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THE DESIGN CHARACTERISTICS OF NATURE-INSPIRED ECO-FRIENDLY BUILDINGS

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Abstract- During 3.8 billion years of changes and evolutions of nature, nature has learned what is optimal and what is appropriate. Nature is a laboratory in which life has evolved the adaptations of its diverse environments. The organisms of nature are the results that changed a sustainable equilibrium conditions in their environments in the Earth. Nature-inspired biomimicry for eco-friendly building is a way of observing the natural world to find environmental- friendly design solutions that may enable us to create the concepts of new building design with sustainable and healthy. The shapes, mechanism, processes, and organisms optimized for the evolution of nature over several hundred million years have helped designers and architects seeking improved and innovative solutions for humans. This study is to analyze what are nature inspirations for the visual and conception building designs and what are the characteristic of innovative designs and technologies inspired by nature.
Keywords – new design source, nature-inspired architecture, nature-inspired biomimicry

1. INTRODUCTION

During 3.8 billion years of changes and evolutions of nature, nature has learned what is optimal and appropriate. The Earth is a little over 4.5 billion years old, its oldest materials being 4.3 billion-year-old zircon crystals. The nature-inspired progresses can be classified into the levels of inspiration by Janine M. Benyus, nature science writer, an innovation consultant and author. A visual inspiration is well understood the shape of various organisms. A conception inspiration occurs when scientists applied principles and processes found in nature, and a computational level is inspired by organisms and mechanisms. Recently, many scientists have been studying nature's design elements in mechanisms and biostructure. Biomimetic research aims to solve mankind's problems by developing the many mysterious elements of nature. The research of natural inspiration is very important for architect, and nature provides creative ideas and limitless inspiration for sustainable eco-friendly designs and technologies. As the Earth's crisis is rapidly growing in the Earth's environment, the exhaustion of resources, and the decline of biodiversity, the coexistance of humans and nature is emphasized [1,2].

When constructing for the new buildings, it is important to find how to satisfy our yearning for harmonious interactions with nature. The research is to get the new design sources by nature-inspired design and technology. This study focused on investigating the environmental-friendly buildings, and it will be analyzed the design characteristics of nature-inspired architecture.

2. NATURE AND CULTURE

2.1. Nature-inspired culture-

Many landscape paintings show the pursuit of a pure depiction of nature, the important aspect in painting, literature, and philosophy was perceived the landscape. Artists have long been transformed from an inspiration of nature for the unknown world. The intrinsic of nature has sublimated into the art of restoring humanity. The scholars of the Joseon Dynasty(1392-1897) of Korea loved four gentleman plants for plum, orchid, chrysanthemum, and bamboo. Plum is the first flower to bloom in early spring. The orchid has the noble appearance and fragrant smell. The chrysanthemum is the flower that overcomes the cold weather in late autumn. The bamboo has its blue color even in winter. The love of the four wonderful plants was visualized as poetry and picture.

Figure 1. Landscape painting

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Figure 2. Plum painting

Figure 3. Orchid paintings

Figure 4. Chrysanthemum paintings

Figure 5. Bamboo painting

2.2. Traditional landscape theory-

The landscape geography is based on the phenomenon of the universe of heaven and earth, and plans to harmonize with the characteristics of the area environment. The land plan was analyzed the landscape of the surrounding mountains, the flow of water, and the contour of land. Many people thought that the situation around the land had an effect on the personality, health, and success of the people living there. A good site for a village was surrounded by mountains in the back of the house, and in front of the house there was a wide land that a river is flowing. People thought the best place for a woman's womb-like land. Korean traditional houses are very similar to the peaks of surrounding mountain.

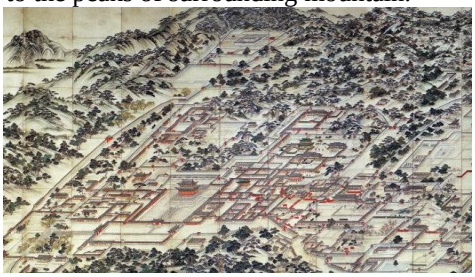


Figure 6. Landscape map of Seoul in Korea (1750)

Figure 7. Korean traditional villages

2.3. Korean traditional houses

The layout plan of Korean traditional houses is consists of various spaces with different characteristics such as mother, father, slave, and ancestral area. The layout of the traditional house is basically divided into the fence and it is linked with the surrounding environment organically. The direction of the house is looking at the peaks of the stunning South Mountain. The materials was to build the house that used all natural materials such as wood, soil, paper, rice straw, and roof tiles of black color.

Figure 8. Korean traditional houses

3. ECO-FRIENDLY GREEN BUILDING CERTIFICATION CRITERIA

3.1. Green building certification

The buildings have widely relationships with the surrounding environment. During construction and occupancy, buildings use energy, generate waste, and release harmful air emissions. It has created a green building standard, certification and evaluation system for eco-friendly architecture. Architects should respond to designing homes that use less energy than average houses for net zero energy, carbon neutrality, solid, well-insulated wall systems, and high-performance residential design. Architects are striving to satisfy architectural compliance, structural safety design, environmentally friendly design, long life design and intelligent design when are the design of buildings [1].

In LEED, when constructing a green home, builders have the choice of following programs, rating systems, and laws. A home can use substantially less energy than the average home? To achieve carbon-neutral and net-zero energy design, buildings must be responsive to their local climates. A home built with non-toxic and non-VOC off-gassing materials? Volatile organic compounds are found in many common household and building products such as paints, varnishes, paint strippers, and cleaning supplies. A true green home acknowledges the importance of all building elements, from designing an air-tight, well-insulated wall system to choosing high-quality windows. The whole building approach will consider a high-performance: accessibility, aesthetics, cost effectiveness, functionality, productivity and health, history, safety/security, and sustainability. Aesthetics applies not just to the outside architecture, but to the interior design, the surrounding landscape, the neighboring buildings and the community. Functionality is to consider the owners' future needs, such as potential spatial changes from re-modelling. The indoor environment can have a strong effect on occupant health and the productivity of occupants, particularly young children and the aged, whose auto-immune systems are more susceptible to toxic materials and off-gassing fumes. Excessive noise, glare, drafts, heat, humidity or cold can be potentially damaging or dangerous.

Table 1. Green building certification

Country	Criteria	Green Building Certification
Korea	GBCC	Green Building Certification Criteria
Japan	CASBEE	Comprehensive Assessment System for Building Environment Efficiency
America	LEED	Leadership in Energy and Environmental Design
England	BREEAM	Building Research Establishment Environment Assessment Method

Figure 9. Green building design

Figure 10. High performance design

LEED proposed the standard of sustainability for residential design. (1)Optimizing site potential includes proper site selection, consideration of any existing buildings, orientation of streets, active solar features, location of access roads, parking and potential hazards. (2)Minimizing energy use and reuse renewable energy strategies through insulation, efficient equipment and lighting, and careful detailing of the entire enclosure. (3)Conserving and protecting. (4)Using environmentally preferable for reuse or recycling, conserve natural resources, reduce overall material use, are exceptionally durable or low maintenance. (5)Enhance indoor environmental quality have a significant impact on health, comfort, and productivity. Other attributes to be considered maximize daylight, appropriate ventilation, and moisture control, and the use of no-VOC products. (6)Optimizing operations and maintenance practices means materials and systems that simplify and reduce operational requirements. (7)Flexible design is a design principle anticipates and allows for future adaptations needed to extend a building's useful life. (8)Design for end of life encourage design for the disassembly, reuse, and recycling of building components and materials at the end of their useful life.

Figure 11. Green home design

Figure 12. The social, environmental and economic relationships

3.2. Natural disaster

An earthquake is the shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's lithosphere

that creates seismic waves. Earthquakes are measured using measurements from seismometers. The moment magnitude is the most common scale on which earthquakes larger than approximately 5 are reported for the entire globe. The instrumental scales used to describe the size of an earthquake began with the Richter magnitude scale in the 1930s. It is a relatively simple measurement of an event's amplitude. There are three main types of fault, all of which may cause an inter-plate earthquake: normal, reverse and strike-slip. Many earthquakes are caused by movement on faults that have components of both dip-slip and strike-slip; this is known as oblique slip. Many earthquakes occur away from the plate boundary and are related to strains developed within the broader zone of deformation caused by major irregularities in the fault trace. Earthquakes often occur in volcanic regions and are caused there, both by tectonic faults and the movement of magma in volcanoes. A particularly dangerous form of slow earthquake is the tsunami earthquake caused by the slow propagation speed of some great earthquake. Since 1900, there have been an average of 20 major earthquakes (magnitude 7.0–7.9) and one great earthquake (magnitude 8.0 or greater) per year. Earthquakes that caused the greatest loss of life were deadly because of their proximity, where earthquakes often create tsunamis that can devastate communities thousands of kilometers away. In order to the effective measures of earthquake disaster, the evaluation of earthquake disaster risk is indispensable. Recent earthquakes in Japan had occurred the tsunami and the radiation damage of nuclear power plants. Architect must be designed the improved building system to resist of huge earthquakes

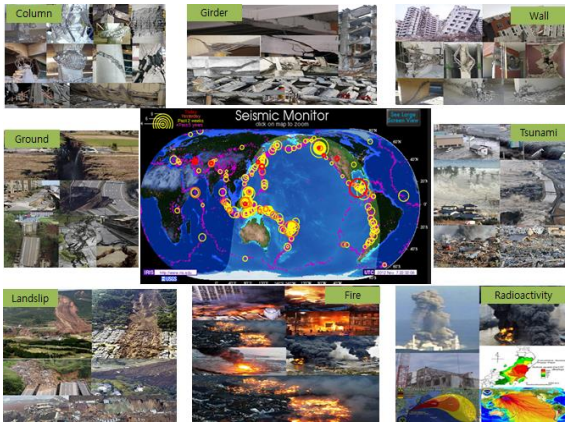


Figure 13. Damages by earthquakes

When designing a building, it is very important to design high-rise buildings and large-space structures to resist wind. The damage have occurred glass on the outer wall of the building, collapse of fences, exterior members and material, and fabric material of roof. In many cases new building materials such as glass and plastics used for facades and roofs are far more susceptible to damage than conventional methods and materials. Wind storm disasters cause widespread damage of buildings and industry facilities due to high wind speeds.

Figure 14. Damages by typhoon

It is important to consider the situation where snow is being blown by wind in snowy areas. The eccentric load of the roof due to snow is mechanically asymmetric, which causes an unexpected concentrated stress. The roof of the large space must be designed considering the several situations where the wind moves the snow. The roof of the fabric material shall be designed so that a part of the roof is not folded by snow. Designing for fire is an important and essential requirement in design process of buildings. The fire resistances for buildings are specified in the national building regulation, but some buildings have the mistakes of fire resistance design. Materials used in buildings should be fire-safe materials. The newly developed lightweight materials are very light and easy to install than traditional materials, but they are very vulnerable to fire.

Figure 15. Fire of buildings

3.3. Retractable roof design considering optimal weather condition

Retractable roofs are playing an increasingly important role in the development of flexible sports facilities that can be operated in optimal conditions, i.e. with the roof open as long as allowed by the weather, throughout the year. The retractable roof can be opened and closed in a few minutes. Retractable roofs are generally used in sports stadium where inclement weather, extreme heat, or extreme cold are prevalent during the respective sports seasons, in order to allow for playing of traditionally outdoor sports in more favorable conditions, as well as the comfort of spectators watching games played in such weather. Open roofs fully close and open by the mechanics of a rack and pinion system or a push or pull drive system. Comparable to the benefits of retractable roofs, open roof systems offer players year-long usage, protection from inclement weather when needed, and the feeling of an outdoor environment. Both retractable roof and open roof systems are also used in the construction of commercial greenhouses and garden center for climate control purposes. Benefits of retractable roofs include in as follows. Retractable roof add aesthetic beauty. When retractable roof are closed they provide shelter from sunshine, strong winds and heavy rain, when they are open, can enjoy the outdoors and give architectural appearance. Sports stadiums across the world are topping off their structures with retractable roofs. The retractable roof offers comfort to both spectators and players with letting stadium to host year-round events in spite of the any environment. The retractable roof offers perfect playing conditions. In stadiums during sudden precipitation the roofs can be close to avoid disturbance during games. Retractable roof is very effective system in sports stadium for climate control purposes.

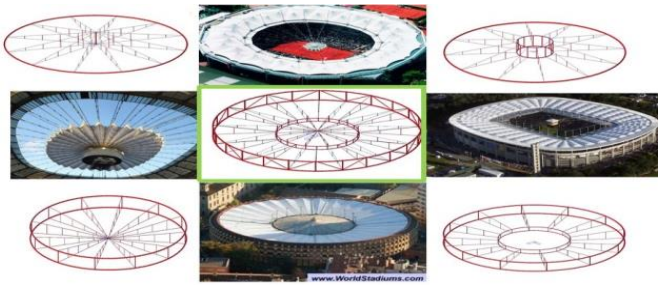


Figure 16. The structural system of eco-friendly retractable roof design

4. NATURE-INSPIRED ARCHITECURE

4.1 Hexagonal design inspired by nature

Hexagonal structures can be found in honeycomb structures, snowflakes, turtles, fly eyes, giraffe patterns, and diamonds. The hexagonal structure is the most economical structure to ensure maximum space with minimal material. At the same time, it is also a stable structure that distributes the most balanced force. Hexagon-shaped structures are stuck to each other when they are attached to each other on a plane, and equilateral triangles and squares do not create any gaps. However, in the case of equilateral triangles, a lot of material is needed for the wall, and space is narrow. In addition, squares are easily distorted, and they do not disperse external forces or impacts. Hollow hexagons are stable as well as robust because they are easily dispersed in external force. The hexagonal honeycomb has a space that can store as much as 30 times of the honeycomb weight. The hexagonal cells make the least total area of wall compared with triangle or square sections. The layer of soap bubbles becomes the combination of irregular hexagonal shapes. Nature is more good boundaries about the condition of economy. The surface tension of bubbles of soap films pulls the liquid surface to create it as small area as possible. The combination of typical bubbles has the polyhedral cells of different shapes and a little different curve. A slightly more economical structure was discovered the combination of a repeating group of different cell shapes for given boundary conditions. This bubble pattern was designed as the inspiration for the structural system of the 2008 Olympic swimming pool in Beijing. The compound eye of fly also can find the hexagonal packing as a bubble raft. The hexagonal patterns can find in radiolarian, the skin pattern of giraffe and the back pattern of turtle [1].

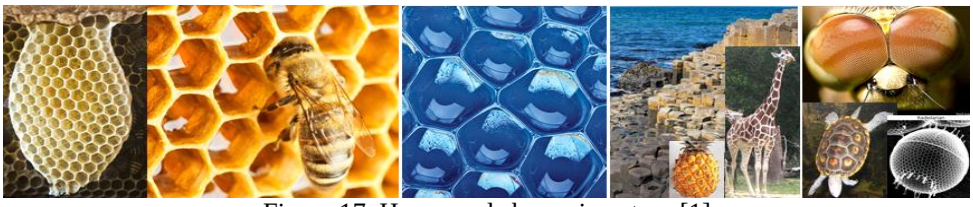


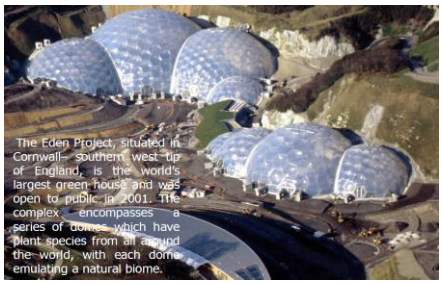
Figure 17. Hexagonal shapes in nature [1]

Snowflakes show various combinations of symmetry and complexity. The symmetrical phase is the result of the hexagonal structure of ice crystals, and the complexity comes from the free flying of individual crystals falling through the atmosphere. The actual snowflakes consist of star-shaped dendrites and star-shaped plates. Snowflake growth has complicated structures as snowflake crystals grow symmetrically. Snowflake growth causes the molecules to condense and form crystals. These crystalline materials can help to create new and better types. Snowflakes have various morphological characteristics depending on temperature, pressure, humidity, density and so on. The physical mechanism governing snowflake growth is one of the most optimized forms in nature

https://math.mit.edu/research/highschool/primes/materials/2014/Li-Jessica.pdf

Figure 18. Snowflake (a) Stellar dendrite (b) Stellar plate (c) Sectored plate

Eden project for a botanical garden is designed the huge domes of the hexagonal steel frames and geodesic spherical network. The cladding system of ETFE foil cushion is a very lightweight system in constraint to glass. The ETFE film allows UV light to pass into a dome and also provides best insulation. The weight and amount of the steel was minimized by the optimum design, the cladding is transparent for the sunlight. The interior dome space and the bubble-shaped appearance are attractive with a high technical level for the architectural design and structural system. The surface has self-cleaning function so that the dirt on the outer surface is washed down by the rain. The hexagonal-shaped cushions are attached on an aluminum frame, the pressure inside the cushion is about 300 Pa. In the design of the high wind suction the outer surface was strengthened by using two layers of foil [1].



Source:http://www.studioseverini.eu/res/DocumentiPDF/eden_project_english.pdf

Figure 19. Eden project in the south-western tip of England

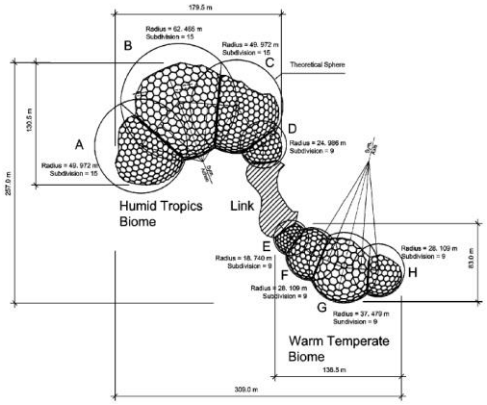


Figure 20. Detail of Eden project

Ideas for a sustainable future between plants, people, and resources were proposed in the design of Eden project. The goal was to educate visitors about the importance of a sustainable environment through the education of plants for future generations. It was searched for many innovative ideas for creating the world's largest living creature in humid tropical biodiversity. This design is structurally stable, so a large space dome does not require internal supports even at 240m spans. In addition, all the steel tubes that make up the grid-typed network were easily transported to the site with small parts. In terms of energy efficiency, the hemispherical dome is because the spherical shape has the largest amount of volume compared to some type of surface area. ETFE is a very light material, and has the advantage of the self-cleaning of the dome surface. The sunlight transmission is very excellent and is essential for the healthy development of plants.

4.2. Bubble design inspired by nature

The soap bubble structure has the ability to make the space with minimal energy consumption. The geometry of the bubble is a spherical shape with slightly curved edges and faces. Soap bubbles have the function of self-assembly according to the atmospheric environment. One of the attractive things about the soap bubble structure is that it always minimizes the surface. Free floating soap bubbles are always spherical and the soap film on the flat frame is always flat. The area of the soap film is minimal in both cases.

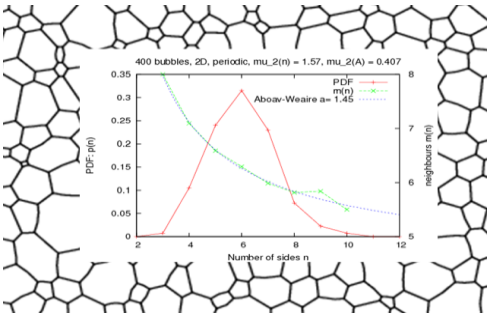


Figure 21. 400 bubble structures

The Beijing National Swimming Center was designed to act as the concept of greenhouse with the innovative design of high technology biomimicry. The design was based on the most effective arrangement of organic cells and the natural formation of soap bubbles. The arrangement pattern of roof has seven different patterns of bubbles and the wall has the combination of 15 repeated bubble patterns. All pillows are permanently inflated by a pump for the internal pressure with 0.2mm film thickness. The ETFE cladding allows more heat penetration than traditional glass, and resulting in a 30% decrease in energy costs. The flame does not spread when a fire occurs. The tensile strength is very good and the strain is very large, so it does not tear. Eco-friendly ETFE materials have 100 % recyclable [1].

Source: http://www.discoverbeijingtours.com/home/Tools/2012/0922/National-Aquatics-Center.html

Figure 22. Beijing National Swimming Center

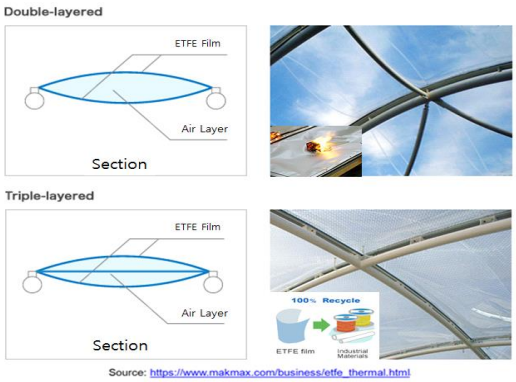


Figure 23. Double-layered and triple-layered cushion

ETFE has been originally developed by DuPont company over 40 years ago as an inert coating material for the aerospace industry. ETFE film conventionally is used in agricultural applications such as large span greenhouses, the coating of solar cells. ETFE films can be highly transparent (from 90% to 98%) and allow for the passing of UVs which are responsible for the promotion of photosynthesis thus facilitating plant growth. ETFE film systems can incorporate a number of patterns on one or multiple layers to alter their solar performance. Colors can be introduced in a variety of ways whether it's applied during the film extrusion process providing a consistent tint in various tones from red to violet or adding lighting with unlimited color options. While ETFE films are very hyper elastic up to 400% at breaking point, they are still structurally resistant. The tensile strength at the limit of elasticity is 20-25 N/mm² but tensile strength to breaking point is 40-50N/mm². For structural calculation a limit of 15 N/mm² is conservatively usually taken. ETFE film has approximately 70% acoustic transmission. The nature of the product enhances the building physics through insulation and daylighting, therefore contributing to the global low energy aspect of the building. Easily recyclable, waste from the manufacturing process or even old ETFE elements can be remolded into new ETFE products such as tubing components, wires or castings. Comparable to a glass system, the increased thermal performance is possible with a multi-layered system. For a double or triple layer pneumatic system, multiple layers of film are welded into panels that are inflated with low pressurized air to stabilize the film and providing the thermal property of the system. A pneumatic ETFE cushion system is generally supplied by one or more inflation units. Each unit consists of two redundant blowers forming a backup system for guaranteed structural stability. The air when entering the machine will be dried to avoid condensation within the cushions. A pressure sensor will continuously monitor the internal pressure of the ETFE cushions maintaining them. In case of high wind or snow loads, if necessary and designed, sensors can automatically and continuously adapt the pressure to compensate external loading up to 30 PSF. The film melts away at around 500 degrees F.

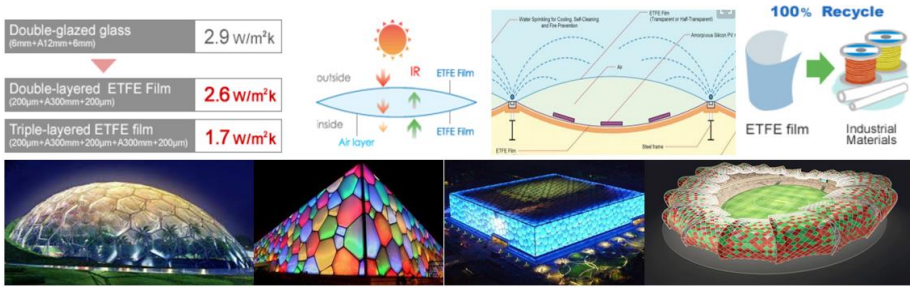


Figure 24. Mechanical characteristics and applications of ETFE film(www.google.ac.kr)

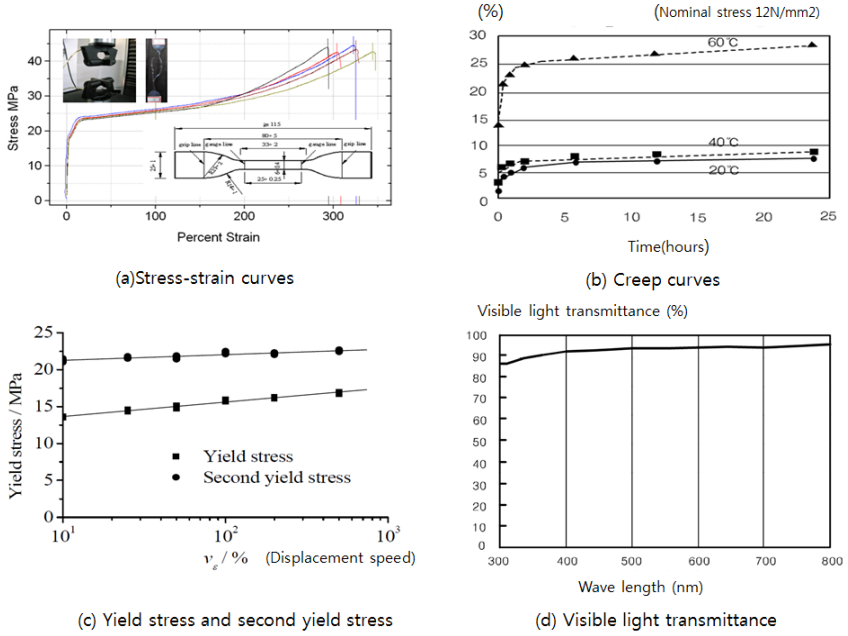


Figure 25. Mechanical properties of ETFE film

4.3. Cable structures inspired by spider web

The spider seems able to vary the natural behavior in order to construct an optimal network structure according to the environmental conditions. The spider web is complex animal architecture. The construction rule of spider provides a useful tool to explore behavioral strategies for the construction of web. Natural spider webs have an analogical structure of a radial

cable network, even though spider nets have no any rigidity. The network is applied to the system of cable structures for a large span space and a lightweight roof. Cable truss roofs mainly use a spoke wheel-like system and a radial roof system to build a lightweight large span roof. A large span cable truss roof is a system that combines two spoke wheel systems to adjust the slope of the roof by adjusting the height of the roof post and the outer ring. The outer part of roof is designed a fixed membrane roof, the inner part of roof have the retractable system that can be opened and closed [9, 10].

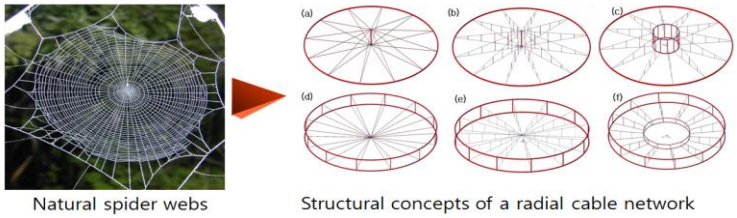


Figure 26. A radial cable network inspired by spider web

The Munich stadium complex for the 1972 Summer Olympics is a perfect arena of how site and structure can harmony together. The design of cable roofs for the arena of first membrane structures in the world is to unify the earth. The Munich stadium complex for the 1972 Summer Olympics is a perfect arena of how site and structure can harmony together. The design of cable roofs for the arena of first membrane structures in the world is to unify the earth. The roof shape was inspired by Alps mountain. The tensile dedign were revolutionary and remain both visually and technically impressive structures.

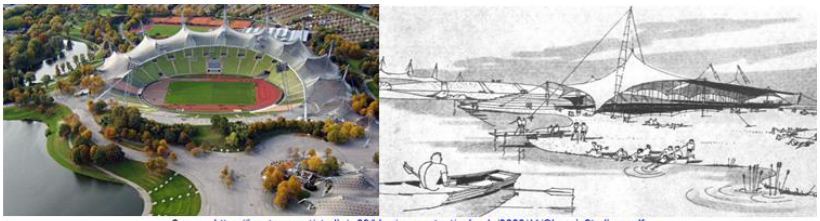


Figure 27. Munich stadium complex

The method of considering the safety in the opening and closing method is different from the opening and closing state when it moves. The conditions of roof should be clarified taking into consideration whether the roof is to be opened, closed or half-opened. It is normally a good for in a closed state at the time of storm and strong wind in the retractable roof and should be closed when the wind speed exceeds the specified wind speed. Variation of wind speed during roof opening and closing should be considered. The folding-type roofs are designed to the membrane in order to form an appropriate curved surface. The movement method of the opening and closing part can be planned a retractable system for horizontal sliding, horizontal folding or rotational movement. The moveable roof should be considered to structural design for the lateral shaking during the movement, and the upward and downward shaking motion when the roof is running.

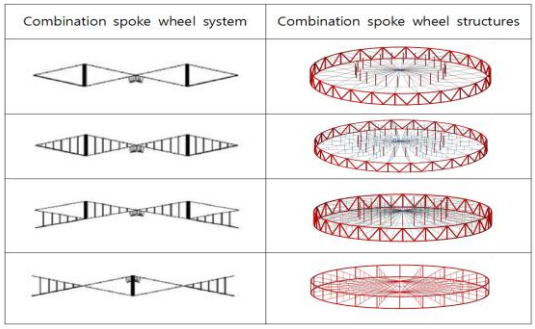


Figure 28. Retractable cable roof systems

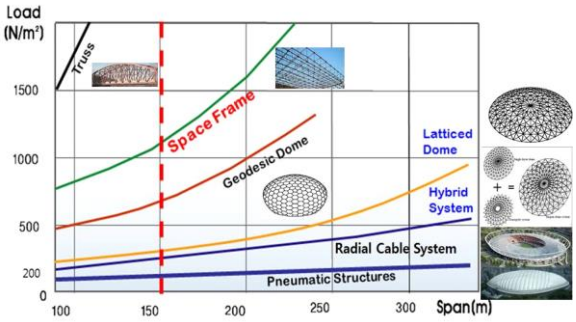


Figure 29. Comparison of self-weight for roofs

The nonlinear behavior and mechanical characteristics of a cable roof system has greatly an affect by the sag and pretension. This paper is carried out analyzing and comparing the tensile forces and deflection of curved roof systems by vertical loads. The elements for analysis uses a tension only cable element and a triangular membrane element with 3 degree of freedom in each node. The authors will show that the curved cable-membrane roof system with reverse curvature is a very lightweight roof and small deformation for external loads.

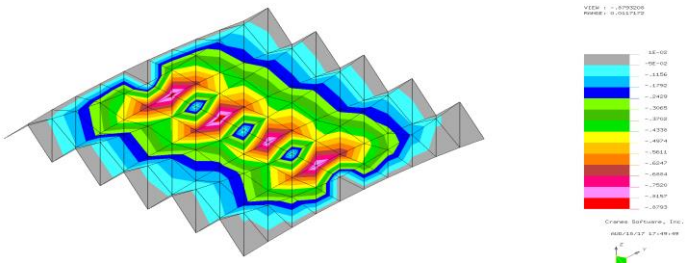


Figure 30. Deflection contour of a rectangular curved roof (0.002 ~ -0.8793m, roof load=1.0 kN/m^2)

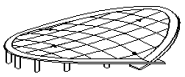
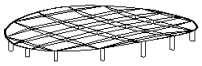
Cable systems	Geometry of roof
(a)One-way cable roof	
(b)Two-way cable network	
(c)HP cable network	
(d)Double-layer cable roof	

Figure 31. Cable systems for a large span

4.4. Building design inspired by flower

The lotus is known to be associated with purity and faithfulness. The blue lotus flower is associated with the spirit of wisdom and knowledge. White lotus flower represents a state of mental purity. The red lotus flower is associated with the compassion and passion for every Buddhist. Lotus leaf and flower has nano-sized hydrophobic surface. As a result, raindrops roll off carrying dirt particles, leaving the surface clean. Lotus flowers are known to be associated with purity, spiritual awakening, and sincerity for all Buddhist saints. Lotus leaves and flowers have wax-like surface of each epidermal cell. As a result, raindrops carry dust particles and keep the surface clean. The properties of cleaning surfaces in plant leaves have opened the possibility of manufacturing various ultra-hydrophobic products, such as paints, glass, and windows. The large-scale imitative Lotus Conference center is the government center in the Wujin district, which resembles the pink lotus flower. The structure is described by a combination of sculpture, and a powerful sensuous and feminine biological form. The building becomes one of the most famous icons in the city. The design is a striking design inspired by the blooming of lotus flowers.

Source: https://www.curbed.com/2014/3/7/10135008/chinas-latest-bizarre-building-is-a-giant-ethereal-lotus-flower

Figure 32. Wujin Lotus Conference Center in China

The Art Science Museum is one of the most eye-catching buildings to be constructed in Singapore recently, a distinctive structure designed in the shape of an open lotus flower. The skin of a massive lotus flower is composed of stainless steel composite material with durable and beautiful. Stainless steel composite material is composed of a non-combustible mineral filled core sandwiched between stainless sheets. With the use of these composite sheets, upscale designs and high corrosion resistance have been considerably reduced at a self-weight. The museum gives to imagine, play and explore in Singapore's largest permanent digital art gallery. At the museum, the visitors can experience to explore the intersection between art, science, technology and culture. It creates the fluid combination of artistic expression, technological ingenuity and scientific enquiry. The Sketch town depicts a fictitious town based on Singapore, including landmarks for Marina Bay Sands. Kids can let their imagination as they color in and draw cars, buildings, and spaceships.

Source: http://www.stainless-steel-world.net/pdf/Art_Science_Museum_at_Marina_Bay_Sands.pdf Source: https://www.tekla.com/references/artscience-museum-0

Figure 33. Art Science Museum in Singapore

The lotus temple, Baha'i House of Worship, is to embody the nine major faiths of the world in order to symbolized Baha'i faith, each component of the temple is repeated nine times. The shape gives an impression of a half open lotus flower surrounded by its leaves. The forms based on a ring of nine arches each covering 40 degrees, these shells are creating 27 petals. The annular hall formed around the inner area of the temple is enclosed by outer leaves having spherical surface by thin concrete shell. The nine entrances are outward direction by each leaf shell.

Source: https://www.Intecc.com/homepage/multislug/demos/images/bnf/LotusConcrete.pdf

Figure 34. Baha'i House of Worship

The Qizhong Forest Sports City Arena has eight sliding steel roofs that resemble the white magnolias of Shanghai, China. It has a foldable steel roof which is switched by the control of the indoor environment. The opening design of the roof signifies the blooming condition of a magnolia. It takes 8 minutes to fully open or close the roof. The stadium is designed to cope with the weather by acting like a blooming of flower that closes and opens its roof. Each of the eight movable petals moves and rotates at the same time over one fulcrum and three rails.

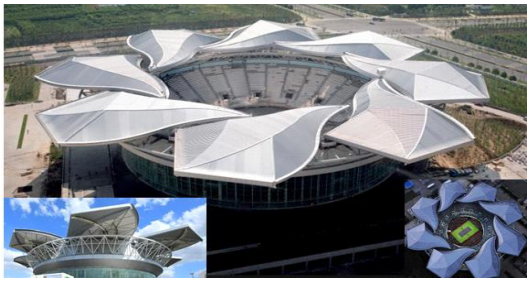


Figure 35. Qizhong Forest Sports City Arena

The design concept of London Lotus City is proposed by an architectural design by architect Tsvetan Toshkow for the future city with a symbolism and a utopia provide an open, green space up in the air. The city plan is a real good example for a megacity of the future, a visionary architect who demonstrates the sky of lotus is not the limit for his imagination, exploring new features of future city. The lotus-inspired city presents an imagery long-beloved sustainable vision with perspectives of a super-shiny and super-clean city.


Source: http://walyou.com/lotus-shaped-city/

Figure 36. London city plan inspired by lotus flower

4.5. Shell structures inspired by nature

Seashells have been successfully playing a role in protecting inner part for hundreds of millions of years. Scientists and chemists are trying to replicate the structure of this material, and can be expected to be used as a stronger building or a bone substitute. When cracks are formed, the polymer of seashell has a structure that grows and strengthens. Natural composite materials are renowned for their mechanical characteristics of strength and toughness. The crossed lamellar microarchitecture of the seashell provides for channel cracking in the outer surface and uncrack structural features that bridge the crack surfaces, thereby significantly increasing the characteristics of fracture and toughness.

General Lee (1545-1598) in Korea was inspired by the cap of a turtle and made a turtle ship. The turtle ship sank many Japanese warships into the sea. A turtle ship was a type of Korean warship that was used during the Joseon dynasty from the early 15th century up until the 19th century. The ship was designed by protective shell-like covering with iron spikes. This design is recognized as the first armored ship in the world. The turtle ship was equipped with five different types of cannons. Their most distinguishable feature was a dragon-shaped head that could launch cannon fire from the mouth.

Figure 37. Turtle-shaped battleship in Korea(1598, http:/www.cha.go.kr)

In Valencia, Spain, the marine city around the sea has been beautifully made using concrete shell structures with the images of seashells. HP dual curvature was used to minimize the bending moment and create a shell structure with a thin curved surface that produces only in-plane compressive forces. In the 1960-70, it was a method of making large space structures using mainly concrete. The geometry of the concrete shell structure was consists of the intersection of hyperbolic paraboloids.

Source: https://www.pinterest.co.kr/pin/196539971214679491/

Figure 38. The marine city around the sea in Valencia

Felix Candela(1910-1997) started experimenting with the umbrella structures in 1952. The shell geometry was created by joining four straight edged hyper whose sides rose upwards. Umbrella structure is a type of inverted pendulum. Precisely, it is a cantilevered structure. The basic structural scheme of an umbrella consists of a foundation, only one column with an embedded pipe to catch the rain water. Candela used to create dramatic roofs of large spaces, such as the roof for the Church of the Miraculous Medal, built in 1955 in Mexico. The church is a remarkable building. It is somewhat reminiscent of the Gaudi's forms. The structure is a combination of super-warped hyper surfaces with a thickness of 4 cm or less. The Cuernavaca Chapel shell is self-supporting with the span of 30 m and dramatic curvature. The open end of the chapel rise to a height of 24 meters and has a visible thickness of 4 cm that represents the frontiers of the form. The underwater restaurant and a large oceanographic park in Spain were the Candela's final projects. The shell is only 6 cm thick that gradually increases up to 22.5 cm at the intersection of the ribs. The geometry of the concrete shell structure for the entrance building was consists of the intersection of three hyperbolic paraboloids [1].

Figure 39. The concrete shell structures

The entire load history for a typical nonlinear analysis may be divided into the step event. An event may have increment load steps. Step size (load increments or time increments) may be determined automatically or user definition. In each increment analysis, it is defines parameters for step (or time increment) size, number of steps, equilibrium checks, tolerances for convergence, iterative procedure and other control parameters. The incremental solution is performed in a step-by-step manner until the full specified loads are applied. In each increment, the above iterative scheme is performed until convergence is achieved or maximum iterations are reached. During each increment, the tangent stiffness matrix may be updated for each iteration, or kept constant in all iterations of the pertinent increment. A cylindrical shell is subjected to a centeral point load. Radius is 2.54m. The 3 cases of thickness are 10, 12 and 14 mm. Modulus of elasticity is 30 GPa. Poisson's ratio is 0.3. The load is applied by incrementing the central point displacement. The objective of this analysis is to obtain the load deflection curve. The central displacement is incremented in equal steps. Number of displacement increments is 30 equal increments. Maximum number of iterations allowed per increment is 100. All tolerances is 0.001. Full Newton-Raphson method is employed in all runs.

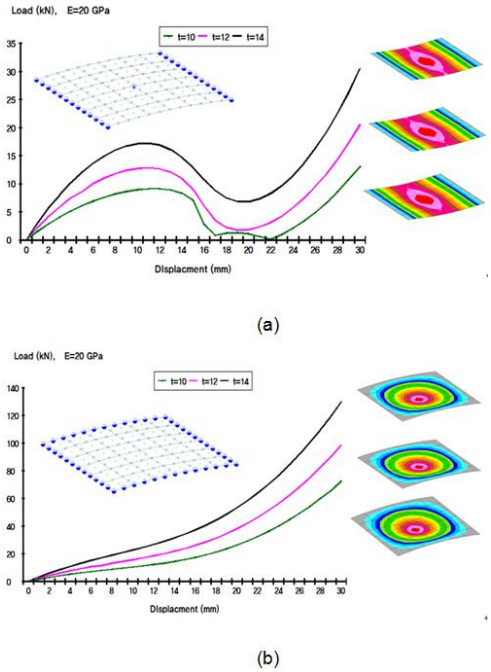


Figure 40. Geometrical nonlinear analysis of a cylindrical shell by boundary conditions (a) Straight edges hinged boundary condition (b) Straight edges hinged and circular edges hinges boundary condition

4.6. Examples of modern architecture inspired by nature

It is a 20 stories residence tower designed in Taipei, Taiwan. It was designed by the Belgian architect Vincent Callebaut and designed the helical DNA structure as a motif. The double helix structure of the DNA form is a building which is effective for the flow of wind and light. Vertical farms built on the balcony of an apartment were cultivated with organic vegetables to make a new lifestyle [44]. The Infosys Building in Kuwait was also designed with the spirit of the shape of the cobra and the DNA. Coexistence of nature and human beings, fusing of information and communication, forming a twisted belt, energy production using solar energy and solar cell to create sustainable residential environment.

Figure 41. City plan of Vincent Callebaut Architecture (http://vincent.callebaut.org/)

It is a concert venue in Singapore, designed by mimicking the exterior shape of Durian, a tropical fruit. Durian is called the king of fruit because of its unique flavor and taste. Their love for Durian was expressed in architecture. Palm Island is an artificial island made in Dubai. It consists of islands shaped like palm trees. Dubai Palm Islands has had a significant impact on the surrounding environment, resulting in changes to area wildlife, coastal erosion, alongshore sediment transport and wave patterns.

Source:http://homeklondike.site/2017/02/28/biomimicry-design-spiky-durian-roof-of-singaporean-theatre/

Figure 42. Eco-friendly building inspired by durian fruit and palm tree

The vast majority of development in China's new cities takes the form of residential housing to build high-density, economically viable housing and architecturally innovative. The building is located on the coastal city of Beihai, narrow oceanfront site. The scheme was producing an undulating building typology, and resulting in a form of a hill. The geometry of the architecture maximizes potential views for the residents, the continuous platform along the roof becomes the public spaces.

Source: http://www.itsliquid.com/mad-architects.html

Figure 43. Fake Hill designed by MAD architect (China)

Toyo Ito creates inspirations from rocks, caves and the transience of water for his design. The NTT theater has the cave-like form to create the continuous surface and acoustic optimization space. NTT has created for extraordinary and wonderful arts in a part of everyday life. It provides the richness and joyfulness of urban life through festivals and cultural events as a landmark of the city. The NTT is provide to the new vision of creating a theatre for the extraordinary and awesome arts, embrace the diversity of artistic programs, including music, dance, opera, drama, music theatre, and digital performing arts. He received the Gold Medal in UIA2017 congress.

Source: http://www.toyo-ito.co.jp/WWW/index/index_en.html

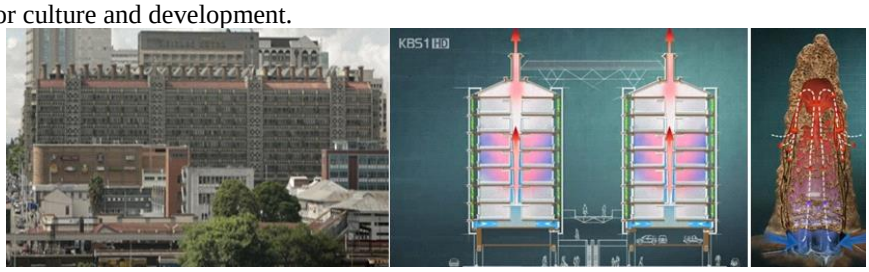
Figure 44. Nature-friendly buildings designed by Toyo Ito

German architect Wolf Hilbertz designed an artificial island. The building is a system that supplies the electricity by utilizing the sun and wind energy by minimizing the use of materials by the vortex form of the sea. London City hall was designed as a swirl system inside the hall. The elliptical design minimizes the energy loss by reducing 25% the surface area. The building inclined to the south with a 31 degree tilt wrapped in glass, minimizing the influx of sunlight in summer and maximizing the influx of sunlight in winter. City Hall planned to respond to the necessity for democracy by the public of its iconic building form. The building designed to set the standard for environmentally conscious system, City Hall was a passive design for sustainability.

Source: http://www.rexresearch.com/hilbertzbiorock/hilbertz.html

Figure 45. Eco-friendly building inspired by spiral

The Eastgate Center was designed by Mick Pearce. The building was the first project in the world to use a natural cooling system. Glass office blocks are needed heating in the winter and cooling in the summer. It is planned that no direct sunlight must fall on the external walls at all and the north façade, window-to-wall area must not exceed 25%. It is required a balance between artificial and external light to minimize energy consumption and heat gain. As the wind blows, hot air from the main chambers is drawn out of the structure, opening or blocking tunnels to control air flow. In 2003 Pearce was awarded the Prince Claus Award for culture and development.



Source: https://ehp.niehs.nih.gov/pdf-files/2013/Jan/ehp.121-a18_508.pdf

Figure 46. Eastgate Shopping Center

Situated in Hamburg, Bio-Intelligent Algae house is the first algae powered building in the world. Five-story passive house designed two differently façade types. The sides of the building that face the sun have a outer shell. Microalgae are produced energy to supply the building. The façade collects energy by absorbing the light that is not used by the algae and generates heat. The building was Prize winner in the competition 'Land of Ideas' in 2013.

Source: http://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world

Figure 47. Bio-intelligent Algae house

Recently, natural inspiration buildings are designed with dynamic and complicated structures unlike conventional box buildings. They are buildings that can produce electricity by using wind and sunlight and are capable of self-sufficiency. It is an eco-friendly building designed as energy zero building. Recent innovative designs are famous for Cobra Tower, Diamond Tower, DNA Tower, Crescent Tower and Oxygen eco-tower.

Source: https://www.google.co.kr/

Figure 47. Nature-inspired architecture for innovative building design

Korea has a very high population density. The 70 percent of the population lives near Seoul, the capital city of Korea. Most of the houses are box-shaped high-rise apartments. It maximizes economic efficiency by designing the most density in the site condition. The speed of building new buildings is very fast. Urban infrastructures are concentrated, traffic, education and cultural facilities are concentrated. Korea is very well known for its collective culture and intercultural culture. The level of school where your child is located is very important. The most expensive apartment is located in a good school where children can go. Because of the spring, summer, autumn and winter, the four seasons are clear, so I like the south direction. If possible, all rooms are designed to look south direction. Many high-rise apartments are concentrated, traffic is complex, but the infrastructure is convenient for peoples. Korean city includes the larger scale of groups of buildings, streets and public spaces, whole neighborhoods and districts, and entire cities with the goal of making functional, attractive, and sustainable environment. Recently urban design aimed to strategic, landscape, and sustainable urbanism. Urban design has been tried to the strands of place-making, environmental conditions, social equity and economic viability into the creation of places with distinct beauty and identity.

Source: https://www.lonelyplanet.com/south-korea/seoul/

Figure 49. Seoul city view coexit with high-rise building, traditional houses and urban regeneration

Recently urban regeneration is one of the important parts of urban design. Urban regeneration is largely divided into urban environment, traffic, social culture, economy, resources and energy efficiency. Urban regeneration projects should not only improve the physical environment of the city, but also the architectural and cultural factors of the city in order to ensure the vitality and sustainability of the city as a whole. It is try to introduce the concept of natural inspiration design from the elements of sustainable urban regeneration to eco-friendly design, urban landscape design, historical and cultural city design, active use of natural energy, and long life design. Natural inspiration design can be applied to sustainable eco-friendly architectural design by mimicking design or technology for form or mechanism optimized for natural changes and environmental conditions for hundreds of millions of years. Research on nature-inspired design can find solutions to the problems that cannot be solved today, and it can be widely applied in high technology field.

5. CONCLUSION

When designing for the new cities, it is important to find how to satisfy our yearning for harmonious interactions with nature. The nature inspirations can be new strategies for achieving new technologies for solving human problems. The environmental pollution is threatening the survival of mankind. Nature inspired models are a field of science that studies nature elements and then imitates or takes inspirations for innovative things. Nature can be an ecological standard to judge the rightness of human life. During 3.8 billion years of changes and evolutions of nature, nature has learned what is optimal and appropriate. The organisms of nature are the results that changed a sustainable equilibrium conditions in their environments in the Earth. The concept of visual inspiration is used to share the visual appearance of nature. Many designs mimicking the shape of nature are playing a role of landmark. Conceptual inspirations are the application of the knowledge found in rules and principles. Computation inspirations are searching to find algorithms like evolutionary technologies.

6. ACKNOWLWDGEMENTS

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