http://dx.doi.org/10.21172/ijiet.94.21

The Design Characteristics of Innovative Nature-inspired Architecture

Shangwha Shin[1], Kanggeun Park[2]
[1]*Department of Urban Planning and Real Estate, International University of Korea, Jinju, South Korea*
[2]*Department of Architectural Engineering, I'ST Institute, Seoul, South Korea*

Abstract- The systems, processes, mechanisms and organisms optimized for the evolution of nature over several hundred million years have helped designers and architects seeking innovative solutions of building design. Inspired by the shape and function of nature, some architects have created great architectures by applying new design sources from nature's elements. The beautiful and mysterious nature landscape surrounding us not only gives us a new appearance for the four seasons, but also provides the source of new ideas for building design. When looking at nature elements such as trees, flowers, animals, and ocean organisms, architects can find unusual perspectives, visually interesting ideas, special structures, creative details and innovative mechanisms. Most modern cities are full of buildings like the shape of supermarkets and boxes, if possible, architects should try to satisfy human emotions with beautiful scenery and natural closeness through eco-friendly environmental architecture. When planning for future cities and constructing new buildings, architects try to consider how to satisfy our yearning for a harmonious interaction with nature and how the historic characteristics of buildings are shown to be presence. All of these are related to our fundamental human feelings and emotions to improve holistic interrelationships between buildings and nature for human life. Nature-inspired biomimicry is a way of observing the natural world to find the design and technical solutions that may enable us to create the concepts of new building design with sustainable and healthy. This study is to analyse what is a nature inspiration for the visual and conception building design and what is the characteristic of innovative design and technology inspired by nature.

Keywords – New design sources, Creative details and innovative mechanisms, Nature-inspired biomimicry, Nature-inspired architecture

I. INTRODUCTION

The Earth is a little over 4.5 billion years old, its oldest materials being 4.3 billion-year-old zircon crystals. The history of life on Earth began about 3.8 billion years ago, initially with single-celled prokaryotic cells, such as bacteria. During 3.8 billion years of changes and evolutions of nature, nature has learned what is optimal, what is appropriate and what is last. It can be find new ideas inspired by nature such as trees, green landscapes, flowers and other foliage. A broader view of the nature world may be recognized an alternate reality and natural elements can really get the creative design from nature. The nature-inspired progresses can be classified into three levels of inspiration that are named as visual, conception and computational level by Janine M. Benyus, American nature science writer, innovation consultant and author. A visual inspiration is well understood the shape of various organisms, and to imitate similarly looking structures and systems. A conception inspiration occurs when scientists applied principles found in nature, and a computational level is inspired by mechanisms occurring in nature. The classifications are to be one of ways to create the design of nature-inspired architecture [1].

The research is necessary for architects to get the new design sources from nature for visual and conceptual design. This study focused on new design buildings inspired by nature, and it will be explained the design strategy of some famous buildings, structural concepts and technical procedures to create a nature inspiration design. The design characteristics of bio-eco architectures which replicate organisms and mechanisms of nature in order to create an innovative design will be surveyed, and then it will be shown how to seek design processes of nature inspired architecture, and how to get new design sources in nature.

II. NATURE-INSPIRED BIOPHILIC DESIGN

2.1 Progresses for nature –inspired design

Looking at the world we live in, a design requires for seeing and feeling nature by a new and different perspective. Depot Staff proposed technical procedures to create new designs inspired by nature. (1)Taking a closer look in nature, the nature scene offers new design details of trees, leaves, raindrops, wind waves and color harmoniousness. (2)New ideas can be obtained by shapes, textures and colours from the source for trees, green landscapes, flowers and other foliage. (3)When looking nature of unusual perspectives, we can find visually interesting results. (4)Thinking of nature in motion can make surprisingly more interesting results adding motion elements. (5)Nature elements such as animals, plants or landscape should be tried to combine them into an integration design. (6)Focusing on shapes and forms in nature to help rethink, designers can find interesting design details adding

creative images to clouds, fog, sunset glow, birds and other nature elements. (7)Thinking how to want feeling falls back on moods that evoke carefree and happy emotions such as four seasons featured from a clear day to a cold night in winter. Each image sets a different mood.
(8)An abstract of photographs help to gather a variety of things to merge them into one composite landscape.
(9)Researching the scenery of new imagination can be an entertaining process that leads to inspiration. (10)Try zooming out nature from a distance can get a fresh perspective. A broader view of the nature world may be recognized what you need for inspiration. (11)Thinking of the future for an alternate reality and natural elements can really get the creative design from nature [2].

2.2. Nature –inspired bio-philic design

The historic structures and beautiful places suggest the best example of biophilic design in a good site. The connections with nature are vital to maintaining a healthful and vibrant existence as an urban species Nature-inspired biophilic design can reduce stress, enhance creativity and clarity of thought, improve our-being and expedite healing. Biophilia is human's innate biological connection with nature, and may also help explain why nature-inspired buildings are preferred over others. These researches in nature support positive impacts pf biophilic design on health and the empirical evidence for human-nature connection. Space patterns have visual connection with nature, rhythmic sensory stimuli, air flow variability, dynamic and diffuse light, connections with nature elements. Western attitudes toward nature were shifting in the mid-19th Century, natural landscapes became valid art subjects.

Figure 1. Korean biophilic design

Figure 2. Examples of biophilic design

2.3. Nature and Culture

Human has developed civilization and culture through the imitation of nature. Artists have been transformed from an imitation of nature to an abstract of the unknown world. Culture in Korea and China has been closely tied to landscape painting and poetry. Landscape painting and poetry is imaginary landscapes, they remain popular to the present. By pursuing the intrinsic of nature, it has sublimated into the art of restoring humanity and finding the essence of art. Man finds the beauty and mystery of nature in touching and looking at nature. Oriental thought considered living in harmony with nature as a virtue. In Korea, the longing of nature can find in landscape paintings of four gentleman plants for plum, orchid, chrysanthemum and bamboo.Plum is the first flower blooming in early spring after cold winter. Orchids look colorful and fragrant. So many people grow it at home. Chrysanthemum is the flower which overcame the cold in late autumn. Bamboo keeps four season blue color, grows straight and does not bend. Bamboo that does not lose its blue color even in snowy winter looks like a nice person. The love of these four wonderful plants is not limited to poetry but is painted and loved by many peoples until now.

Figure 3. Four gentleman plants for plum, orchid, chrysanthemum and bamboo (1700-1800)

Figure 4. Korean landscape paints

The layout of houses in Korea is based on oriental landscape geography. 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. The basic elements of oriental geography are mountain and water. The land plan was analyzed the landscape of the surrounding mountains, the flow of water, and the shape of the land. Many people thought that the situation around the land had an effect on the personality, health, and success of the people living there. Successful peoples have lived in the site of the best possible environment, in order to be successful, peoples thought to live in a good natural environment and make an ancestral tomb where they have the best site conditions. As time went on, many peoples thought that the energy of the surrounding mountains and ground would greatly affect the happiness and success of the local peoples. A good site was surrounded by mountains in the back of the house, and in front of the house there was a wide land with rivers flowing. This theory is closely related to the monsoon climate conditions of the four seasons in Korea. People thought the best place for a woman's womb-like land. Korean traditional houses had a rank according to the status of society in the form of roof. The spaces between women and men were separated. The spaces of father, mother, child and guest were separated. The roof shapes of traditional Korean houses are very similar to the peaks of surrounding mountain.

Figure 5. Landscape map of Seoul in Korea (1750)

Figure 6. Korean traditional village

Figure 7. Korean traditional houses

III. NATURE-FRIENDLY GREEN BUILDING DESIGN CERTIFICATION CRITERIA

The building has widely direct and indirect relationships with the surrounding environment. During construction, occupancy, remodel, repurposing and demolition, buildings use energy, water and raw materials, generate waste, and release harmful air emissions. This fact has created a green building standard, certification and evaluation system to mitigate the impact of buildings on the natural environment through sustainable design. When construct buildings, 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: accessibility, aesthetic effects, and cost efficiency, functionality, productivity and health, history, safety, security and

sustainability [4]. Architects are striving to satisfy architectural compliance, structural safety design, environmentally friendly design, long life design and intelligent design when designing buildings. However, many buildings in the city are very vulnerable to earthquakes, typhoons, heavy snow, and fire, causing many problems. The life of buildings is only about 40-50 years, the half of human life, causing serious environmental pollution, urban slums and economic losses. Current design standards are too numerous, complex, and less interdependent. If the design criteria do not set the lowest score for each item, it cannot satisfy the desired eco-friendly long-lived intelligent building.

(a)Green building design (b)Performance building design (c)Green home design Figure 8. Green Building Design and High Performance Building Design (LEED)

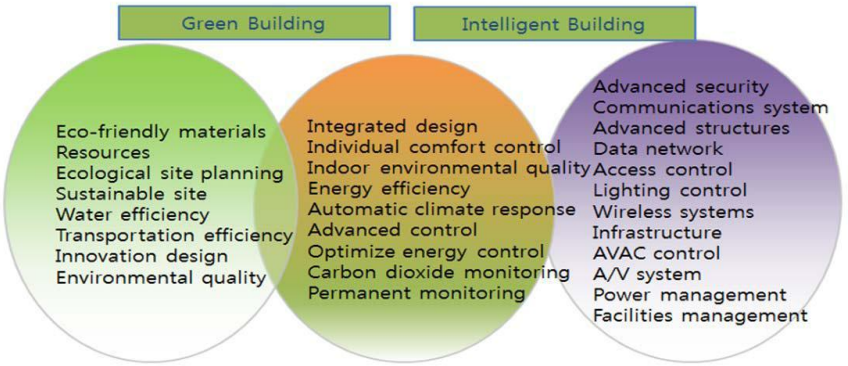


Figure 9. Comparison of green building design and intelligent building design (LEED)

Figure 10. Disasters by huge earthquake

Figure 11. Disaster by typhoon, heavy snow and fire

IV. INNOVATIVE NATURE-INSPIRED ARCHITECTURE

4.1. Flower-inspired architecture

Lotus flowers are known to be associated with purity, spiritual awakening, and sincerity. Blue lotus flowers are associated with winning souls rather than with wisdom, intelligence and knowledge. White lotus flowers represent

mental cleanliness and spiritual perfection. Red lotus flowers are associated with compassion and passion for all Buddhist saints. Lotus leaves and flowers have wax-soluble solids on the 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 of the Wujin district, which resembles the pink lotus flower. 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 area surrounding the pond has been converted into a public park. The design is a striking design inspired by the blooming lotus flowers. The building is surrounded by steel petal ribs that remind you of the third stage of a lotus flower and uses a nearby lake to regulate the temperature of the building with minimal energy [21].


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

Figure 12. Wujin Lotus Conference Center in China

The Qizhong Forest Sports City Arena has eight sliding feather-shaped iron roofs that resemble the white burnished magnolias of Shanghai, China. It has a steel foldable roof which is switched by the control of the indoor environment. The opening of the roof signifies the bloom 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 flower that closes and opens its roof. Each of the eight movable roof petals moves and rotates at the same time over one fulcrum and three rails [21].


Source: https://www.slideshare.net/AsthaAgarwal5/kinectic-building-70576613

Figure 13. Qizhong Forest Sports City Arena

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 [21].


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

Figure 14. Baha'I house of worship

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. The artwork grows and evolves constantly as different images are added. The objects move at different speeds and in different directions, as the audiences touch them, bringing the town to life [21].

Figure 15. Art Science Museum in Singapore Figure

Figure 16. London city plan inspired by lotus flower

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 [21].

4.2. Curved structures inspired by seashell

In Valencia, Spain, the marine city around the sea has been beautifully made using a concrete shell structure with 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 [21].

Figure 17. Concrete shell structures

The perfect surface can find a soap film in which the surface tensions are the same in all directions. This forms a minimal surface and is a good starting point for finding a surface tensioned structure. Frei Otto was used to stretch fabric models for a form finding modelling. The inverse hanging chain models is the form by the self-weight loads would produce only compression forces. Recently, instead of a roof system using concrete, steel pipes and cables has been developed. The weight of the roof reduced dramatically [21].

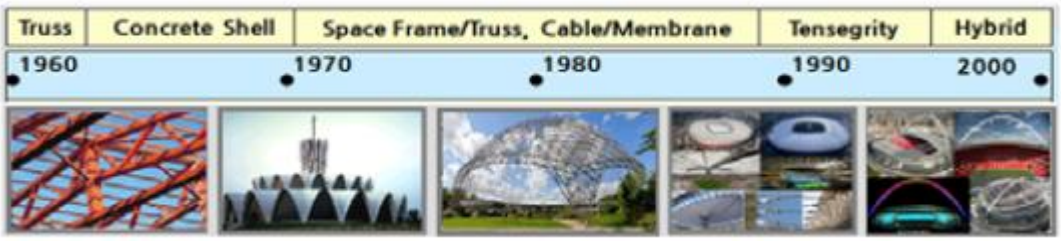


Figure 18. Development of shell and spatial structures

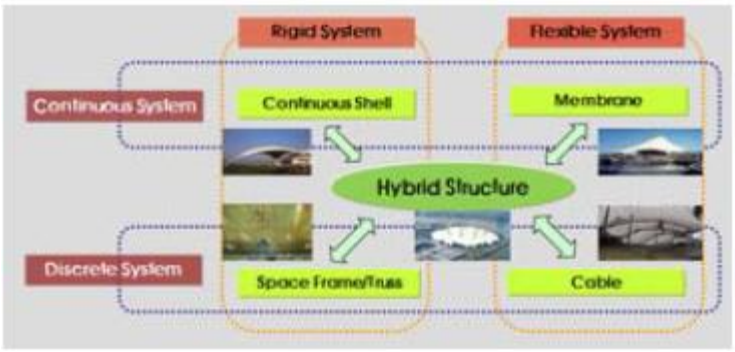


Figure 19. Continuum system and discrete system

Most of structures have nonlinear behavior beyond a particular level of loading. Nonlinear analysis can be classified as geometric nonlinearities, material nonlinearities, combined nonlinearities and boundary nonlinearities. In geometric nonlinearities the changed shape cannot be neglected and its deformed configuration should be considered. Material nonlinearities behave nonlinearly and linear Hooke's law cannot be used. The more complicated material should be used nonlinear elastic model for material like rubber and elastoplastic model for Huber-von Mises for metals and Drucker-Prager model to simulate the behavior of granular soil material. The nonlinear behavior of a structure can be caused by a single structure element or a nonlinear force-deformation relation in whole structures. If the response plot is nonlinear, the structural behavior is nonlinear. The response combines linear, hardening and softening. The linear response until fracture is characteristic of pure crystal, glassy and high strength material. The response with geometric nonlinear stiffening and hardening is typical behavior of cable, cable net, pneumatic structures and inflatable structures which may be called tensile structures. These tensile structures come from geometry adaptation to the applied load. The response with softening is followed by a softening regime that may occur suddenly yield, slip or gradually. The combination response is snap-through response, snap-back response, bifurcation of buckling and bifurcation combined with limit points and snap -back. The snap-through response combines softening with hardening follows the second limit point, the response has a negative stiffness and is therefore unstable. The snap-through response is typical of slightly curved structures such as shallow arch and shells. The snap-back response is an exaggerated snap-through, in which the curve turns back with consequence appearance of turning points. The snap-back curve is exhibited by trussed dome, folded structures and thin shell structures in which moving arch effects occur following the first limit point. Bifurcation point may occur in thin structures that experiences compressive stresses. The response with bifurcation, limit and turning points may occur in many combinations, an example can find thin cylindrical shells under axial compression. The geometric nonlinearity can be accounted for the analysis by updating the global stiffness matrix and the global geometric stiffness matrix on every step based on the deformation position. The equilibrium equations must be written with respect to the deformation geometry. To describe large displacements and large rotations, it is necessary to calculate the equilibrium with respect to the deformed configuration. In incremental method for nonlinear analysis the load vector is divided into n equal increments. A load increment is applied to the structures in the state of equilibrium for the previous increment is achieved. The norm of unbalanced forces are specified for each step, allowing for searching the structure-deformation relationship. The load increment is used when dividing a load into smaller segments. The number of load increments influences the number of calculation iterations. The greater the number of increments, the greater the probability for the calculations to reach the point of converge. The displacement increments and unbalance force are sufficiently small in comparison with the tolerance, the iteration process stops if divergence occurs. The number of load increments can be increased, which usually helps the process

to converge. The process for increment method are the initial stress method, the arch length method, the modified Newton-Rapson method, the full Newton-Rapson method and Crisfield method [7].

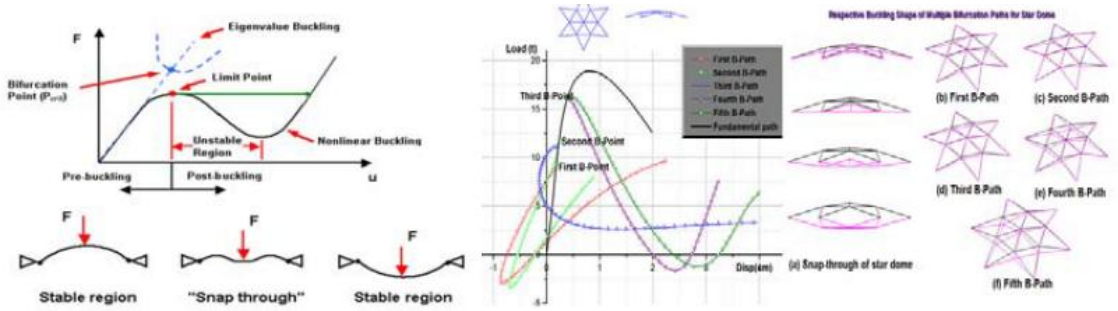


Figure 20. Pre-buckling and post-buckling of a star dome

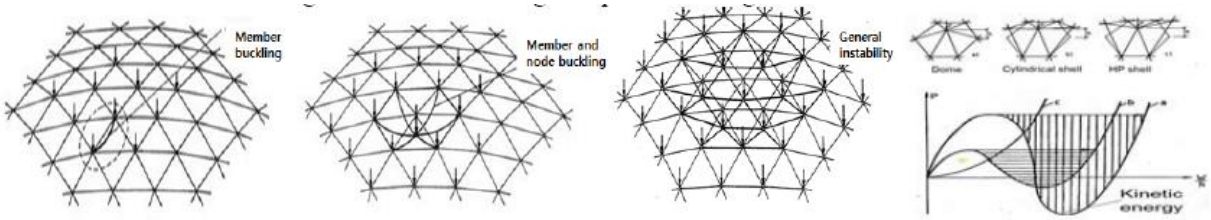


Figure 21. Buckling of lattice dome

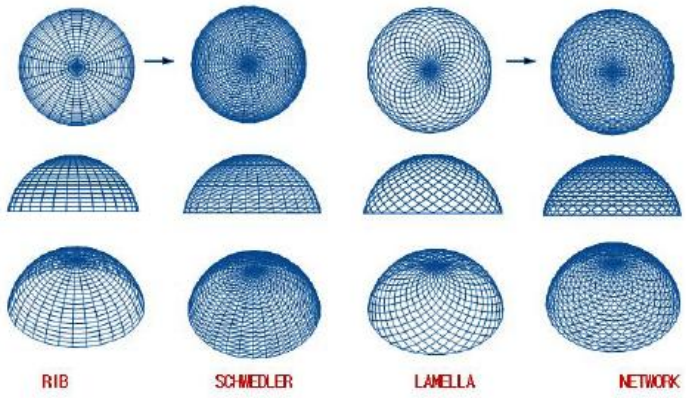


Figure 22. Composition of space truss

A static analysis under self-weight load with thickness of 0.3m has been carried out. Grade 30 concrete has been adopted as the material. The corresponding material properties used are as follows: Young's modulus = 2.5 x 1010 N/m^2, Poisson's ratio=0.20 and density = 2400 kg/m^3. All three shells were assumed to be hinged support. The study of egg shaped shell was supported by K.K. Choong, professor of Universiti Sains, Malaysia.

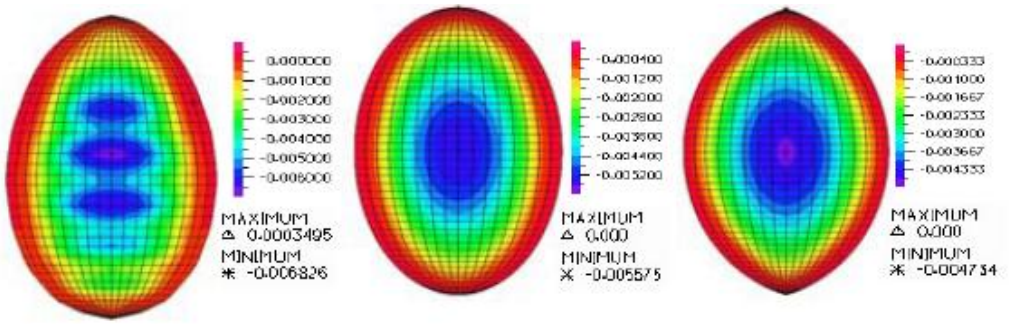


Fig. 23 Distribution of vertical displacement (m) for egg-shaped shell, elliptical shell and spherical shell

4.3. Cable structures inspired by spider web

Natural spider webs have an analogical structure to a radial cable net, even though spider nets have no any rigidity. Such tensile structures inspired by a spider web include inner hoop cables, upper ridge cables and bottom valley cables along radial direction, and bracing cables extending there between. These cable structures can be found sports arena such as tennis court roof, football stadium roof and retractable cable truss roof systems which have span 100-300m. A natural spider web is a kind of analogical prototype structure for a radial cable roof system. A nature inspired design of a cable system is not replicating the natural forms, but understanding the rules governing those forms. The design concept seeks to exploit new design concepts such as creative design and complex system in nature. The double arrangement of a spoke wheel system with reverse curvature works more effectively as a load resistance system, the pretension can easily increase the structural stiffness. The cable truss system can carry vertical load in up and downward direction, and act effectively as load bearing elements. The cable roof system with reverse curvature is a kind of very lightweight and little deformation systems that can resist vertical loads. The spoke wheel roof system is structurally more advantageous than the radial cable roof system because it has an X-shaped cable truss system, and the slope of the roof is easily controlled by the height of a center hub. The radial cable roof system is composed of the reverse direction of bearing cables and stabilized cables by roof posts, and the inclination of the roof is controlled by the height of roof post. The entire roof is lifted up by the tension of a lower ring cable connecting the roof posts to form a structural system. The radial cable roof system and the cable spoke wheel roof system are need to a compression member in a roof, but the curved cable network system does not need the compression members. The curved cable network roof system is composed of cables and membrane that only can transmit the tensile forces, the weight of roof can be dramatically reduced for long span roof. With the sets of cables having opposite curvature to each other, a curved cable network is able to carry vertical load in both upward and downward direction. As a result of the geometric nonlinear analysis for the whole roof, the tensile strength of the cable and the compressive force of the center post increased almost proportionally according to the nodal loads converted into the roof load. As the sag ratio by roof slope increased, the tensile strength of cables decreased and the compressive force of the roof post increased almost proportionally [10,11,12].

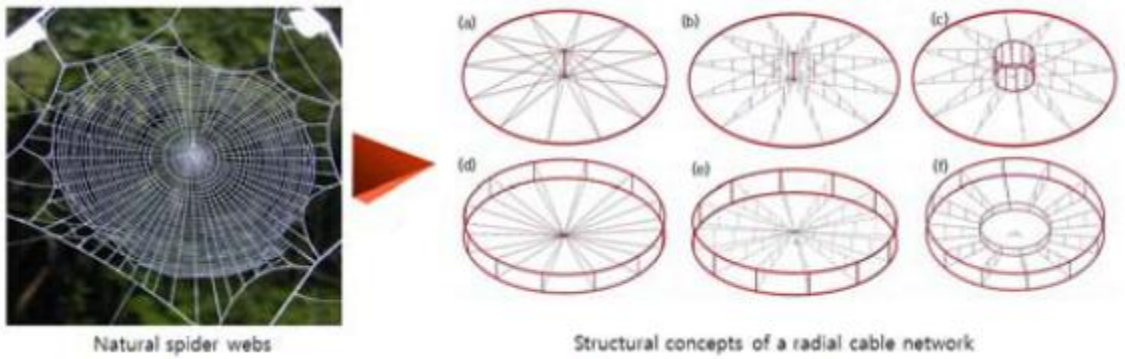


Figure 24. Cable structures inspired by spider web

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 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 [21].

Figure 25. Munich stadium complex (1972)

Seoul Olympic Gymnasium is the first tensergrity system. Tensegrity structures are based on the combination of loading members only in pure compression or pure tension, the cables yield or the rods buckle preload or tensional prestress. The cables are to be rigid in tension mechanical stability, which allows the members to remain in tension or compression as stress on the structure increases. The weight of a cable spoke wheel roof greatly can reduce, and this cable roof system can easily make the required rigidity by the sag ratio and pretension forces. It recognized that the roof fabric is weak to resist wind and snow load.

Figure 26. Seoul Olympic Gymnasium (1988)

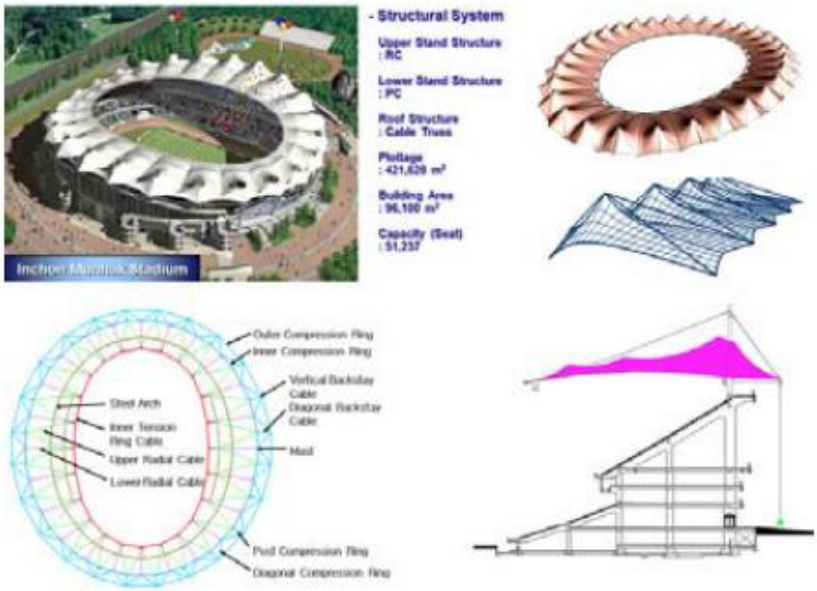


Figure 27. Incheon Worldcup stadium in Korea (2002)

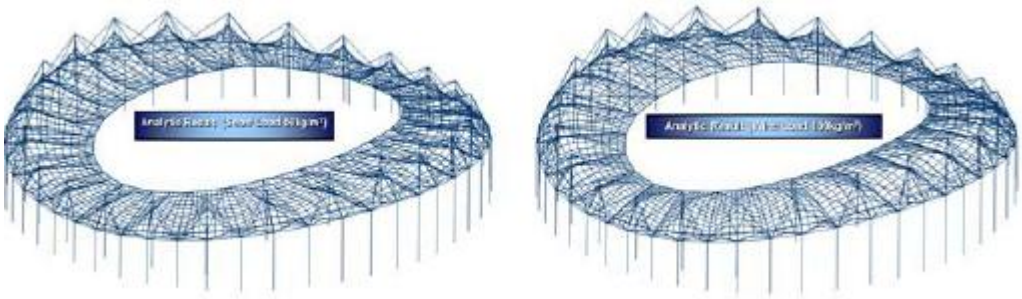


Figure 28. Results of nonlinear analysis for the Incheon stadium

Retractable roof systems are as simple as possible, easy to open and close the movable roof and easy to drive. The lightness level of the interior can be changed according to the opening condition of retractable roof, and the influence of the shadow should be considered for the spectator and the player. The opening and closing time of a roof is required to a comprehensive judgment on power consumption and safety issues, the time is a good for 10-20

minutes. The effects of wind load in open, closed, and half-open conditions are different. The tilt up by the difference of roof level and the local concentrated load can be occurred, and the rain does should not flow into the inside of the roof. Deformation or vibration by the wind may occur at the entire roof. The strong wind may cause the rising of the retractable roof and the detachment of the traveling pulley. Wind can cause the retractable panel to rise and the wheel can escape the rail. Cables can occur swinging, pulsation, the failure of end fixation, pretension loss by creep, loosening, and the like. The membrane can cause tearing and ponding by snow and raining water. The difference between the behavior of entire roof structure should be analyzed. Creep and eccentric load may occur during long- term snow load. The movement of bulk snow may occur to the impact load and eccentric load. The moving roof becomes difficult to drive due to snow. Ice becomes difficult to move the roof. A roof slope to flow snow should be designed. No local deformations should occur. The vibration characteristics between the entire roof and that of the panel are different. The pivot axis has a great influence on vibration. It is should be installed a seismometer to have an automatic stop function when an earthquake occurs. There is a possibility that vibration, swinging, collision or sagging by hanging vibration may occur. An earthquake may occur during running of the roof [10, 11, 12].

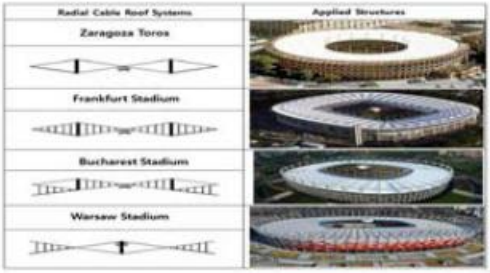


Figure 29. Retractable roof system

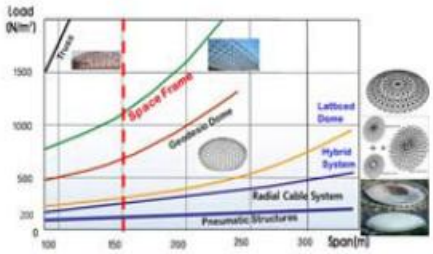


Figure 30. Comparative roof weight for structural systems

The objective of this study is to analysis the mechanical characteristics and nonlinear behaviors on the geometric nonlinear analysis of a cable spoke wheel roof system with span 200m for the retractable and lightweight roof. Determining the pretension and initial sag of cable roof system is essential in a design process, and the shape of roof is changed by pretension. The flexible cable system has greatly affected on the sag and pretension. This study is carried out comparing the tensile force and deflection of a cable spoke wheel system by the post height of center hub for the vertical load.

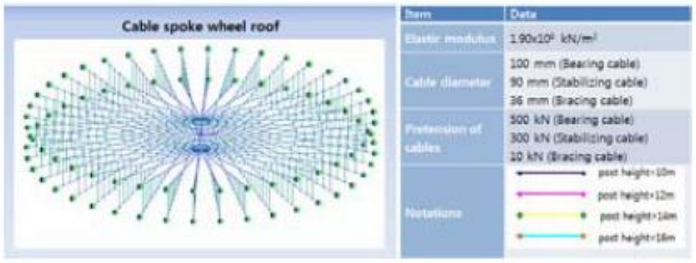


Figure 31. Total structural system of a cable spoke wheel roof

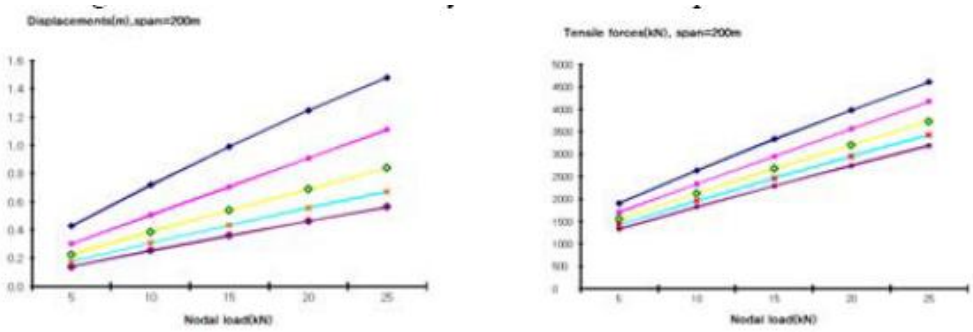


Figure 32. Dispacement and tensile forces of roof (nodal load = 25kN)

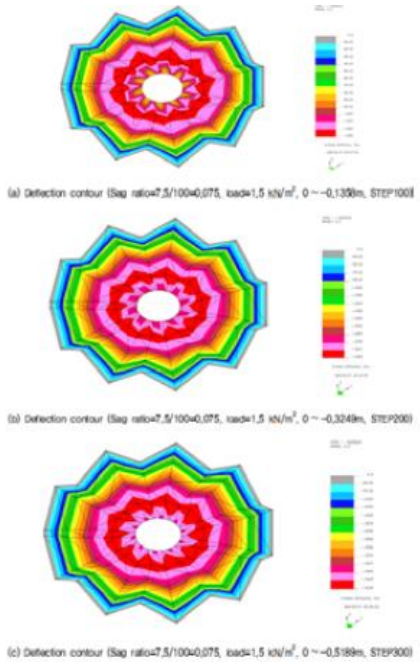


Figure 33. Deflection of a circular cable roof with fabric (radius=50m)

4.4. Bio-dome inspired by nature

ETFE (Ethylene Tetra Fluoro Ethylene) is fast becoming one of the most exciting materials in today's design industry. ETFE foil is a plastic polymer related to Teflon and is created by taking the polymer resin and extruding it into a thin film with high light transmission. ETFE is one of the most promising materials that can be used in building due to its high melting temperature, excellent radiation, electrical and chemical resistance properties. ETFE is a transparent material and has an approximate 90-98% light transmission. ETFE foil is an extremely durable material, the material has a life span in excess of 40 years. ETFE scores well on the eco-friendly elements. ETFE is 100% recyclable and requiring minimal energy for transportation and installation means that it makes a significant contribution towards green construction and sustainability. The ETFE panels can be supported by a cable-net to accommodate the larger spans, ETFE film prove the innovative design for new building [10, 11, 12].

Figure 34. Hexagonal network in nature

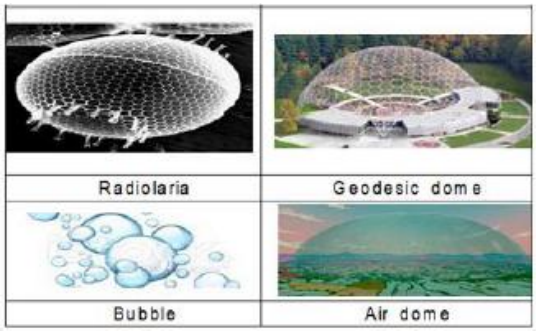


Figure 35. Bio-domes inspired by nature

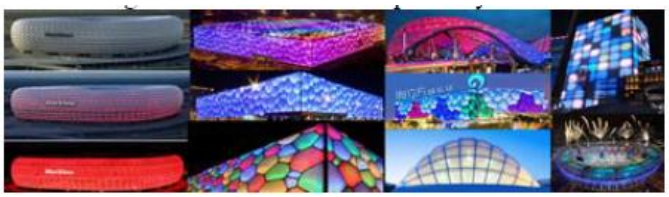


Figure 36. Innovative ETFE film structures (Makmax co.)

Figure 37. Innovative Eden dome

The Water Cube was more symbolic design for Chinese culture and the idea is symbolized water. It is the largest ETFE-cladding structures in the world that are 0.2 mm in thickness. The ETFE cladding allows more light and heat penetration than traditional glass. The design is inspired by the natural pattern of bubbles in soap lather and the cladding is made of 4,000 ETFE bubbles [21].

Fig. 38 Beijing national aquatics center

Figure 39. Light transmittance (%) and insulation properties of ETFE film (Makmax co.)

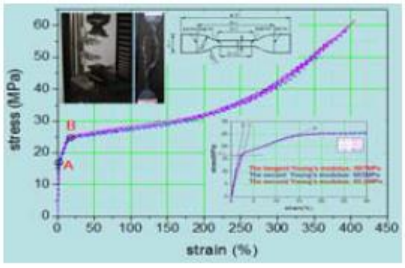


Figure 40. Stress strain relationships of ETFE film

4.5. Modern architecture inspired by nature

The 20 stories residence tower 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. The Infosys Building in Kuwait was also designed with the spirit of the shape of the cobra and the

DNA for the coexistence of nature and human beings, forming a twisted belt, energy production using solar energy to create sustainable residential environment [14, 15]

Figure 41. Eco-friendly building inspired by DNA

Source: http://vincent.callebaut.org/

Figure 42. Eco-friendly city plan of Vincent Callebaut Architecture

German architect Wolf Hilbertz designed an artificial island. It is a system that supplies the electricity by utilizing the sun and wind energy for minimizing the use of materials and introducing the natural form by designing the vortex form of the sea. London City hall was designed as a swirl system. The elliptical design minimizes the energy loss by reducing 25% the surface area of box-shaped buildings. In addition, 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 [16].

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

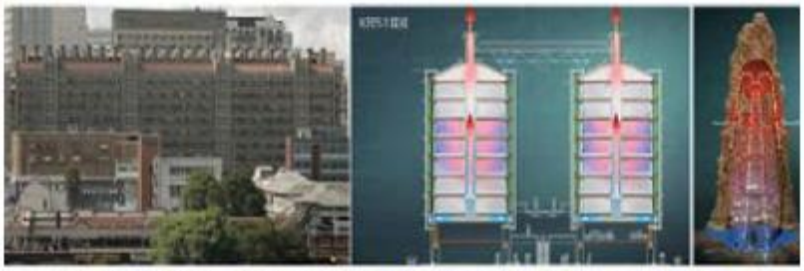
Figure 43. Eco-friendly building inspired by spiral

Beijing National Stadium was designed by Swiss architects Herzog & de Meuron Due. The innovative "Bird's Nest" has to hold the world in the building and capturing the attention of the international architecture community. The stadium is the landmark by the shape design of a giant bird's nest. The roof was covered to the transparent ETFE film which provides roofing by supporting the steel members [17].

Figure 44. Beijing National Stadium

The Eastgate Center is a shopping center and designed by Mick Pearce. Designed to be ventilated and cooled by entirely natural means, it was probably the first building in the world to use a natural cooling system. As the wind

blows, hot air from chambers is drawn out of the building, opening or blocking air tunnels to control air flow. In 2003 Pearce was awarded the Prince Claus Award. The building is the best eco-friendly design, and provides how to inspire by nature [18].



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

Figure 45. Eastgate Shopping Center

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 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 heat. The design was Prize winner in the competition "Land of Ideas" in 2013 [19].

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

Figure 46. Bio-Intelligent Algae house (Hamburg)

Toyo Ito designed from the inspiration of rocks, caves and the transience of water for his design. The theater takes the cave-like form and the shape was designed by acoustic optimization through space. NTT has created a theater for extraordinary and wonderful arts, and has made the recognition of art in a part of everyday life. It provides the richness and joyfulness of urban life through festivals, performances, and cultural events centering on the theater as a landmark of the city. Pritzker winner and UIA 2017 gold medalist, Toyo Ito, the NTT become the most awesome theater for artists and audience [20].

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

Figure 47. Nature-friendly building designed by Toyo Ito

V. DESIGN CHARACTERISTICS OF NATURE-INSPIRED ARCHITECTURE

The nature inspired designs and technologies are a way of observing the natural world to identify new ideas that may enable us to create mechanisms and processes that are sustainable for natural ecosystem. (1)The nature inspirations can be new strategies for achieving new technologies for solving human problems. (2)Nature inspired models are a field of science that studies nature's elements and then imitates or takes inspirations for innovative things. (3)Nature can be an ecological standard to judge the rightness of human life. (4)During 3.8 billion years of changes and evolutions of nature, nature has learned what is optimal and what is appropriate. (5)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. (6)Visual inspirations of buildings are used to create designs or engineering systems that share the visual appearance of nature.
(7)Conceptual inspirations are the use of the knowledge found in rules, principles, or patterns. (8) Computation inspirations such as algorithmic bio-mimicry are searching through nature to find algorithms like evolutionary technologies such as generative representations. (9) The nature-inspired biophilic design for architecture is the designing for people as indicators of health and wellbeing in health condition and socio-cultural interrelations. (10)Materials and design patterns with nature can be applied across all climates and environments, but may have different resulting forms, aesthetics specific to their respective regions. (11) Nature-inspired design for air quality, thermal comfort and acoustics is an essential source of environmental quality that expands the conditions from daylight, material toxicity, water and soil quality to improve human biological health and well-being. (12)From an architectural perspective, nature-inspired designs have the links between people, health, high-performance design and aesthetics. (13)Thoughtful applications of nature-inspired design can create a multi-platform strategy for challenges associated with building performance such as thermal comfort, acoustics, energy and water management. (14) It can be reduce particular matter in the air and urban heat island effect, improve air infiltration rates and perceived levels of noise pollution[8, 9, 13, 21].

Figure 48. Nature-inspired biomimicry design and technology

VI. CONCLUSION

The study was a part of wide area that determines how to get inspirations from nature and how to apply the visual or conceptual designs in architectural design. And it showed that nature can be dominant sources of inspiration for understanding the nature processes. Nature-inspired design seeks to exploit the new concepts of biological design such as bio-eco -friendly sustainable processes, creative designs and complex systems. Inspirations through the forms and bio-system of nature are classified with visual, conceptual and computational inspiration. In the nature-inspired progresses and green design concepts, architects will be able to design not only sustainable, bio-eco-friendly and null-emission buildings, but also integrate into the building designs by the visual, conceptual or computational inspiration of nature.

VII. ACKNOWLEDGEMENTS

This research was supported by a grant (17AUDP-B100343-03) from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

VIII. REFERENCES

[1] Janine M. Benyus(1997), Biomimicry : Innovation Inspired by Nature , ISBN0-06-053322-6
[2] https://www.webdesignerdepot.com/2009/08/17-techniques-for-creating-designs-inspired-by-nature/
[3] https://ko.wikipedia.org/wiki/%EC%83%9D%EC%B2%B4%EB%AA%A8%EB%B0%A9
[4] https://new.usgbc.org/leed
[5] https://www.curbed.com/2014/3/7/10135008/chinas-latest-bizarre-building-is-a-giant-ethereal-lotus-flower
[6] https://en.wikipedia.org/wiki/Qizhong_Forest_Sports_City_Arena
[7] NISA manual(2016), Crane software
[8] Park, K., Lee, S. and Lee, D. (2015), A Study on the Structural System of Flexible Large Span Spatial Roofs Using Steel Cables, Journal of The Residential Environment Institute of Korea, Vol.13(No.4), pp.393-404
[9] Park, K. and Lee, D. (2016), A Study on the Nature Inspiration Design of Eco-friendly Spatial Buildings, Journal of The Residential Environment Institute of Korea, Vol.13(No.5), pp.1-29
[10] Park, K. and Lee, D. (2016), Mechanical Characteristics of Cable Truss Roof Systems, Journal of Korean Association for Spatial Structures, Vol.16(No.2), pp.89-96
[11] Park, K. and Lee D. (2016), Mechanical Behavior of Cable Net Structures Considering Sag Ratio, Journal of Korean Association for Spatial Structures, Vol.16(No.3), pp.47-58
[12] Park, K., Lee, D. and Kwun, T. (2016), Mechanical Characteristics of Large Span Spoke Wheel System, International Association for Spatial Structures (IASS), N. 1341
[13] Park, K., Lee, D. and Lee, S. (2016), A Nature Inspired Design Philosophy of Spatial Structures, International Association for Spatial Structures (IASS), N. 1342
[14] http://beautiful-amazing-nature.blogspot.kr/2013/05/awesome-infosys-building-kuwait.html
[15] http://vincent.callebaut.org/
[16] http://www.rexresearch.com/hilbertzbiorock/hilbertz.html
[17] https://www.thebalance.com/beijing-s-bird-s-nest-stadium-2340205
[18] http://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world
[19] http://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world
[20] https://archinect.com/toyo_ito
[21] Park, K. and Kim, J.(2018), Design Characteristics of Nature-inspired Architecture, ISBN 976-613-5-95851-5