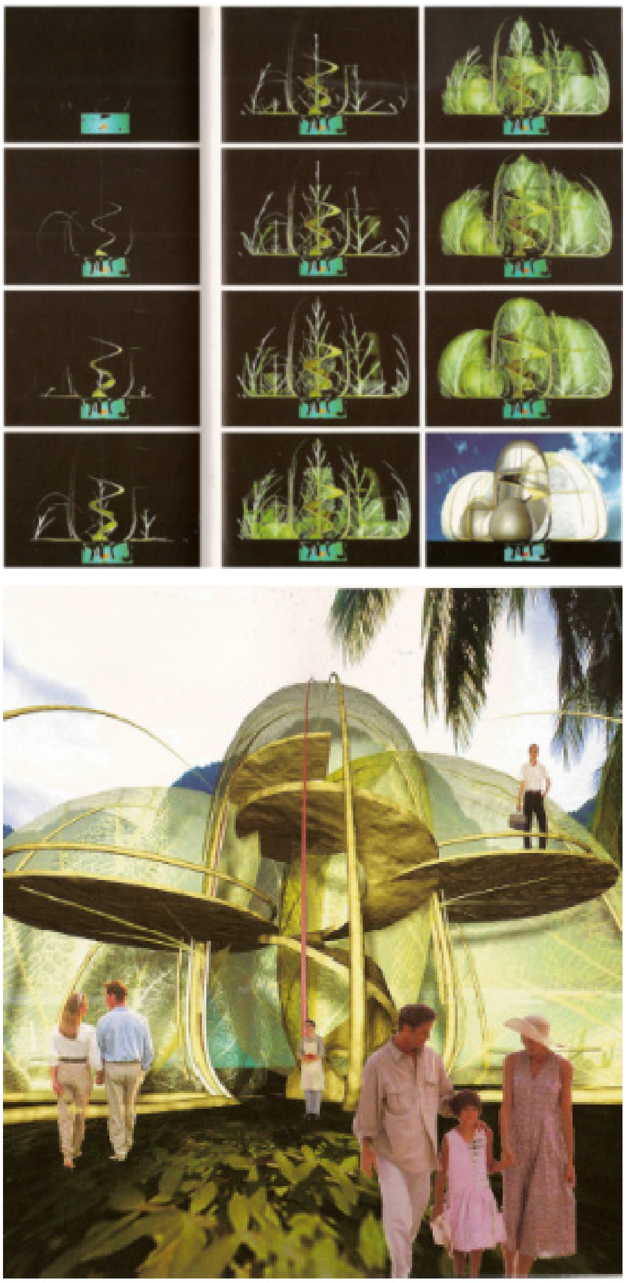

Figure 13. The growing process of the Molecular-engineered House of Johansen

Another growth building project, called ***Fab Tree Hab,*** is introduced by architect Mitchell Joachim. The concept envisions growing houses from trees referred to as the tree houses of childhood. It is based on prefabricated scaffolds set up for natural plants to cling and grow on and around. The bodies of trees are the load-bearing structures, and the branches make the lattice frame for the walls and roof. The surfaces puddle with a mixture of clay and straw. The tree home also produces food for human inhabitants in exterior walls and gardens. It could grow together with tree through their bioplastic windows [31] (Figure 14).

Figure 14. Fab Tree Hab

The STEMcloud v2.0 project proposes an architectural prototype operating as an oxygen making machine, designed and produced as an installation by Claudia Pasquero and Marco Poletto for the Seville Art and Architectural Biennale 2008. The STEMcloud v2.0 technological matrix will operate as a breeding ground for micro-ecologies found in the local river of Seville, the Guadalquivir. The transparency and porosity of the architectural system makes it visible and open to interference. The public will feed the colonies present in the river water with nutrients, light and CO_2. First, a wide spectrum light is positioned strategically to generate a radiation field, which is kept constant in time. Algae growth is stimulated by the field and will respond to it; feedback arises while each block develops its own internal equilibrium. Second, nutrients are inserted into the system to prime its starting condition. More active blocks will consume more nutrients and grow faster. Overgrown blocks will be more opaque to light affecting the radiation field. Coordination between nutrients and radiation will push the differentiation further. And finally, photosynthetic activity will be monitored live and will be visually fed back to the user. More active blocks will signal the need to be fed with CO_2 provided by the user. Users will respond to visual cues (LED intensity) and trigger modifications with their actions [32] (Figure 15).

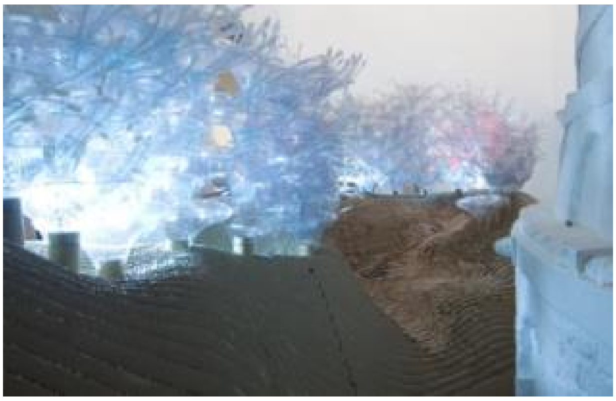

Figure 15. STEMcloud v2.0

Belgian architect Vincent Callebaut has designed a conceptual transport system that would involve airships powered by seaweed. Called ***Hydrogenase***, the project envisages that by 2030 there could be farms in the ocean producing biofuel from seaweed and acting as hubs for aircraft. Its inspiration comes from the beauty and the shapes of nature, but also and especially from the qualities of its materials and its self-manufacturing processes. Able to produce electricity and biofuel without emitting CO_2 or other polluting substances, hydrogen, especially is nowadays such a very promising clean energy source.

Hydrogenase is thus a jumbo jet vessel that flies at an average of 2 000 meters high. This inhabited vertical airship sets itself in the heart of a floating farm of seaweeds that reload it directly with bio-hydrogen. These two interdependent entities are both nomadic and organic. The first one flies in the sky and the second one on the seas and oceans. The semi-rigid non-pressurized airship stretches vertically around an arborescent spine that aero-dynamically twists more than 400 meters high and 180 meters in diameter. Forming a big flower ready to open, the spaces divide in a cross under the shape of petals for the main sectors of activities: housing, offices, scientific laboratories, and entertainment. The stems around one these functional petals structure themselves and have the vertical circulations, the technical premises and the goods warehouses for the freight. These four inhabited spaces are included between four great bubbles inflated with bio-hydrogen, a renewable energy. These bubbles are made with a rigid hull of a light alloy shaped with twisted longitudinal beams linked together by wide sinusoidal rings. Every end is finished by a cone, and the one at the bottom, the most sharpened one, carries the stabilizers and the rudders to manage depth and direction. The vessel is built with lighter and more resistant composite materials (fiberglass and carbon fiber) in order to reduce the weight of its structure as much as possible. It would have different materials and systems to avoid the accumulation of ice and snow or the toxic effects of the adhesion of bacteria or to reduce turbulence or others. On top of producing clean energy, this floating station is also a suggestion for observing sea fauna and flora and for revitalizing beds of corals and endangered species [33] (Figure 16).

Figure 16. Hydrogenase vessels

Fibrous Tower was designed for the Taiwan Tower Competition by Austrian architecture firm, Soma. The proposal is based on the underlying principles of the structures of plant and animal life. The structure has biomimetic fibrous lamellas which are intertwined and connected to form a whole. They adapt to weather conditions by opening and closing, much like the mechanisms of flowers. Its form is generated by using genetic algorithms found in natural growth processes of plants and applying them to digital models. The final form was derived by calculating and comparing more than 2.5 million alternative solutions. The project is made up of bundles of tubes and sub-tubes that create the form of the undulating building. For stability, the eight tower legs are connected by diagonal members. To make them easier to build, design forms dissolve into bundles and regroup, much like the fibers of trees or the growth of muscles. An aerodynamic waved silhouette also maximizes the wind load resistance. The skin of the tower is also a vertical solar absorber with 25.000 square meters of exterior surface covered with flexible PV modules. This allows all electricity needed to be produced on-site. Architects predict that the bundled ducts will be made of locally available materials and will be easy to construct on the ground [34] (Figure 17).

It can be said that these design experiments include the first two categories together. They intend to be living architecture in terms of both form and materials. Although it is impossible to demarcate between categories, these works differ from others by their production techniques, formations, and materials. For instance, designs in the second category are determined as hybrid systems which are constituted by integrating the nanomaterials or special techniques on conventional buildings. They seem like ordinary architecture sanctified by scientific technology. On the other hand, the designs in third category have the potential to point out architecture of a different age. However, they have an even lower probability of realization, as they are still utopic. Accordingly, there is a requirement for much more research on real DNA, not computational.

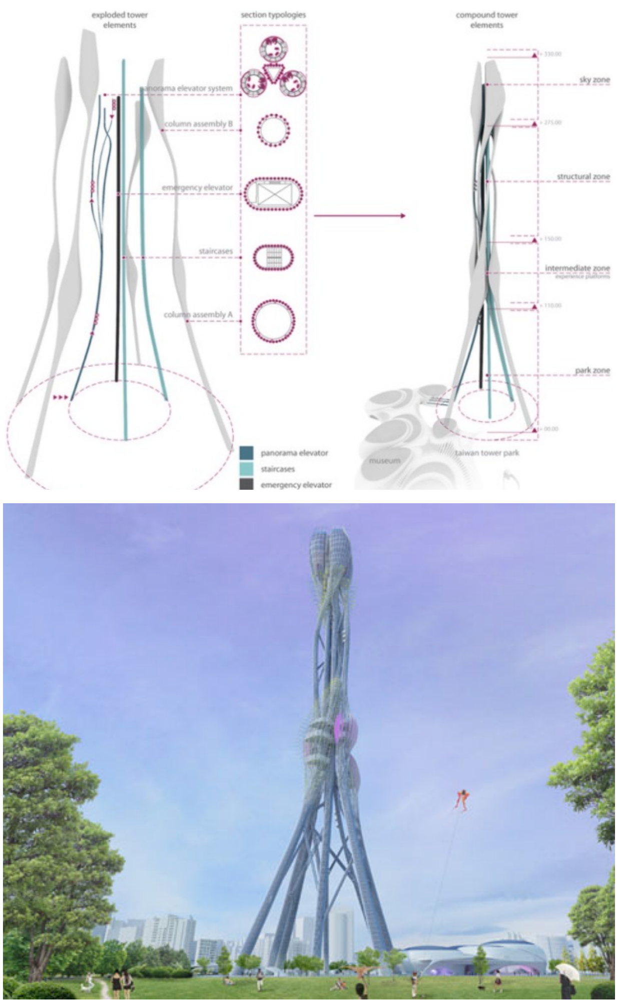

Figure 17. Production diagram and 3d model of Fibrous Tower

5. Conclusions

In the 20th century, Le Corbusier metaphorically likened the house to a living machine. In the 21st century, it is predicted that buildings will really be living organisms, not like machines but like organics. Actually, this idea contains aims of designing buildings in harmony with nature and protecting the symbiotic equilibrium as mentioned above. Architects have thought about a better and more sustainable environment and space quality in the future because the resources of the world have become restricted, and ecology has gained more and more importance. They would also have to cooperate with other disciplines, obtain information, and gain experience in scientific developments.

It is possible to mention that there is a conceptual confusion in theoretical areas and classification problems with design works. In addition, it requires querying some aspects. First, architects should show regard to the fact that imaginer's attraction to biogenetic forms in architectural media does not mean that they suggest satisfactory spatial organization for users. In our age, many things could easily be used to serve consumption and with the facts distorted even in scientific areas. It is known that the sustainability of many energy-efficient techniques or systems is arguable. Many commentators recognized too that the genetic technologies or sustainability and energy policies are part of a new capitalist paradigm that becomes a special object for politics and the financial production-consumption process. So being fascinated by the trends and keeping track of them could not be the best way every time and might bring only commercial success. Second, all these developments have unknown effects on humanity. For example, would people really be comfortable sitting in a house supported by columns having almost the diameter of a needle? Or what would be the effects of living buildings with their changeable materials on us? The social and psychological effects of the foreseen architecture of the future must be researched synchronously with the design process. Living architecture might be a solution for the loneliness or alienation of our metropolis and might strengthen our sense of belonging. But the situation of being in an organism and having mutual interactions with space are main research topics.

Despite all the developments of the processes, we live in great white hope for the future. Constructing a living building which grow like a plant is still theoretical. But in the future, the fields of microelectronics, genetics, nanotechnology, and molecular engineering represent a new frontier in architecture. When these approaches are evaluated, it can be claimed that specifically genetics, molecular-nanotechnology, and robotics could start a radical revolution in architecture as in many other areas. And as a result, architecture could reach a very different stage from where we are now. Ray Kurzweil, in his 1999 book '*The Age of Spiritual Machines*', stated that if the technology develops with that speed, computers would pass the human brain in terms of memory capacity and operation speed. As a matter of fact, today's computers that are integrated into buildings can observe some conditions such as temperature, air circulation, energy consumption and wind load using their sensors and can respond if they have already been programmed. Although we crawl on all fours, living buildings or cities constructed by robots could be made possible with the coordination of architecture, science, and technology when considering the development of mankind in the last two centuries. Therefore, a more livable environment could be constructed from real living buildings. To express with Johansen's words [30], "Much of yesterday's fiction is now reality, and much of today's fiction may be reality of the future."

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