Envisioning Expressions of Divergent Evolution: a Biomimetic Approach to Architectural Design

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Abstract

In recent years sustainability in design has become a central part of the plan in architecture that has led to the pertinent need of design that is rooted in natural phenomena's to balance both cost-effective and ecological challenges. This influence has compelled new methodologies to architectural design process. Design methodology that inspires from processes as complex as "genetics and evolution" as a model are still intangible in architecture. This research is an attempt to explore the phenomenon called 'divergent evolution' and express it as an architectural solution by designing architectural prototypes in the form of museum pavilions. The interest of this research lies within the realm of utilizing inspiration found from nature and translating the acquired information into an architectural solution. The process lends itself into an architectural discourse of experimentation and investigation, which is addressed at the scale of a pavilion design. This research discovers biomimetic process as a latent technique that help assimilate organic sustainability to architectural design. This has been achieved by studying a natural process to realize its form and the environment within a system. This research look at Biomimetic theory, and presents a model, which is appropriate to architecture. This model is tested as an experimentation that proposes two ways of rivalling nature: direct and indirect that detect naturally occurring alteration and assimilation processes. The aim and outcome of this research is a unique methodology that emphasizes adaptability of biomimetic concept into architecture.

Key Words: Nature, Phenotypic Plasticity, Divergent Evolution, Environment, Pavilion Design, Biomimetic architecture

1. Introduction

Evolution of form in any organism is not only a product of its own internal genetic makeup but is inflected by the field in which it is modeled. It is a depiction of the effects, of its developmental field and dynamic environment surrounding it during morphosis. Divergent evolution is a natural phenomenon that happens when the species of similar genetic makeup are left to evolve in different and varied environmental conditions. Resultantly, new diverged species are unique yet better adapted to their environmental and surrounding conditions. This complex process in some cases expresses several highly morphologically distinct results; in other cases, a continuous norm of reaction describes the functional interrelationship of a range of environments to a range of phenotypes [1]. In this research authors have studied this evolutionary phenomena and used it to design three museum pavilions. This study falls under the broader domain of bio mimicry in architecture or biomimetic architecture. There are three levels of bio mimicry which are termed as organism level, behavior level and ecosystem level [2]. The organism refers to a specific living thing like a plant or an animal and it may involve mimicking a part or the whole organism. The behavior level relates to how an organism behaves or relates to a larger context. The third level allows us mimicking the whole ecosystem having common principles that allow them to successfully function [3]. Application of these levels depends upon the context or design programs. The main purpose of investigating this area, communal to biology and architecture is not to draw peculiarities or even to assert that architecture is an alive entity, it is more to learn from what is presently happening in the intersecting field. The aim is to employ bio mimicry as an apparatus in architectural process. The domains in architecture where this is relevant and necessary are varied. Studies like these will support to resolve existing problems associated to architecture and ecology to an extent. It also widened the scope of new conceptual mergers in architecture. The examination of natural processes is the paramount prerequisite for an improved cognizance of the environment and it also provides an enhanced thoughtfulness of integrations. Apart from this, a well-founded inclination for evolutionary design must exist. A methodology like this does not automatically lead to fine architecture but it can definitely supply preliminary ideas and open up new prospects.

2. Research Methodology

This research investigates how evolutionary processes which are generally vigorous, buoyant and adept of acclimatizing to perpetual change, can be transformed to conceive strategies that could be convertible to an architectural interpretations. This aims at providing critical thinking for the architectural creations, or environments that help enhancement to assimilate with and donate to ecosystem. Specifically, this study inspects the complex phenomena of “Divergence and Phenotypic Plasticity” and presents a cohesive framework that could become the basis of architectural design approach. This piece of writing is significant because it provides an in depth understanding of how this unique natural phenomena happens and also sets a precedent on how to adopt evolutionary process to produce architectural design. Although this can be considered as an attempt to underline a framework appropriate for use in a design process, it have not been possible to define, or almost charted to express how these processes may be correlated. Yet, there is a clear understanding of transformation that helps employing evolutionary processes in architecture. Explorations like these could result in better understanding of various built environments by the designers and can help in mitigating the causes of climate change and adapting to its impacts consciously.

3. Literature Review

Drawing on the sciences of complexity, Goodwin Brian in his book “How Leopard Changed Its Spots”, has tried to prove that how self-organizing patterns of network are important to explain natural processes. Genes are important, but only as a part of a process constrained by environment, physical laws and the universal tendencies of complex adaptive systems [1]. Evolution of form is not only a product of its own genetic makeup, but is also inflicted by the field in which it is modeled. The most interesting natural phenomena that result due to this is: Divergent evolution in which species with similar genetic makeup, when left under different environmental conditions, tend to change their phenotype in order to survive or better adapt to their environment. There is a process whereby the generative field, influenced by the inherited particulars, produces the adult form of the organism. The important part is the role of the environment, which can have a specific influence on development by acting on the generative field. Evolutionary process in organism is self-organized. In self-organizing systems, pattern at the global level emerges solely from interactions among lower-level components [4]. Remarkably, even very complex structures result from the iteration of surprisingly simple behaviors performed by individuals relying only on local information. This striking conclusion suggests important lines of inquiry: to what degree is environmental rather than individual complexity responsible for group complexity? [5] To what extent have widely differing organisms adopted similar, convergent strategies of pattern formation? How, specifically, has natural selection determined the rules governing interactions within biological systems? [6].When organisms have to deal with different conditions like atmospheric changes, shortage of food, and protection from predators, to attract the opposite sex etc., they tend to find out ways to better adapt to the situation and use self-organization as a tool to survive [1]. There is a strong similarity between the above-mentioned genetic theory and recent developments in architectural design i.e. the role of environment in finding the form of any architectural structure. Towards the end of the last century; the environment came to the forefront of architectural debate [7]. Whilst focusing on opportunities for improving the environmental performance of architecture, architects are also trying to focus on design directed by the surrounding environment. Further study on this leads to another important terminology that needs to be discussed here: phenotypic plasticity. Phenotypic plasticity can be demarcated as the creation of several phenotypes from a single genotype, contingent on environmental conditions. It is now clear that a wide diversity of organisms express phenotypic plasticity in response to biotic and abiotic aspects of their environments. These flexible retorts include changes in behavior, physiology, morphology, growth, life history and demography, and can be expressed either within the lifespan of a single individual or across generations [4].Some organisms have more capacity (phenotypic plasticity) than others. Here are a few common examples in nature reflecting phenotypic plasticity.

Fig. 1: (a) Daphnia Longiremis (b) Two Adult ZebraFinches.Source:http://www.indiana.edu/~curtweb/Research/Plasticity.html

Many Caducean species exhibit multiple extreme morphologies that are often associated with differing environments or seasons. The image above shows a typical specimen of Daphnia longiremis from Salmon Lake in Alaska with Daphnia longiremis from a nearby pond with abundant copepod predators. The picture next to it is showing two adult Zebra finches having the similar genetic makeup but one has pattern and color variations while the other is pure white.

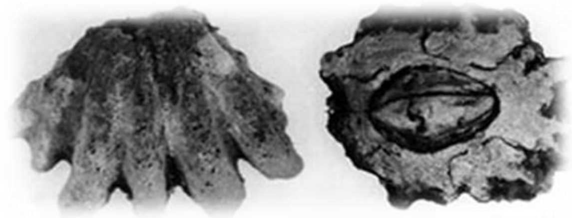


Fig. 2: Barnacles Morph showing Phenotypic Plasticity.Source:http://www.indiana.edu/~curtweb/Research/Plasticity.html

The picture above is another example showing phenotypic plasticity in two barnacle morphs. The eggs are brooded on either side of the rostral carinal axis, which runs from left to right in the photo. The bend in the bent morph reduces the area for brooding embryos, which incurs the reproductive cost. The slower growth rate in the bent morph is most likely due to the fact that growth occurs only at the base of the shell, and is thus restricted to one side. In a nutshell, phenotypic plasticity is a common property of the reaction norm of a genotype (for a given trait, within a certain range of environmental conditions). Plasticity is what makes possible the appearance of an environmentally induced novel phenotype, and a process of selection on the expression of such phenotype in a new environment may end up 'fixing' (genetically assimilating) it by altering the shape of the reaction norm [5].There are different kinds of phenotypic plasticity mainly depending on what environmental factors are responsible to bring about changes in the appearance. Some of these factors are abundance or shortage of food, predator attacks, surrounding temperature and attraction for the opposite sex. In case of humming birds the amount of sound is produced to attract the mate. There is a conceptual similarity between the way an organism and a building engage with their environment. The major aim of this research is to transform this phenomena into architecture which will be explained in the next section but here it's important to talk about the literature that already exists on the biomimetic architecture. Commonly, bio mimicry and biomimetic are interchangeable terms; however, the latter focuses more on the technical aspect. Biomimetic is an emerging field that has been recognized as a promising approach for a more resilient environment [8]. Biomimetic architecture seeks to remedy the errors that exist in designing efficient systems and products [2]. For instance, Myers [9] presented a dramatic technique to design by incorporating living materials into elements and structures. Myers' approach pushes the concept of mimicking to integrate literally biology within buildings to create new forms. Mazzoleni [3] explored ways of utilizing animal skins for per formative buildings. However, biomimetic research faces challenges in creating effective design tools in the built environment. Several academic research are conducted in this line, such as 'BioSkin' [3], 'Towards the living envelope' [8] and 'Architecture follows nature' [2] that introduced a strategic methodology. In order to thoroughly identify, define and extract key aspects of a biological source, key parameters can be set to help measure the process in detail.

The most established parameters are form, material, construction, process and function. These can be measured at different levels of organism, behavior and ecosystem [2] Application of this process in architectural designs can become a veracity by reconnoitering the concrete ways of applications. It also can developed into an apprehension process for ecological environment. This approach to design can be divided in two major technique: 1. Define the design problem and then mimicking the biome of other organisms to that design problem. 2. Study the biological systems and then identifying a specific characteristic or behavior or function in that organism or system and transforming that to architectural designs. Within these two approaches application of bio mimicry to the architectural design can be categorized under three levels, viz, form, process and function. In analyzing an organism or ecosystem, form and process are the key components that could be mimicked [2].In this research authors have used the second technique to find out the architectural solution. This research hence fall under the biomimetic category as it is looking at the organism at a behavior level.

4. Site Constraints and Analysis

4.1. Land Pavilion

A chunk of land was selected near Silver Lake and the environmental constraints were identified as (a) the pavilion has to be surrounded by natural landscape, (b) it has to create a vista and there has to be strong visual interaction with the surrounding landscape, (c) it should be adaptable to the surrounding and existing site conditions and it should have connectivity and linkage to the surrounding residential area.

4.2. Hanging Pavilion

The second pavilion was to be designed hanging from the bridge, which is located right in the middle of Silver Lake and the environmental constraints which were identified were: (a) the pavilion will be detached from the land and will be connected to the bridge only, (b) it should have adaptability to the water, (c) should have paths of multiple linkages, (d) it should have visual connectivity, (e) it will be in the state of suspension and tension, (f) the form should be adaptable to get support from the bridge and (g) it should have adjustment for the smooth traffic flow on the bridge.

4.3. Water Pavilion

The third pavilion was to be designed in the water, surrounded by water from all sides. The environmental constraints which were identified were: (a) It should be adaptable to the surrounding water conditions, (b) it should have accessibility to the land for the support, (c) it should have multiple connections and (d) it should have visual interaction with the surroundings as well as a structure to support itself on water. This site for these three prototypes ensures that each of them (pavilions) has been placed in different environmental conditions. The next step was to study the various forces acting on each of these organisms (pavilions).

Then a study of different forces directly acting on the three pavilions was conducted. Difference in site conditions is responsible for different forces present on the location where the pavilions have to be designed. To initiate the design process it was decided to jot down these forces and changes that they bring about. The design constraints and parameters will be based on this study of forces and reactions which are in turn dependent on the site conditions and the amount of changes and adaptability techniques each pavilion has to undertake.

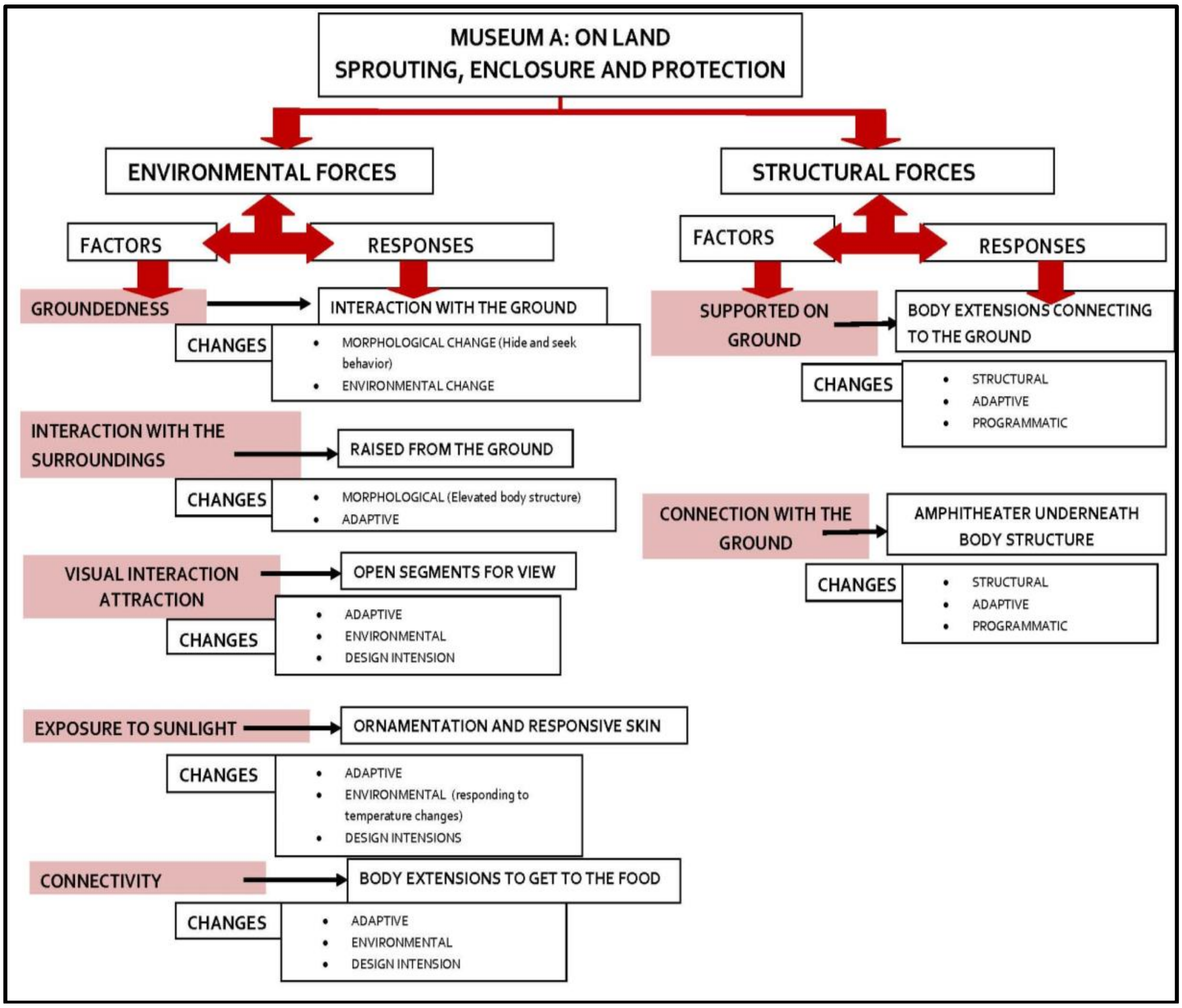
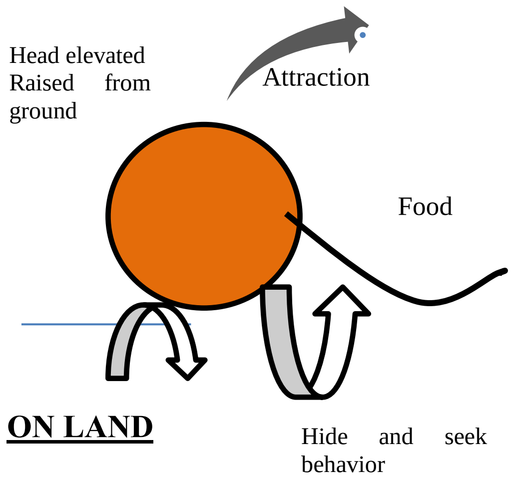
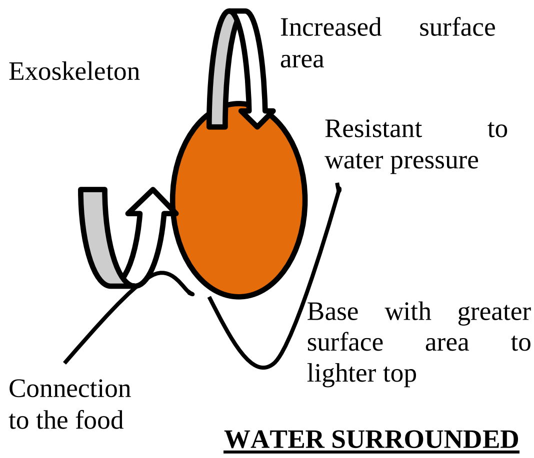
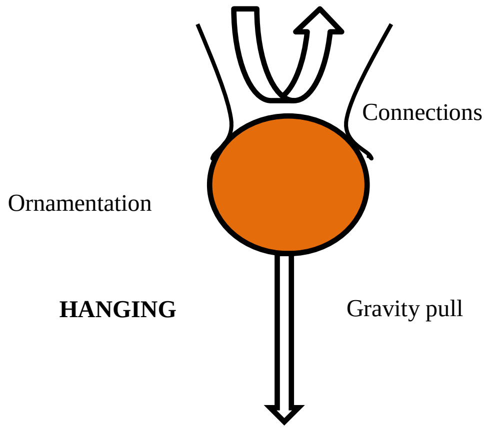


Fig. 3: Flow Chart of the Forces acting on the land pavilion

The above chart shows the study of forces for the museum pavilion on land. Two major forces were: environmental and structural respectively. By using the word forces; author wants to emphasize on the fact that natural forces are acting on the organism and a study of the natural forces will help in the transformation of the natural phenomena into architectural design. While structural forces can be defined as adapting and molding the form due to some surrounding limitations, structural changes were adopted by the pavilion.eg. The land pavilion is supported by the ground so it has embraced body extensions to gain support from the ground. The study of several organisms helps to understand that how complex the system of living and surviving even for little creatures in nature is and how most of them adapt themselves to all kind of environmental conditions they had to face. Due to the dynamic and frequent changes in the surroundings almost every organism naturally has the tendency to adapt to its environment. To survive through these changes organisms tend to make changes in their forms according to their need. Nature is one huge cradle to various creative modes of adaption [1]. This chart above is trying to explain that how the forces and dynamic changes in the surrounding environment are making the pavilion change in their forms. Fig (I) Morphological study details is explaining the process. In this chart above the land pavilion's form has been analyzed and its analogy has been drawn with an organism. The three major terminologies used here are explaining the process of form finding for the pavilions: Factors can be defined as constraints and the physical conditions surrounding the pavilions.







Response is the reaction of the museum pavilion to these conditions in terms of structure and environment. Their reaction to environmental and structural forces is recorded in the chart and the changes are then adopted in the form or morphology of the pavilion. The final form of the pavilion is the result of all these factors effecting the organism. The chart highlights the forces acting on the organism (pavilion) and how the body adapts or responds to certain force by prominent changes in the form. For example land pavilion has to force visual interaction with the surroundings to attract visitors and that is why it has been raised from the ground to become visible in the surroundings. Here are the diagrams showing the different forces acting on the sphere, which is used as a representation of the comon genetic base for the three pavilions.

The response to the environmental forces predicts the development of the form and how it adapts to each condition. Structural forces bring about morphological changes.

The analysis of the forces shaped the design constraints on each pavilion.

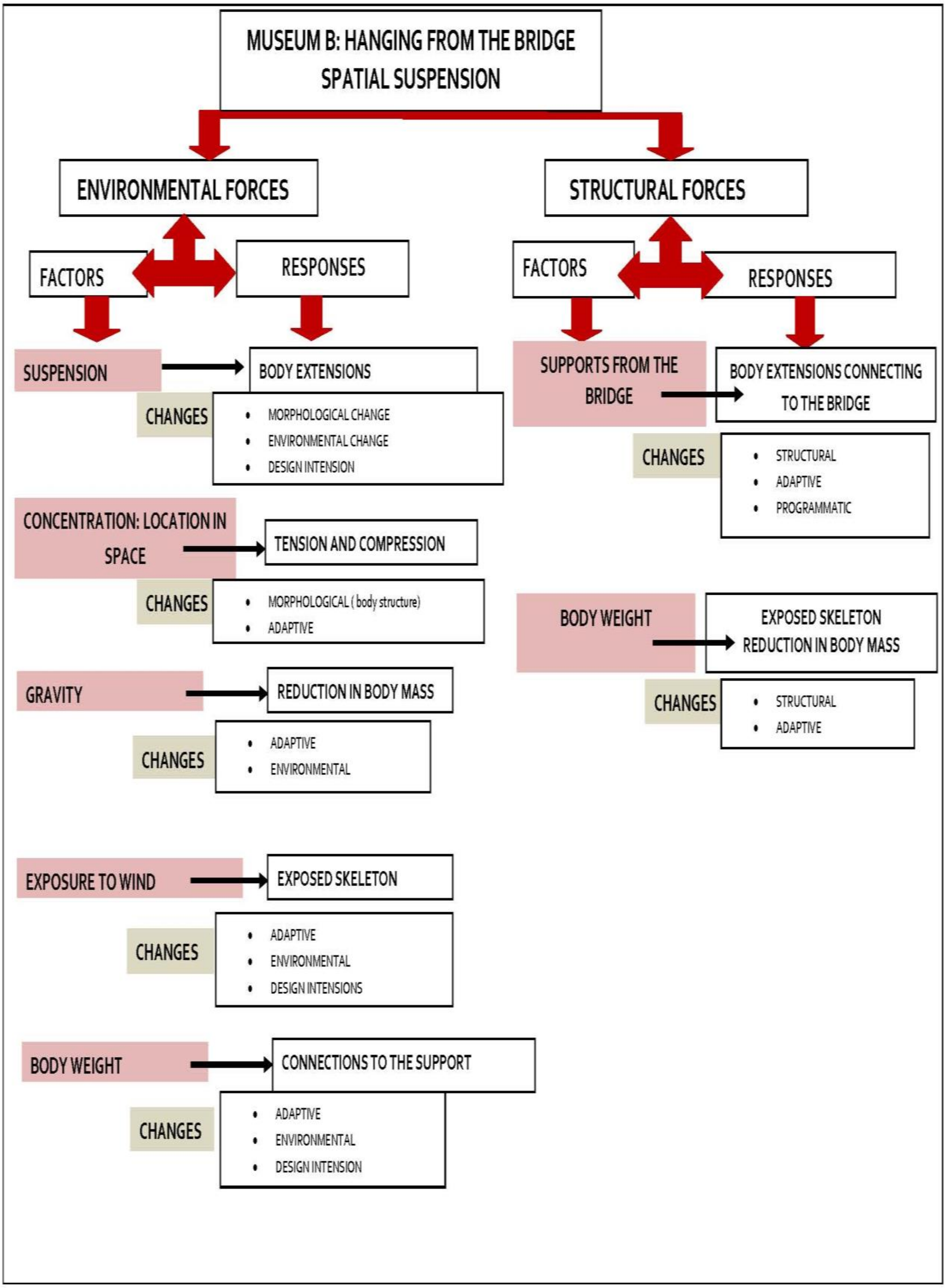


Fig. 4: Flow Chart of the Forces acting on the Hanging Pavilion

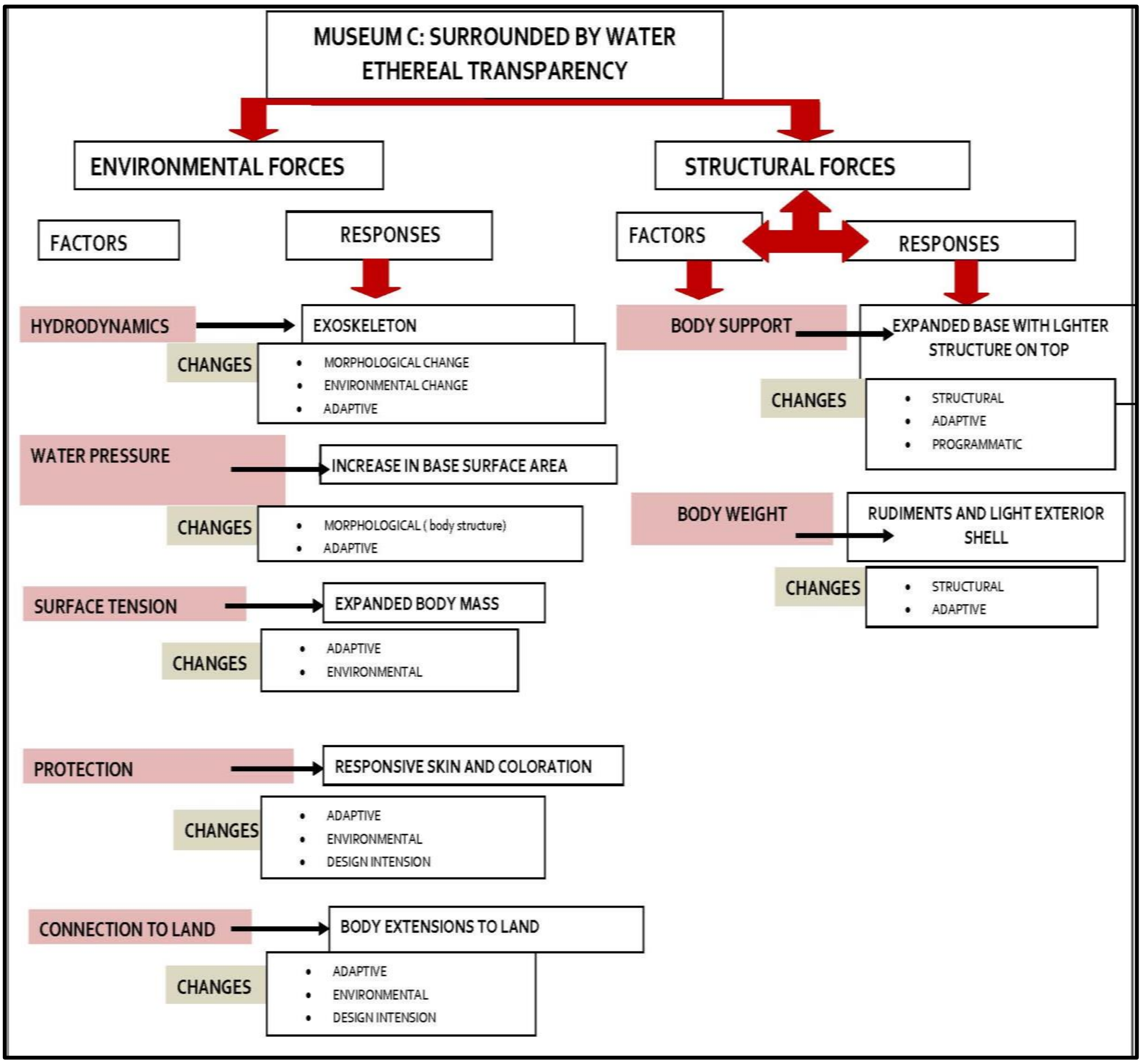


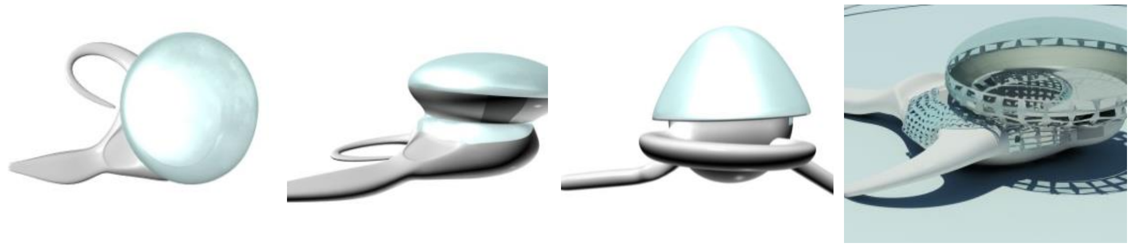
Fig. 5: Flow Chart of the Forces acting on the Water Pavilion

5. Performance Study

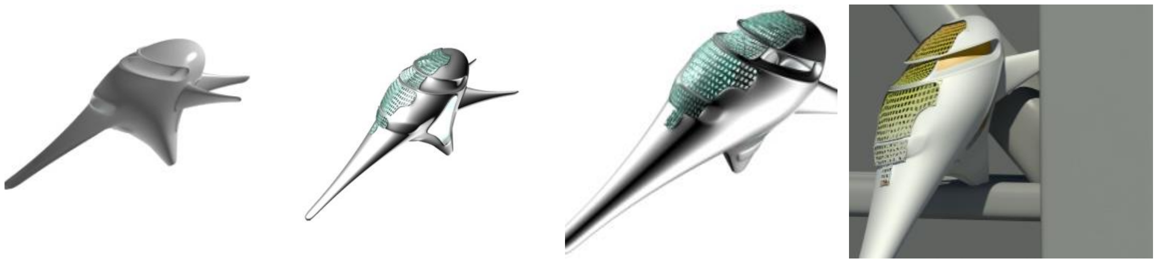
To keep the genetic base similar as per the divergent evolution phenomena, the performance study was initiated. This study is called performance study as it can be considered as the first experimentation that is going to prove the validity of the proposed hypothesis. It was instigated by using a sphere as a common genetic base for all three pavilions.The product was a result of these forces and their responses when they act on a sphere.This exercise was done as a preform study. The process lends itself into an architectural discourse of interesting experimentation and investigations.

The land pavilion is raised from the ground to attract visitors and develop visual interaction with the surrounding urban area. It has to have good connectivity and hence has extended enterance for the visitors. It is adapting to the existing landscape by utilising the area underneath the structure as amphitheatre.Hanging Pavilion is in the state of tension and compression. For structural support it needs to attach itself to the bridge and hense develop body extensions towards the bridge which helps to transfer the load. It also has to deal with the gravity pull due to its position so the form becomes elongated and is able to adapt to this condition.For Water Pavilion, the major force is the hydrodynamics.

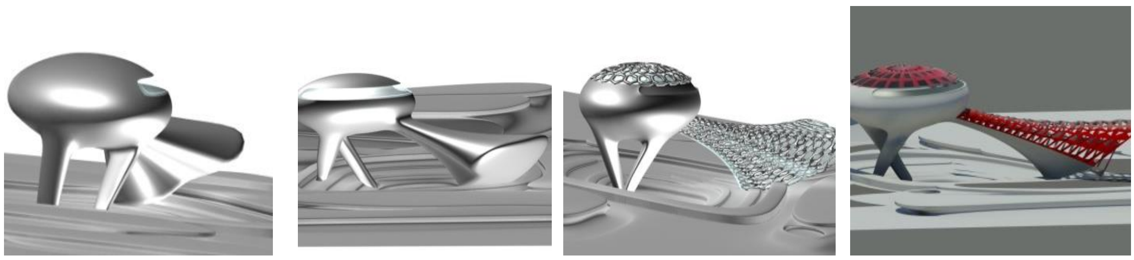
In order to deal with that, it has to increase its base surface area to float. Body extensions have been placed to connect to the ground for support. The method helps in keeping the body weight as light as possible. It also needs to develop the exoskeleton to protect the lighter structure.



Water Pavilion



Hanging



Land Pavilion

Fig. 6: Growth process/Design itierations

5.1. Morphological Study

These study images shows the morphological development of each design. Notice that color and pattern emergence take place in the latter stages. The component is same in all three but it varies in its movement as well as colors accordingly to a response to certain forces. The forms have developed from a simple sphere and even the product is simple yet responsive to the forces acting on it.

With the help of these, one can see how structural and environmental forces are driving the form formation which has been initiated from a sphere (representing the similar genetic base). Body extension for connectivity, transparency, colors and pattern (component) are all responses to the forces acting on the pavilion. The component was designed using sketchup and then it was populated in Paracloud Gem. The meshes which were used to populate were different in each pavilion. The component was populated parametrically so that it acts as a responsive skin on the pavilions.

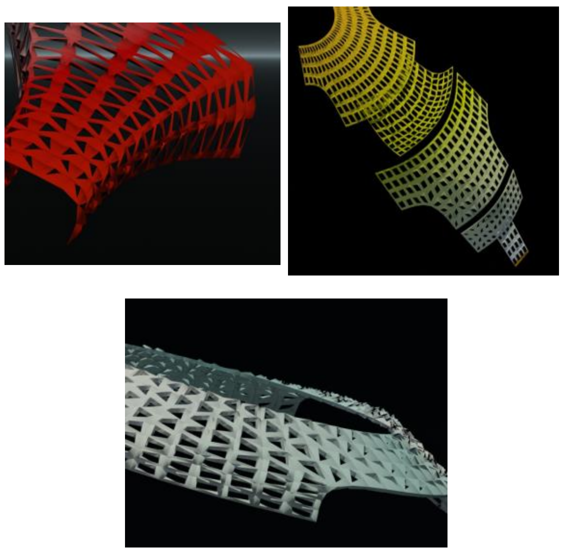


Fig. 7: Component populated mesh on land, hanging and water pavilion with different color and sequence

The different colors used on components have animal logics which the author has used in architecture. The component part at the land pavilion was coloured red to cater to its need to attract the visitors and become prominant in the surrounding landscape. Red color was specifically used to as it is the brightest color and known as the color to attract. The enterance was made grander and top was populated with the component to make it look fancy and attractive. This whole concept can be compared with the concept of pattern formation and colors variations in certain organisms. The use of component on the hanging pavilion is imitating the concept of different patterns found on certain organisms. The mesh part, which has component populated on it, represents the frame structure of the pavilion which has been exposed. The colour is applied using multiple hues to represent the too much and too little exposure to the sunlight. Component is parametric to maintain the similarity among three of them and at the same time to react to the sunlight exposure.The component mesh on the sea pavillion is acting as an exoskeleton and the component is used externally to serve the purpose of protection. In organisms, exoskeletons contain rigid and resistant components that fulfill a set of functional roles including protection, excretion, sensing, support, feeding and (for terrestrial organisms) acting as a barrier against desiccation. Exoskeletons have a role in defense from predators, support, and in providing an attachment framework for musculature. The blue coloration is applied to help camouflage in water in the time of need.

6. Museum Pavilion’s Architectural Interpretations

After exploring the idea of divergence with the help of a soft body as a preform study, it was the time to transform these samples into actual museum pavilions. Starting with a line and by using the lofting technique in Auto desk Max, it was decided to make these prototypes architecturally strong and less creature like.The staright line will represent the similar genetic base for all the three pavilions. This line will further transform into different shapes depending on the forces acting on it. For architectural interpretations, the basic line diagrams for the three pavilions was drawn.

Lofting technique was used in 3D Max to design the pavilions from these lines and then some parts of the mesh are taken and populated in ParaCloud Gem with the same component.

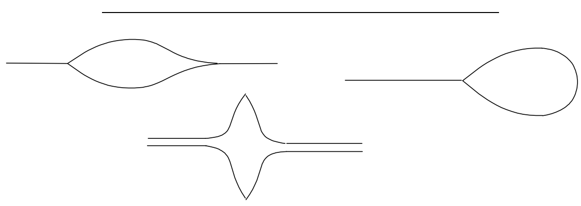
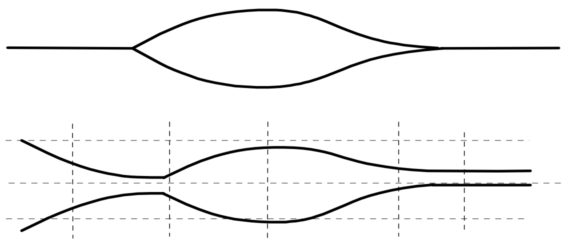


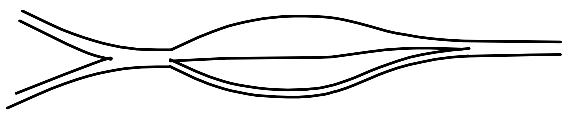
Fig. 8: Diagrammatic representation of the forms starting from a staright line

The basic concepts started with drawing simple line and work out its transformation when certain force is applied on it. The design was intended to maintain the symmetry and diverge to a very limited extent following the philosphy of phenotypic plasticity.

6.1. Form development and morphological changes



Symmetrical Body Plan



Bifurcation

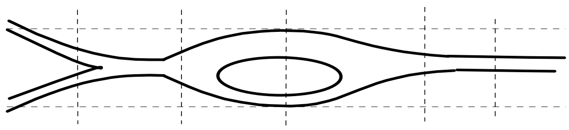
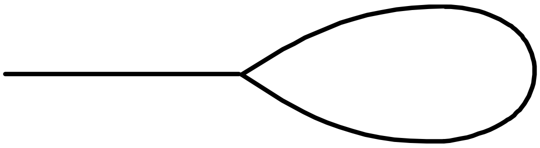


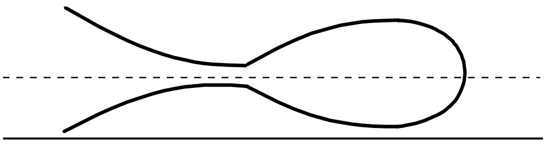
Fig. 9: morphing stages of Land Pavilion

The land pavilion is acting as a connecting bridge between the residential area and the Silver Lake Park so the major force of divergence is connectivity. The body plan is symmetrical. Bifurcation occurs to make main enterance on one side to diverge into two on the other end.

The daigrams above highlight the design process clearly.For the Water pavilion, expanded base to float on water and connection with the land to support itself were the major forces of divergence. The line diagram and how it develops is shown below:



Line Diagram for water Pavilion



Symmetrical Body Plan

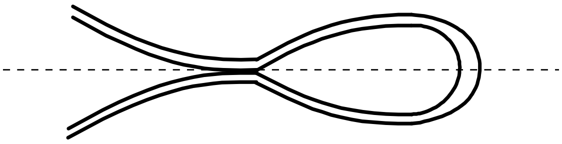
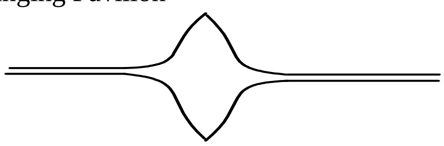


Fig. 10: Morphing stages of Water Pavilion

To get the expanded base on the water, the paths returns to from where it also started maintaining the symmetry of the body. For the Hanging Pavilion the major force of divergence was the gravity pull and the state of suspension and tension. As a response to these forces and maintaining the symmetrical plan for the body, the line daigram develops as shown below.

Hanging Pavilion



Line Diagram

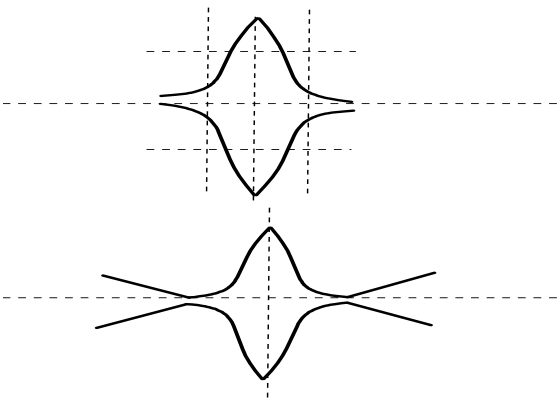


Fig. 11: morphing stages of Hanging Pavilion

7.1. Architectural Design Proposal

Fig. 12: Different views of the Land Pavilion

The hanging from the bridge, a new path was developed that holds the pavilion to the existing bridge so that traffic flow remains uninterrupted. The visitors pass through this side path and see the exhibits on their way. The viewing deck is designed so that visitors can also experience the suspension. The form of the pavilion, dictated by the forces, is discussed in fig 13.

Fig. 13: Different views of the Hanging Pavilion

The component mesh in this pavilion is for bringing in light and for better views. The component shape remains the same but the openings vary from smaller at one end to bigger on the other side. This pavilion has added another path to the existing bridge to improve the circulation. The Water Pavilion is surrounded by water from all sides. So, in order to deal with the hydrodynamics forces, it has expanded base and strong connectivity from the land. The pavilion has perforated (component populated mesh) on the waterside for views.

Fig. 14: Different views of the Water Pavilion

The pavilion has a symmetrical plan. The growth development process is shown in the rendering above. Circulation path is close ended rather than an open ended. Gem populated openings on the pavilion (for the view) serve two purposes: on one hand these are parametric and on the other these imitate the pattern on the body of any organism [10].

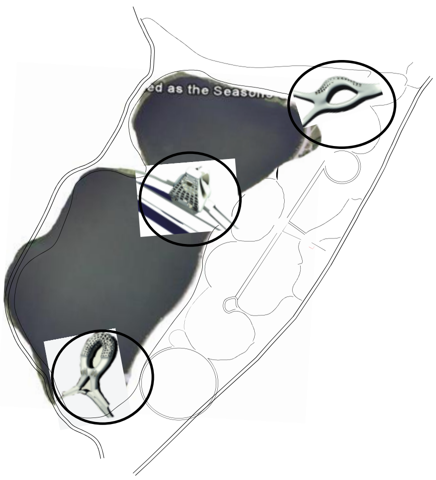


Fig. 15: Diagram showing site engagement with the three genetically similar Museum Pavilions

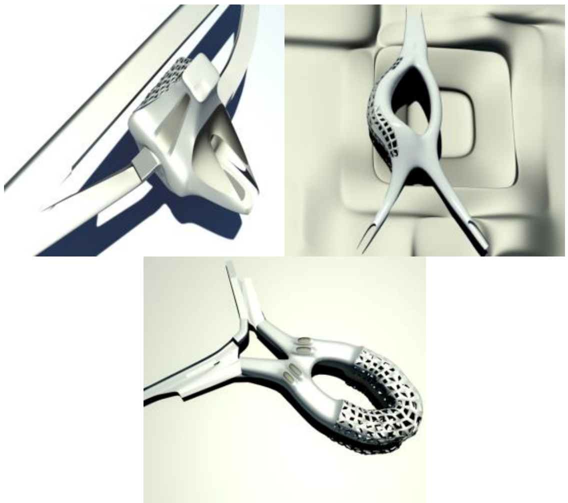


Fig. 16: Three pavilions evolved from a single line (used as genetic base) better adapted to their varied surrounding environments

8. Discussion and Conclusions

Phenotypic plasticity makes us understand that genes and environment are exclusively linked. Biological existence is a repetitive and communal process between genes, human beings and environment. Genes provide a set of choices of evolving prospects and phenotypes, and the environment determines the phenotypic product. The environment consequently selects among transformed individuals to alter population gene occurrences, which determine how in future, the persons will react to environmental unpredictability. Similar process should be applied in architecture where despite the rest of the existing constraints, importance should be given to the environment and environmental changes as well as building designs. Very importantly, the form should be flexible and adaptable to their surrounding environment and changes. Nature's experimentations over time provide us with a guide that enables an extraction of natural systems, which will generate a new future - a different way of life and survival for our human species. It is nature's capability to test organisms under different circumstances, opening a new horizon into the performance of animals and plants for their life-long survival. Unfortunately architecture is often designed under preconceived standardized and idealized conditions, but what happens when architectural projects encounter unprecedented conditions? [3]. This research synthesizes the framework on how to use the complex phenomena like Divergence in Evolution as an attempt to develop an architectural theory for creative architectural design where design of the form is dependent on the surrounding environmental challenges. The experimentations conducted through this research instigate a fundamental approach in the current debate of biomimetic and its implication in architecture, which require the prevalence of conceptual models to be derived through an elaborate inquiry of biological networks. These are the frameworks of nature and have the potential to produce a more provocative way to live and build sustainably. The processes developed through this research influenced researchers to enhance their knowledge on the fields of biology building in order to rethink and learn how to adapt particular biomimetic investigations into an architectural paradigm that has not been fully explored. Yet, it offers great opportunities to create an architecture that goes beyond the decorative qualities. It discovers the likelihoods that this biomimetic approach to designing will produce an evolving architecture that is administered by a bottom-up hierarchy. These animal inspired forms created a multiple physical and programmatic instantiations. The authors however had, hitches to translate the theoretical aspects of her design studies into a complete buildable and inhabitable forms. They acknowledged that they would require more time to design a complete proposal for the pavilions and the framework presented still needs in depth architectural investigation to be resolved. Therefore, author has presented her work in two stages, the theoretical and the practical. The process of analysis and theory has been explained in the first part and the translation into a workable build form is presented in the second part. In order to increase the proportion of environmentally considered work in design production, reliable harmonizing methods of subjective and objective research must be both experimented. The abstraction phase is crucial for the whole biomimetic transformation process. If the abstraction is vague it is most likely because the research field is too hefty, and so no specific knowledge is expanded. Several types of biomimetic methods were developed since the last two decades [2]; however, their reliability for application is still challenging in architecture. The major drawback is the lack of a clear selective design procedure and the practical application of a design methodology that remains indefinable in architecture. Cohen et al mentioned that mimicking biological organisms into technical systems through function and materials need to be based on a solid platform and clear methodology. This research proposes a methodology to transform a complex phenomenon into architecture.

8.1. Future approaches

By adopting evolutionary methods as an inspiration, architecture can become an entity of research and development in the subsequent ways:

- Investigating the explanation of architectural principles to be improved.
- Identifying the projects showing these principles, making changes, observing for projects depicting the changed criteria and working with simulations.
- Measuring the attributes like success, liking, market price, biodiversity and impacts.
- Instigating the enactment of the more effective solution.

This is the way forward for a gradual improvement but original design for innovation must not be ignored. Biomimetic design in architecture still absences a fundamental design theory, and the development of transformation strategies and methods is a pertinent issue for the future of the methodology.

9. Acknowledgment

I would like to thank my Master's thesis advisor Jason Vigneri-Beane from Pratt Institute New York, (www.splitstudio.com) who gave me this opportunity to do this scientific research based on this exclusive and broad topic of Biomimetic in Architecture, which also helped me in exploring various other domains of this area and I came to know about so many new things I am really thankful to him. Secondly I would also like to thank architecture department, University of Engineering and Technology Lahore and friends and colleagues who supported me in this research.

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