New Trends in High-Performance Architecture: Shifting To Bio-Inspired Innovative Green Technologies In Future Architecture

Shirin Sotodeh, Mohammadjavad Mahdavinejad, Parisa Baharloo

Abstract*: This paper aims to explain recent trends in adoption of bio-inspired innovative green technologies in architectural theory and practice. Literature review of the paper shows that "bio-inspired" concept might be seen as major generator for materializing future architecture, which constantly referred as "high-performance architecture". The most important questions of the research are: 1- What are the most influential trends in architectural design practice regarding to learning from nature in architectural design process? 2- How future architecture could be described in relation to adoption of bio-inspired innovative green technologies in order to meet highperformance architecture? A hundred case studies selected by purpose from among Pritzker Prize winners in recent 40 years in order to build chronological pathway. The results of the research indicate that new trends in architectural theory and practice might be underscored by their attitudes toward "nature". In other words, the characteristics of future architecture might be understood via "shifting to bio-inspired architecture" as well as adoption of innova-tive green technologies. The most leading characters to describe future architectural trends might be summarized as followings: biophilic character, water-sensitivity, adoption of new architectural technologies, innovative green technologies, performance-based design, live and porous, energy-efficiency and daylightophil architecture.

***Key words*: Bio-inspired concept, Future architecture, High-performance architecture, Innovative green technologies, New trends in architectural technology.**

I. INTRODUCTION

It is more than important to understand future of architecture in order to plan and prepare more accurately for upcoming necessities. This paper is to address new trends in contemporary architecture namely high-performance architecture, It is contemporary architecture that demonstrates the most significant trend in science and technology more accurate than its rivals because an architectural building should materialize theoretical issues as well as performance boundaries. The paper by means of theory and practice is going to address shifting to bio-inspired innovative green technologies in future architecture. Since Human has been relied upon nature for all his/her needs, consequently there had been a profound association between human and nature. (Hadianpour et al., 2018) .at the point when industry has spread its impact on human life essentially after modern revolution, this association has been debilitated. Human was prompting rely upon manufactured industry in modernized urban areas rather than genuine nature (Saadatjoo et al., 2018) subsequently he had been gradually estranged from nature. This alienation was felt so threatening by scholars of different fields such as psychology, philosophy, environmental sciences, literature etc., that they have begun an endeavor to restore human's association with nature (Moghadam: 2015). During the last century, explores has been progressively drawn (Heidari et al., 2018) toward comprehension the human– nature relationship (Guiney, 2009)and has uncovered the numerous ways people are connected with the indigenous habitat (Davis, 2009).

Some examples of these include humans' preference for scenes dominated by natural elements (Kaplan, 1989), the sustainability of natural resources (Foster,2012), and the health benefits associated with engaging with nature (Ryan CO,2014). Of these instances, the effects of the human nature relationship on individuals' wellbeing have developed with interest as evidence for a connection accumulates in research literature (Thompson Coon,2011). Such connection has underpinned a host of theoretical and empirical research in fields, which until now have largely remained as separate entities.

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II. LEARNING FROM NATURE

Human being has a lot to do with nature. Nature is a precious for-tune that must be found and comprehended for prosperous future. (Pourjafar et al., 2014) As "Alfred Billings Street" mentioned: "Nature is man's teacher. (Mahdavinejad et al., 2014) She unfolds her treasures to his search, unseals his eye, illumes his mind, and purifies his heart; (Aliabadi et al., 2018) an influence breathes from all the sights and sounds of her existence." or as Micah Hobbes Frazier said: "If we are in rhythm with nature, we are in rhythm with ourselves." (Fallahtafti & Mahdavinejad, 2015) In addition, if we pay close attention, we can experience the wonder that emerges from the beauty, magic, miracles and patterns all around us. (Hadianpour et al., 2019) From the beginning of creation, human being was surrounded by nature. (Amini et al., 2014) Everything in nature is efficient and in concordance with alternate pieces of it (Kshirsagar,2017). The world of natural phenomena draws our consideration as a source and motivation (Mahdavinejad & Javan-roodi,2014) Although learning from nature is not a new concept

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(Mohtashami et al., 2016) with the improvement of innovative technological advancement, it is a re-re-developing methodology inside a wide scope of orders. (Nikoudel et al., 2018) The concept of bio-mimicry, considered as the science and philosophy of learning from nature (Benyusis, 2002). The consideration that nature offers qualities that feed human development is not new (Cobb,1977). Yet, there is a developing acknowledgment of nature's characteristic esteem and its special contribution within childhood (Gullestad, 1997; Kahn & Kellert, 2002; Louv, 2005; Warden, 2010)

III. THEORETICAL FRAMEWORK

The most important lessons which can be learnt from nature in architectural design process might be summarized as followings:

A. Biomimetics

Biomimetics or biomimicry is the imitation of the models, systems, and elements of nature for the intention of solving complicated human difficulties (Vincent:2006). Biomimetics is the field of scientific effort, which attempts to design systems and synthesise materials through biomimicry. (Mahdavinejad et al, 2018) Biomeaning life and mimesis meaning imitation are tak-en from Greek (Pramachandra: 2003). Biomedical engineers consider biomimetics as a methods for directing engineering and trace the origins of biomimetics to primeval times when Mayan, Roman and Chinese civilizations had learnt to use den-tal implants made of natural materials. Material scientists view biomimetics as a tool for learning to synthesis materials under environmental conditions and with least contamination for it (Shilov 1996).in the late 1990s and now Biomimetics become a mainstream area of science, since the quantity of studies and licenses which are newly labelled as 'biomimetic' is expanding (Bonser:2007). Biomimetic architecture is a current and contemporary philosophy of architecture that searchs solutions for sustainability in environment and nature (Eskandari et al., 2018) not by reproducing the common forms, however by understanding the tenets overseeing those structure (Janine, 2002). Biomimicry can work on three dimensions: the organism, its behaviors, and the ecosystem. (Mahdavinejad & Javanroodi, 2016) on the organism dimension mimic a organism with specific Mechanism also this level alone without mimicking how the organism participates in a larger context may not be enough to produce a building that integrates well with its environment because an organism always responds to a larger context (El Ahmar, 2011). Buildings On a behavior dimension mimic how an organism carries on or relates to its larger context. (Javanroodi et al., 2018) A building mimics process and cycle of the greater environment. Nature On the dimension of the ecosystem (Kasraei et al., 2016) The Qatar Cacti Building (Fig 2) that its shape and performance Imitates the cactus plant,this tower based aesthetics Architects for the Minister of Municipal Affairs and Agriculture is a projected building that uses the cactus's relationship to its environment as a model for working in the desert. The functional procedures quietly at work are inspired by the manner in which desert plants (cactus plant) support themselves in a dry, hot

Fig 1: Qatar Sprouts a Towering Cactus Skyscraper(https://newatlas.com/qatars-giant-cactus-biomimicry/10993/:2019)

atmosphere. windows open and close in react to heat, just as the cactus undergoes transpiration at night rather than during the day to hold and save water , the form of canopy and window frames shade on building.

B. Primitive generator

Primitive generator happens when an engineer utilizes traits found in nature in their product and structure, for example, the biological principle of homeostasis. This principle states that any living organ-ism reacts correspondingly to recover its vital functions when at-tacked by an external agent. A designer can apply this principle, for example, to determine the optimal shape of shell roofs subjected to thermal and mechanical loads (Samadzadehyazdi et al., 2018) .Un-fortunately, using conceptual inspiration for Primitive generation of designing requires a solid understanding of Both nature and structural engineering and cannot be used in a mechanistic way by an automated designing system (Kshirsagar, 2017) .Primitive concept generation in industry and architecture may be inspired from the geometries form of nature or general patterns and processes we can find in nature, which can be inspirational for de-signer to produce better form and function.

Fig 2: Lotus Building ,China(https://architizer.com/projects/wujin-lotus-conference-centre/:2019)

C. Pattern generator

Fig3:Façade of Manuel Gea González Hospital in Mexico City. (http://www.prosolve370e.com/home:2019)

Biomorphic Forms & Patterns are symbolic references to contoured, patterned, textured or numerical arrangements that persist in nature (Blau, 2018). The goal of Biomorphic Patterns generation is to provide representative forms of components and elements that shape Indore spaces and build outdoor form. The visual perception of natural forms patterns and texture of the material the more connection of user to nature. There are two main intention to apply Biomorphic Forms & Patterns, 1-as cosmetic decorative component of a larger design, 2- as integral to the structural or functional de-sign. Both intention enhance the biophilic experience. Natural Analogues encompasses three patterns of biophilic design :(Terrapin,2012) .

• Biomorphic Forms & Patterns. Symbolic references to contoured, patterned, textured or numerical arrangements that persist in nature.

• Material Connection with Nature. Materials and elements from nature that, through minimal processing, reflect the local ecology or geology and create a distinct sense of place.

• Complexity & Order. Rich sensory information that adheres to a spatial hierarchy similar to those encountered in nature

D. Energy efficiency

Energy efficiency (EE) and renewable energy (RE) can advantage general wellbeing and the atmosphere climate by displacing carbon dioxide (CO2) from fossil fuel-fired emissions electrical generating units (EGUs). Benefits can vary substantially by EE/RE installation type and location, due to differing electricity generation or savings by location, characteristics of the electrical grid and displaced power plants, along with population patterns (Buonocore,2015). Moving towards energy sustainability will require changes in the manner in which energy is provided, also in the manner in which it is utilized, furthermore, diminishing the measure of energy required to supply different merchandise, administrations or services. Opportunities for improvement on the demand side of the energy equation are as rich and diverse as those on the supply side, and often offer significant economic benefits (Inter Academy Council ,2007) Renewable energy and energy efficiency are sometimes said to be the "twin pillars" of sustainable energy policy. Both resources must be developed in order to zero carbon dioxide emissions. Technologies boost sustainable and renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bioenergy, tidal power and also technologies designed to improve energy efficiency. For all of this in developed countries costs have declined and continues to fall.

Fig4:SolarLeaf. Algae bio-reactive façade (http://plezirmagazin.net/alge-kao-alternativa-fosilnim-gorivima/:2019)

E. Porous interaction with context

Building facades plays two main roles: **1**-as hindrances for separation of indoor and outdoor of buildings, **2**-as an elements that de-fines the image of buildings. Climate adaptive facade are not only just hindrances among inside and outside; but also , they work as building systems that provide convenient spaces by using the outer environment including natural lighting, shading, appropriate air turbulence and etc. Porous façades in hot climates decrease heat gain of sun radiation by using a folded surface for self-shading, and heat by convection lose by using small perforations inspired by the porosity of termite mound surface (Forooraghi:2015). Computational software plays key role in the development, analysis of porous facade design and optimization of its performance. The porous have capability of reducing cooling loads, good performance of daylight. In addition it gives a positive indication that double facades can be used in hot climates if well shaded and ventilated (el Ahmar:2015).totally porous faced is adaptable in different climate and in different countries we can choose different angles conditions to customizing interaction with context and have best performance it can help to improve indoor thermal comfort and acoustic insulation.

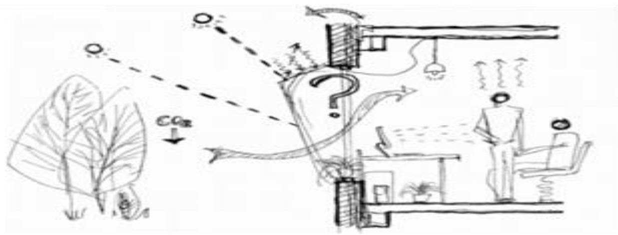

Fig5: The function of porous facades and how interact with context (Forooraghi,M:2015)

Fig6 : modular porous façade (Forooraghi,M:2015)

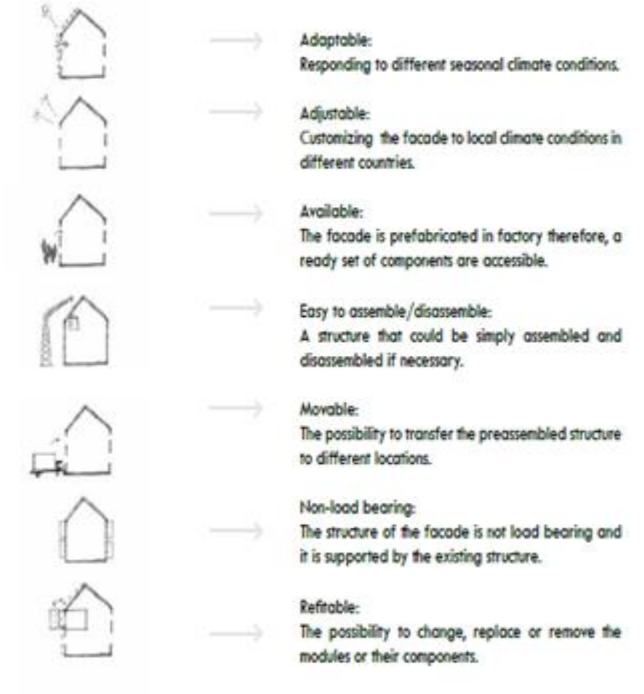

Fig7 : the privilege of modular porous facade (Forooraghi,M:2015)

F. Structural technology

Structural inspiration is the subject that relatively well comprehended and broadly used by engineers. In this case, structure of various living organisms, or their system, are used to produce similarly looking engineering systems. Structural inspiration can produce satisfactory result especially in architectural design from the aesthetic and stability points of architecture. For example, a sea turtle shell form (fig: 11) can be used to shape a reinforced concrete for a large span roof structure in an exhibition building(fig: 12). It requires designer who is aware of structural engineering and the theory of elastic shells, and who is able, most importantly, to avoid using inspiration in a wrong context (Kshirsagar,2017). Mostly, nature as structural inspiration plus mathematics move beyond the sketchy inspiration then after realize structurally rational designs can produce resistant structure for predicted loads. Mathematics offer rules, which guide architects and engineers for example the irregular non-Euclidean geometry of natural trees have been now possible to explain through mathematics by the concept of complex, non-linear and fractal geometries. 'Fractal', coined by Benoit Mandelbrot in the1970s, can theoretically define the geometry of many natural objects (Mandelbrot,1982). Form finding is very crucial part of structural designing; there are many structural systems that resist external flexural and transversal load because of their forms. Funicular structure and reciprocating structure are two of most evident models. A reciprocating structure is a system that overall span is longer than that of its individual pieces, in nature, a bird nest is a reciprocating structure; in construction, truss system is a reciprocating structure. The natural environment in fact inspires a number of structural systems that are considered great man-made achievements, such as Sydney Opera House (Ming hu ,2016).

Fig8,9: (a) Turtle shell in nature,(b) Exhibition hall inspired from turtle shell:(Kshirsagar,A:2017)

G. Performance-based design

Performance-based design is relying on comprehension that architectures or structures reveal their performativity capacity by being integrated in a mechanism, which could be a single building or a group of buildings (Hensel,2013). The connection between building's design-construction and external environment factors is set on a spatial organizational level, materials and patterns of individual elements. When we describe the performance of building's primary organization we should take into consideration material specific exterior-to-interior relations, as well as the order and hierarchy of form – to function extension, and all those above live within a dynamic environment. In reality, nowadays performances of the building have been divided into separate categories and measured by separate metrics: energy performance, material performance, structural performance, aesthetic performance and occupancy satisfaction are designed and measured individually (Ming hu ,2016). Buildings with successful use of bio inspired materials, products, design factors , construction and installation methods that have achieved a Performance Solution relative to specific topics such as energy efficiency, structure, health and amenity complies the Performance-based design Requirements.

Fig 10:john curtin school of medical research' by lyons architecture, the form of façade Controlling the amount of light inside building

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(http://yourenvironmentoftheweek.blogspot.com/2011/03/john-curtin-school-of-medical-research.html:2019)

H. Non-linear algorithmic thinking

Fig11: woven research pavilion 2013-14 (https://designbuild2015.wordpress.com/category/research/page/4/:2019)

Generative programming (GP) is a kind of computer programming, which provide prototypes, templates, aspects, and code generators to improve programmer productivity. In the field of architecture such editors are tightly integrated with modeling tools that require no knowledge of programming or scripting, but still allow designers to build form Generators from the simple to the awe-inspiring (Issa, R,2009). The idea of generative algorithms in architecture, is reminder of the conventional method of digital design. Digital modeling involves the definition of spatial elements (solid or plane/surface), their transformation and modification. Each change in the design leads to modifications in the geometry, making it extremely complicated to intervene on every single element, which is directly interdependent with the other elements. It is important with any such changes to adapt, scale and reorient each individual element, which is very time consuming (M. Stavric,2012). from the previous fifteen years digital media in engineering was utilized in various ways and affected the entire field of development and de-signs. Toward the starting digital media was connected just as a representational device.

With rising technology in architecture and innovation engineering has discovered another device for theoretical plan in advanced media (Schnabel,2007). on the one hand structural and architectural design was roused by the different potential of digital technology and innovation itself. on the other hand numerous themes from various fields impacted the structure and designs. Previous "invisible" mathematical and geometrical algorithms, forms and structures are now visible and spatial understandable for architects and, therefore, usable. Using new technique architectural design has established computational concepts such as: topological space (topological architectures), isomorphic surfaces (isomorphic architectures), motion kinematics and dynamics (animate architectures), key shape animation (metamorphic architectures), parametric design (parametric architectures), genetic algorithms (evolutionary architectures) or fractal geometry (fractal architecture) as discussed in Kolarevic (Kolarevic,2003).

Table I: Theoretical framework of interaction of nature and architecture (authors)

	Nature & Architecture	
	Nature	Architecture
1- Biomimetic	cactus	Qatar Sprouts a Towering Cactus Skyscraper
2- Primitive generator	Flower	The Lotus Building in Wujin, China (references the floral shape that it takes on)
3- Pattern generator	honeybee hive	geodesic dome
4- Energy efficiency	Solar energy	photovoltaic cell which converts the energy of light directly into electricity for buildings
5- Porous interaction with context	Birds' eggs shell	Porous modular Facade
6- Structural technology	tree	column
7- Performance-based design	Mechanical defence: Control the amount of sun's light and Heat in human body	Controlling the amount of light inside building
8- Non-linear algorithmic thinking	Lady fern	Muqarnass: stalactite vault

IV. CASE STUDIES

A. Case study selection

100 building sample selected by purpose from among Pritzker Prize winners in recent 40 years which are investigated(tables:2,3,4and5)

B. Sample study

Tjibaou Cultural Centre1998Nouméa, New Caledo-nia(Renzo piano)

Fig 12:Renzo Piano's Jean-Marie Tjibaou Cultural Centre, New

Caledonia (https://www.archdaily.com/600641/ad-classics-centre-culturel-jean-marie-tjibaou-renzo-piano:2019)

location of Tjibaou Cultural Center by Renzo Piano's is in New Caledonia, in the South Pacific ocean in island about 1600 km east of Australia. Kanak huts was the significant inspiration idea for pavilions. Piano Used vernacular materials assembled with modern era materials and technology, also he uses green building strategies to pavilions ventilation and integrate the center with natural environment. The location of the project site is on the bay side and ten wooden cases with their curved facades facing the prevalent winds from the ocean. Site climate is semi-tropical also can be called "oceanic tropical." The temperatures range is from65 degrees Fahrenheit to 93 degrees Fahrenheit (the minimum in winter to maximum in summer). To achieve maximum ventilation , thermal comfort and supplying fresh air in such a hot and humid climate, efficient passive cooling systems and shading devices can be used with a strong accentuation . Building is constructed on a top of the hill where is the most Air circulation to supply natural ventilation, by receiving prevailing wind of the south. There is no barrier to the wind because of fewer trees in this side of island. On the other hand, tall trees are planted along the east and west side as a method for "piping" the breeze and wind into the central part of the building. In addition of passive cooling system (natural Ventilation), in the warm and humid air evaporation mechanism of surrounding water on site is also cooling the buildings and its peripheral environment. During the day be-cause of temperature differences between land and water, cool sea breezes are provided and land breezes at night. Moreover, the building is raised above ocean level, and the incline on the south side, toward the prevailing wind, has a cooling impact on the breeze as it goes up the slant from water to land. Stack ventilation system and ventilation due to wind forces are two main approaches used to achieve natural ventilation in the design of the Cultural Center. There is an insignificant contrast between the indoor and open-air temperatures on the island; therefore, by increasing the vertical elongation of the building a desired ventilation rate can be achieved because of Temperature difference between inlet and outlet of the building. between two layers of wood laminate desirable air circulation exist which double-skin system brings breezes down into the building .convection currents up and out of the cases The external shell supports wanted convection currents through its orientation and spacing of the wooden cladding. The internal skin of the building is a series of horizontal louvers at the base and below the roof. Louvers underneath the rooftop are fixed open so as to keep up a pressure beyond any balance between the inside and outside, stopping wind from going up the roof. The lower

Fig13:site plan :the building is elevated above sea level, and the steep slope on the south side, in the direction of the prevailing wind(https://airfreshener.club/quotes/breezes-sea-diagram-and-land.html:2019)

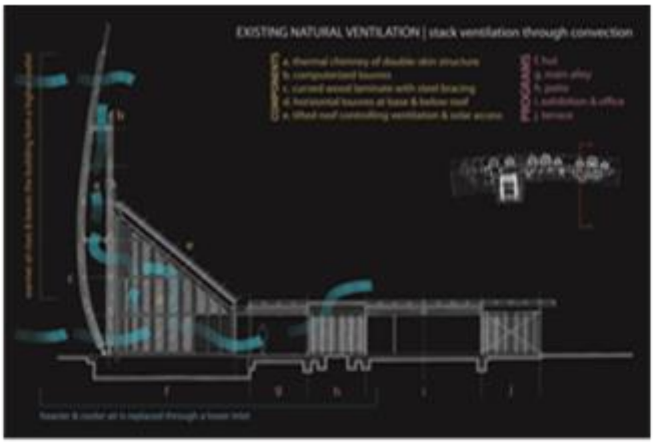

Fig 14: EXISTING NATURALVENTILATION IStack ventilation through convection (https://cellcode.us/quotes/cultural-ventilation-centre-tjibaou.html:2019)

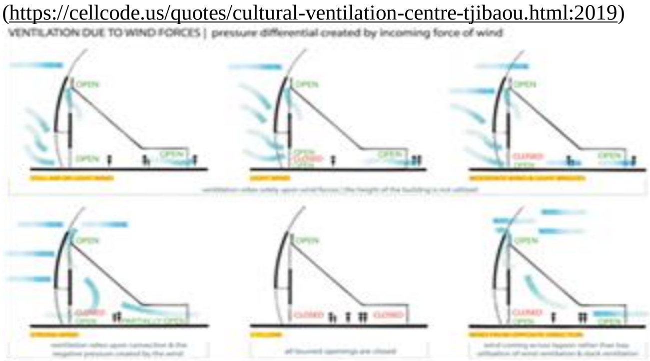

Fig15: VENTILATION DUE TO WIND FORCES pressure differential created by incoming force of wind (https://cellcode.us/quotes/cultural-ventilation-centre-tjibaou.html:2019)

louvers are controlled for ventilation dependent on wind direction and power. In addition, the louvers act as shading gadgets controlling sun oriented access into the building. Climatic biomimicry is the one where many and varied examples in nature can be found, both, in terms of concepts as well as in processes and strategies. This building provides a clear abstraction of cooling strategies generated by stack effect, solely. However, wind moderation by opening and closing inlets and outlets in the building is a process related to the one found in ants and termites' mounts in their home - static strategy. In this case, patrons have the possibility to adjust wind speed and cooling rates to keep a thermal equilibrium within the building (J Pólit , 2014). The materials used in the construction of the cases are: Iroko, steel, aluminum, concrete, and glass. Iroko (Clorophora excelsa) is native to tropical Africa, from Sierra Leone to Tanzania. It is entirely tough and practically resistant to bugs, growths, and molds. It doesn't require additive medications except if the color must be held.. Left untreated it will weather to an even grey. Piano says that it will weather until it reaches the same colour as the bark of the palms that surround the site. The choice of aluminum as a structural material is not good choice with respect to sustainability.

Also The materials used in the building of the conical domes Consisted of laminated wood and natural

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wood. The frames of all cases were pre-fabricated in France and assembled on-site. These buildings have a curved shape that references traditional Kanak constructions but here rather than the traditional woven vegetable fiber, these buildings are made of wooden ribs and slats: traditional exteriors inside of which all the benefits of modern technology are provided. Low-maintenance, termite-repellent as mentioned before the Iroko wood was chosen for the project .Renzo Piano decided to use the idea of weaving (such as basket-work, mats and fish traps)for the material covering the facades in order to economic reasons, to design the current façade with its overlapping wooden slats the architect did broad research on the best way to utilize the materials, the structures of traditional objects, You can sense the outline of a piece of weaving work, the interwoven materials which make full and empty spaces, light and shade.

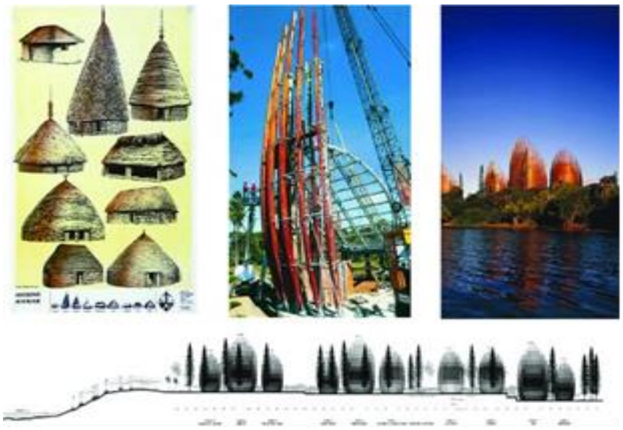

Fig16: Jean-Marie Tjibaou Cultural Centre (New Caledonia, 1991/1998): The Centre followed two main guidelines – Kanak ver-nacular knowledge in construction competencies, on the other hand making use of modern materials, such as glass, aluminum, steel and advanced lightweight technologies (in addition to traditional materials wood and stone). These buildings strongly express the harmonious relationship with the environment that typifies the Kanak-tribe cul-ture.(http://okolimg.pw/Tjibaou-Cultural-Centre-Renzo-Piano-New-Caledonia-Ethnic.html:2019)

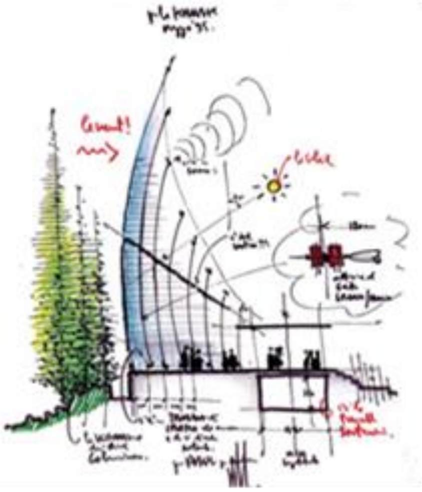

Fig17: Diagram of performance of a case drawn by architect Renzo Piano (http://www.freeformland.com/en/freeformland/138/JEAN-MARIE_TJIBAOU_CULTURAL_CENTER:2019)

In general, the exhibits in the Cultural Centre are organized in the three villages. In the first village, the emphasis is on exhibition activities. Right at the entrance is the permanent exhibition where visitors are given an insight into the Kanak culture. The cases that follow have displays related to the history of the community and the natural environment. This is followed by areas for temporary exhi-bitions and a theatre, a sunken auditorium where 400 people can be seated. An open-air theatre is provided behind the auditorium where cultural performances are held. The second village complex is used for the offices for historians, researchers, curators of exhibitions and administrative staff. The cases in front of the offices have a multimedia library and the halls here are used for conferences. The village at the end of the path, which is located slightly away from the visitors' area and which has studios, is devoted to creative activities such as dance, painting, sculpture, and music. There is also a school for children where they are taught the local art forms.
The form of Building Information Modelling contains of double layered wooden coronaries secondary steel bracing prototype Exterior Surface, Shape, Subdivision Primary Structure, Building Frame Organization and Geometric Organization includes of nonlinear Geometric Logic / Differences Detailing Geometries.

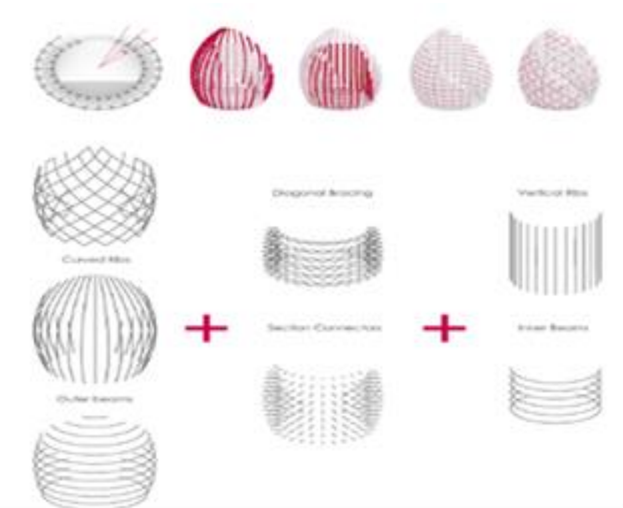

Fig18: nonlinear Geometric form of cases (http://cool-boy-roro.wixsite.com:2019)

V. DISCUSSION

This section is going to analyze the collected data in order to under-score the major trends in contemporary architecture in order to understand the future trends in adoption of bio-inspired new technologies. The scores of signs are respectively: (0-9%),(10-29%:),(30-49%:)-(50-69%:)-(70-89%:)-(90-100%:)

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Table II : bio-inspired analysis of 1980-1989 by(authors) **Table III** : bio-inspired analysis of 1990-1999 by(authors)

Building1	Biomimetics	Primitive generator	Pattern generator	Energy efficiency	Porous interaction with context	Structural technology	Performance-based design	Non-linear algorithmic thinking
Sangath Architect's Studio1980, Ahmadabad, India	○	○	⊕	◕	◔	◔	◕	○
Diplomatic Club Heart Tent1980Riyadh, Saudi Arabia	◓	◓	◓	◓	●	◕	◓	◔
Silver Hut (house) 1984Nakano-ku, Tokyo, Japan	⊕	○	◓	◕	⊕	◓	◕	◔
Protective Housing for Roman Excavations1986Chur, Graubünden, Switzerland	○	○	⊕	◕	◔	◓	◕	○
Saint Benedict Chapel1988Sumvitg, Graubünden, Switzerland	⊕	◔	◔	◓	⊕	◓	◓	◔
Institut du Monde Arabe (IMA or Arab World Institute), 1987Paris, France	○	○	◔	◓	◕	◓	◕	⊕
Logrono Town Square1981,Logrono, Spain	○	○	⊕	◓	⊕	⊕	◕	○
Prevision Espanola1988Seville, Spain	○	○	⊕	◓	◓	⊕	◓	○
Fredericks House1982,New South Wales, Australia	○	○	⊕	◕	◓	◔	◕	○
Chapel of Saint Peter, Campos de Jordão1987,São Paulo, Brazil	○	○	○	◓	◔	⊕	◕	○
Forma Store,1987,São Paulo, Brazil	○	○	○	◓	⊕	⊕	◕	○
The Menil Collection Museum (interior) 1987 Houston, Texas	○	○	⊕	◕	⊕	◔	◕	⊕
Netherlands Dance Theatre,1988, The Hague, Netherlands	○	○	○	◕	◔	⊕	◕	○
Magney House1984, New South Wales, Australia	○	○	⊕	●	◕	◓	◕	◔
Church on the Water1988 Tomamu, Hokkaidō, Japan	⊕	○	⊕	◕	◕	⊕	◕	○
Church of the Light (interior) 1989 Ibaraki, Osaka, Japan	⊕	⊕	⊕	◕	⊕	⊕	●	○
Fujisawa Municipal Gymnasium1984 Fujisawa, Japan	◓	◓	◔	◓	◔	◕	◕	◓
Gordon Wu Hall (interior) 1983Princeton University, New Jersey	○	○	⊕	◓	◔	⊕	◓	○
California Aerospace Museum1984Los Angeles, California	○	○	⊕	◓	⊕	◔	◓	◔
National Commercial Bank1983 Jeddah, Saudi Arabia	⊕	⊕	◔	◕	◔	◓	◓	⊕
San Cataldo Cemetery,1984, Modena, Italy	○	○	⊕	◓	⊕	⊕	◕	○
Yokohama Museum ofArt1989Yokohama, Japan	⊕	⊕	◔	◕	⊕	◔	◕	⊕
High Museum of Art (interior) 1983Atlanta, Georgia	○	○	○	◓	◔	⊕	◕	⊕
Hartford Seminary 1981Hartford,Connecticut, USA	○	○	○	◓	○	○	◕	○
Kuwait National Assembly1982 Kuwait	○	⊕	◔	◓	◔	◓	◕	⊕
score	120	120	300	970	500	480	920	190

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Building2	Biomimetics	Primitive generator	Pattern generator	Energy efficiency	Porous interaction with context	Structural technology	Performance-based design	Non-linear algorithmic thinking
Amdavad Ni Gufa1994 Ahmedabad, India	◔	◓	◔	◕	○	◓	◕	◔
O-Museum,1999,Iida, Nagano, Japan	○	○	○	◕	◔	⊕	◓	○
Library of Wenzheng College1999-2000Suzhou, China	⊕	○	○	◕	◔	◔	◕	○
Millennium Dome,1999London, United Kingdom	⊕	○	◓	◕	⊕	◓	◔	◔
Tjibaou Cultural Centre1998Nouméa, New Caledonia	◓	⊕	◓	◕	◓	◓	◕	◕
Servei de Meteorologica,1992 Barcelona, Spain	○	○	⊕	◓	○	⊕	◓	○
Centro de Art Gallego,1993Spain	⊕	○	◔	◕	⊕	◔	◕	⊕
LF one Landesgartenschau1999Weil am Rhein	◔	◓	◓	◕	◓	◓	◓	◔
Done House1991New South Wales, Australia	○	○	⊕	◕	◓	○	◕	○
Grand Palais,1994,Lille, France	○	⊕	◔	◓	⊕	◔	◓	◔
Nexus Housing1991Fukuoka, Japan	○	◓	◔	◕	◔	◓	◕	◔
Faculty of Law, University of Cambridge1995Cambridge, United Kingdom	○	○	◕	◕	◕	◕	◕	◔
Naoshima Contemporary Art Museum1992,Naoshima Island, Japan	◔	⊕	◔	◕	○	⊕	◕	◔
Columbus International Exposition1992Genoa, Italy	◔	◓	⊕	◓	◕	◕	◓	◔
atocha Station1992 Madrid, Spain	⊕	○	◔	◕	◔	◓	◕	◔
Curtain Wall House,1995,Tokyo, Japan	◔	○	○	◕	◕	◕	●	○
Paper Church1995Kobe, Japan	◔	⊕	◔	◕	◓	◔	◓	◔
Paper Log House2001Bhuj, India	⊕	○	◓	●	⊕	◓	◔	○
Facultad de Arquitectura, University of Porto,1993,Portugal	○	○	○	◕	◓	○	◕	○
Serralves Museum of Contemporary Art1997,Porto, Portugal	○	○	⊕	◓	◔	○	◓	○
Guggenheim Museum1997Bilbao, Spain	⊕	◕	◔	◓	⊕	◓	●	◓
Tokyo Metropolitan Gymnasium1990 Tokyo, Japan	⊕	⊕	◔	◓	⊕	◓	◓	◔
Hillside Terrace Complex1992 Tokyo, Japan	○	○	⊕	◕	◓	○	◓	○
Tokyo Church of Christ1995Tokyo, Japan	○	○	◔	◕	◕	⊕	◕	○
Cité de la Musique,1995,Paris, France	○	◔	◔	◓	◓	◔	◕	◔
Rokko Housing I and II1993Kobe, Hyogo, Japan	◔	○	◓	◕	◓	⊕	◕	⊕
Score	240	230	460	980	540	540	910	330

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Table IV : bio inspired analysis of 2000-2009 by (authors)

Building3	Biomimetics	Primitive generator	Pattern generator	Energy efficiency	Porous interaction with context	Structural technology	Performance-based design	Non-linear algorithmic thinking
Japan Pavilion, Expo 2000, Hannover,Germany	◔	⊕	◓	◕	○	◕	◔	◓
The Rolex Learning Center, Ecole Polytechnique Federale2009,Lausanne, Switzerland	⊕	○	◔	◕	◔	◓	◓	◔
Ningbo History Museum,2003-2008 Ningbo, China	○	○	◔	◕	○	⊕	◕	◔
Sendai Mediatheque,2000,Sendai-shi, Miyagi, Japan	◔	○	◔	◕	◓	◓	◕	◔
Serpentine Gallery Pavilion,2002 London, U.K.	◔	⊕	◓	◓	◓	◓	◓	◕
Meiso no Mori Municipal Funeral Hall 2006Kakamigahara-shi, Gifu, Japan	◔	◓	◔	◓	◔	◓	◓	◔
Phaeno Science Center,2005 Wolfsburg, Germany	⊕	⊕	◕	◓	◓	◓	◓	◔
House in Serra da Arrábida,2002 Serra da Arrábida, Portugal	○	○	○	◕	⊕	○	◕	○
Quinta Monroy Housing,2004 Iquique, Chile	○	○	⊕	◓	⊕	○	◓	○
St. Edward's University Dorms,2008 Austin, Texas, USA	⊕	○	◔	◕	⊕	◔	◕	⊕
Five Scattered Houses,2003-2006 Ningbo, China	⊕	○	◔	◕	◕	⊕	◕	○
Ceramic House,2003-2006,Jinhua, China	○	○	◔	◕	◕	⊕	◕	○
Naked House,2000,Saitama, Japan	⊕	○	○	◕	●	⊕	◕	○
Quai Branly Museum,2006,Paris, France	◔	◓	◓	◕	⊕	◔	◕	⊕
Tour de Verre,2007 (in progress) New York, New York	◔	⊕	◕	◓	⊕	◕	◓	◔
Cultural and Conference Center,2000 Lucerne, Switzerland	○	○	◓	◓	◓	◓	◕	◔
Laban Dance Theater,2003,London, United Kingdom	○	○	◔	◓	◔	⊕	◕	⊕
Sant Antoni – Joan Oliver Library, Senior Citizens Center and Cándida Pérez Gardens,2007,Barcelona, Spain	⊕	○	◔	◕	◓	◔	◕	⊕
Siamese Towers2005San Joaquín Campus, Universidad Católica de Chile, Santiago, Chile, University classrooms and offices	○	○	◔	●	◓	◓	◕	◔
Bell–Lloc Winery,2007 Palamós, Girona, Spain	⊕	⊕	◓	◓	◓	◓	◕	◔
Car Park and Terminus Hoenheim Nord 2001	○	⊕	◔	◔	◓	◔	◕	◔
Barberí Laboratory 2008,Olot, Girona, Spain	⊕	○	◓	◕	◓	⊕	◕	○
terminal 4, Madrid Barajas Airport2005Madrid, Spain	◕	⊕	◕	●	◓	◓	◕	◓
Hotel and Tourism School 2009,Portalegre, Portugal	○	○	○	◕	◓	⊕	◕	○
Agbar Tower 2005 Barcelona, Spain	◔	◓	◓	●	◕	◕	●	◓
score	360	160	560	920	560	540	930	270

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TABLE V: BIO INSPIRED ANALYSIS OF 2010-2019 BY (AUTHORS)

Building4	Biomimetics	Primitive generator	Pattern generator	Energy efficiency	Porous interaction with context	Structural technology	Performance-based design	Non-linear algorithmic thinking
Toyo Ito Museum of Architecture 2011,Imabari-shi, Ehime, Japan	○	○	⨁	◕	⨁	⨁	●	⨁
Ocho Quebradas House 2013 – ongoing,Los Vilos, Chile	⨁	◕	⨁	●	◓	⨁	◕	⊕
La Lira Theater Public Open Space, In collaboration with J. Puigcorbé 2011,Ripoll, Girona, Spain	⊕	○	◓	●	◕	⊕	◕	⊕
Les Cols Restaurant Marquee 2011,Olot, Girona, Spain	⨁	⨁	◓	◕	●	⨁	◕	⨁
Ningbo Tengtou Pavilion, Shanghai Expo,2010 Shanghai, China	⊕	⨁	◕	●	◓	⨁	◕	⊕
Centre Pompidou-Metz 2010 France	◕	⨁	◕	◕	●	◕	◕	◕
Cardboard Cathedral,2013 Christchurch, New Zealand	⊕	○	◕	◕	◕	◕	◕	⨁
Tamedia Building 2013,Zurich, Switzerland	⊕	○	◓	◕	◕	◕	◕	⨁
El Petit Comte Kindergarten,2010 Besalú, Girona, Spain	⊕	⨁	◓	◕	◕	⨁	◕	⊕
Row House,2012 Olot, Girona, Spain	⊕	○	◓	◕	●	⊕	●	⊕
Novartis Office Building 2015 (under construction) Shanghai, China	○	○	⊕	◕	⊕	⊕	◕	○
Villa Verde Housing 2013,Constitución, Chile	○	○	⊕	◕	⨁	⊕	●	○
Post-Tsunami Sustainable Reconstruction Plan of Constitución 2010 - ongoing Constitución, Chile	◓	○	⨁	◕	◓	⊕	◕	⊕
UC Innovation Center – Anacleto Angelini2014 San Joaquín Campus, Universidad Católica de Chile, Santiago, Chile	○	○	⊕	●	◓	⊕	◕	○
La Cuisine Art Center,2014,Nègrepelisse, France	⊕	○	◓	◕	◓	⊕	◕	○
Soulages Museum 2014,Rodez, France	⊕	○	⨁	◕	◓	◓	◕	⊕
Guangzhou Opera House 2010, Guangdong Sheng, China	◓	◕	◕	◕	◓	◕	◕	◓
Haesley Nine Bridges Golf Club House, 2010, Yeoju-gun, Gyeonggi-do, South Korea	⨁	⊕	◓	◕	◕	◓	◕	⨁
IE Paper Pavilion, 2013, María de Molina 11, Madrid, Spain	⊕	○	⨁	●	◕	⨁	◕	⊕
Villa at Sengokubara, 2013,Japan	⊕	⊕	◓	●	◕	⊕		⨁
London Aquatics Centre,2011, Olympic Park, London, UK	⨁	◕	⨁	●	⊕	◓	◕	⨁
Riverside Museum,2011,Glasgow, Scotland	⊕	⊕	⨁	◕	◓	◓	●	⨁
Ayelén School, Rancagua, 2015. Photograph by Elemental	○	○	⊕	◕	◓	⊕	●	○
Monterrey Housing, Monterrey, 2010.	○	○	⊕	⊕	⨁	⊕	●	○
Constitución Cultural Center, Constitución, 2014.	○	○	◓	◕	◕	⨁	●	⊕
Score	280	230	620	1040	820	530	1030	320

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VI. CONCLUSION

1980-1990 Architecture comprised of new ornamental based and functional designs .Structural Expressionism called as High-tech architecture or Late Modernism emerged as a part of modernism. At the beginning of the year 1980, high-tech architecture begun appearing to be unique from the modern ones. They have the presentation of the functional and technical ingredients of a building Incorporated the best worthy arrangement of the fabricated elements (Steel frames as glass walls). The show off the technical features along with the arrangements for load bearing was obvious feature. However, this kind of architecture Due to the use of inorganic materials that were in opposite with the sustainability was criticized. It is necessary for future to make a decision that all the components structure would be made of recyclable material and it is better to have geometries that exist in nature in order to be sustainable and reduce costs and energy and it is important to minimize mechanical excavation in future.

Buildings of 1980-1990 architects showed a tendency of inclusiveness of solar and energy saving design strategies. The first ideas of energy neutral buildings and renewable energy integrated systems were introduced in several building prototypes and concepts. The use of empirical simulation and measuring based technique to quantify building performance was based on energy codes and standards that were created in this phase. In addition, Sustainable Architecture was dominated with nature designs to build architecture. Along with many others; they expanded the purview of sustainable design by embracing aesthetics and human experience in addition to environmental performance. This procedure and energy conscious architecture continues in 90 decade also The Green Architecture was dominated by the ideas of green and smart design, ecological community design, integrated design and passive energy concept .some of others building in 90 decades cannot be named green exactly and they coincide with climate and the position as site so they attention to nature resource and interaction with context. The trend of using sun and renewable energies should be held in futures as before and the standards must be localized to have better performances. in both 80 and 90 decades performance based design and energy efficiency are 2 factors with the most prominent score since other factors except them increased in 90 decades.

the1990-2000 is affected by deconstructive architecture and Getting used to digital technology, computers and software advancements .the concept of non- linear architecture was born in this decade. In 2000 to 2010 climate change had a strong impact on architectural research and practice in addition to mentioned solution Carbon Neutral Architecture was dominated in this era. Biomimicry and pattern regenerative architecture was dominated by this time. Other factors like structural technology was continued with the same rhythm of its last decade.in this period natural Pattern and material were used in too-tall towers to Scattered Houses more than before.

in recent decade the views to nature were different in some aspect, architects try less to show- off the structure but they use technological structure with no tendency to Exaggerate in the structure display .The locally-based architects evoke universal identity through creative and extensive use of modern materials such as recycled steel and plastic.in this time supporting the land scape , respond to the local climate and high energy efficiency is important by use of innovative technologies and Strategies like use of porous facades and natural light. As general conclusion it seems that in future architects work closely with the public and users, like in recent decade and it will be essential to maximize the performance based of their biological and environmental comfort .they will have challenge with designs for site-specific and buildings that should have added benefit of large-scale clean energy generation. totally it can be concluded that the most influential in bio inspired architecture will be energy efficiency and architects try to use technology to improve this for last 40 decades. In addition, as The rapid technological and social changes and Current economic recession in future using bio inspired patterns , materials and structure and porous façade is the most important factors to optimize the two leading 40 years factors (1-energy efficiency,2- performance based design,) in order to Social Welfare.

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