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Designing Structural Systems Based on the Hip Joint

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Abstract

Bionics and bionic architecture is a science which deals with the technical inspiration of buildings from different behaviors and communications of the world of organisms and solve technical issues through biological ways. Bionics was initially proposed in the 1950s and is visible in a variety of the works of different sciences. Today, bionic architecture is introduced as one of the three world’s top sciences and this shows that the world has realized that inspiring from nature and that nature itself would be very efficient at this time period. Given that living organisms have been changed over time according to their evolutionary trend, thus they have the best structure according to the environment and the architecture which is consistent with them, is a responsive architecture with the capability of interacting with its environment.

There are extensive examples in nature for modeling and many of them have already been used. In the meantime, taking advantage of the human body especially in the field of construction has been neglected. At first glance, it might be thought that the human body is very complex, but having studied this point, we can conclude that in spite of our imagination, it is much understandable structure and yet useable. There have been also many studies about its’ anatomy.

In this article, we have tried to achieve an appropriate design for the/its structural system by kinesiology of the hip joint and recognition of the relation of all its components with each other in order to find an efficient structure like the hip joint. OR In order to find an efficient structure like the hip joint, recognizing the relationship with all of its components must be found.

Keywords:
Bionic architecture, hip joint, acetabulum cavity, femur

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Introduction

Bionic

The word "bionics" is a combination of the two words, biology and technic, which means technology. This word was applied for the first time by Jack E. Steele at the conference “living patterns, a key to the new technologies” in 1960. As the name suggests, bionic science deals with the review and study of the structures and patterns in nature and applies them to solving human problems. In other words, the meaning of bionic is the application of knowledge obtained from living organisms in order to solve technical problems.

This science is not seeking to copy or merely imitate nature, but it aims to model from the knowledge derived from nature correctly (1).

Advantages of inspiring from nature:

Over billions of years passing from the emergence of nature, it has perfectly solved the problems which we are facing today. Animals, plants and unicellular organisms are expert engineers which are well adapted to their environment and show us the way of interacting with nature. What has remained for us in the 8.3 billions of years is the lesson that its’ learning will lead to the reduction of many material costs and prevent waste of resources and time. The more similar our performance is to nature, the more guarantee for our longer survival. The process of creating natural forms has had a long evolution journey over millions of years. Throughout many centuries, natural forms have been developed against external factors to achieve acceptable solutions. During this process, only the most efficient, the most powerful and the most flexible natural forms have been able to survive these millions of years (1).

Bionic-based approaches:

Bionic-based approaches as a design process are generally divided into two groups:

Problem-oriented approach: defining a human need or design issue and studying other organisms and ecosystems to find what solutions and strategies they can use for dealing with this issue.

There are six steps in inspiring from nature:

1- Design issues
2- Searching to find biological similarities
3- Identifying appropriate legislations
4- Abstraction and separation from the biological model
5- Testing, analysis and feedback
6- Design solution
Solution focused approach: specifying a particular characteristic, behavior or performance in an organism or ecosystem and translating it to design a human who is called as a biologist influencing design.

This approach also has six steps:

1. Biological researches
2. Biomechanics, morphological yield and anatomy
3. Understanding basic regulations
4. Abstraction and separation from the biological model
5. Technical tools
6. The design solution (1)

**Bionic architecture:**

Bionic in Architecture is an emerging field that is currently being defined and explored. The application of observations made in nature to architecture has always been a challenge for architects and designers (2).

Bionics which is also known as Biometrics, or creative life engineering, is the application of systems biological methods of the nature in engineering systems and modern technologies (3).

Bionic architecture is proposed as a style with different and variety of samples for many decades; it is also one procedure of using the structure of living and organic systems in architecture. Although today, in the twenty-first century, we see a version more different than the former definitions of bionic architecture which deals with complex interpretations of the combination of realities based on biology, mathematics, construction and mechanics and it is called architecture derived from nature. New sciences associated with algorithmic geometry, fractals and chaos theory, intelligent materials and systems, opening and closing mechanisms, all make changes in our landscapes. In fact, our view towards the structure of natural organisms has changed; having focused on the multidisciplinary deep relationships in nature has changed the simple view of benchmarking them to a scientific and interdisciplinary study. A good example of benchmarking from nature in discussions of non-structural elements in building is Nano evaluation of the structure of the lotus leaf which has led to the production of self-cleaning glasses (1).

Bionic architecture or the science of studying the living creatures’ life system has been introduced as one of the three world’s supreme sciences (Bionics, Nano, IT). Enlivening buildings is one of the tendencies in bionic architecture. It is a supreme belief that complete coordination or harmony with nature is created (4).

Inspiration from nature in architecture has existed at all times. The first human dwellings were natural shelters, and archetypes such as caves and trees have been used as models for architectural design throughout history (5). By the quirk of fate, all architects who have been interested in nature have achieved valuable scientific and theoretical successes.

All living creatures in nature have an evolutionary process and change over time based on their needs. In this approach, it has been tried to represent the most fundamental principle of life, which is evolution. Thus, what eventually occurs is a kind of responsive architecture with the capability of interacting with the environment (6).
Three perspectives about human interaction with nature:

In the way people interact with nature, researchers have proposed this division which is comprised of three distinct perspectives:

1- **Architecture of nature:**

The order of nature is more the environment and its related factors such as water, soil and air.

In this architecture, man tries to change nature with his own desires and overcome it. Unfortunately, the man in this category is in the first place at the outbreak of the negative consequences of environmental degradation, because he has become more dominant on the environment and the planet on which he lives through achieving advanced tools and technology. In this way, he has made serious damages to the environment and even it can be said that he has disrupted the ecological balance. Of course, this approach will lead to the loss of natural resources. In the past, the scope of this destruction was not too extensive due to a lower population and nature compensating for the gaps by itself. Gradually, nature was no longer able to compensate for these losses due to the increase of the human population and growth of this destruction.

2- **Architecture with nature**

Consists of the ecosystem, climate and related elements such as the sun, wind and the energies derived from them and its’ product is a sustainable and green architecture. This architecture consists of two sub-categories:

1- The attitude to a kind of architecture that aims to have the least damage in the environment and tries to integrate the architecture with nature and these two are not separable. The origin of this architecture can be traced to the era of modern architecture and organic architecture. Examples of such architects were Alvar Aalto and Frank Lloyd Wright.

2- In addition to the integration with nature, nature should also be used in a suitable way for making the building self-sufficient in terms of energy and other related issues. This is considered sustainable architecture. In fact, the principle of sustainable architecture should be based on this fact that the building is a small part of the surrounding nature and should act as a part of the ecosystem and its place in life's cycle.

Sustainable building goals:

1- Proper utilization of resources and energy
2- Prevention of air pollution
3- Compliance with the environment

3- **Architecture from nature**

It expresses the nature in a broader sense. In this view, everything that man has not intervened in with its creation is called nature. Thus, plants, animals, humans and even cells and perceptions in humans are included. From this perspective, humans try to draw inspiration from nature by looking at its correlation between life and technology, in general, and architecture, in particular.
Meditation on nature and using appropriate patterns in life is taken from it. This attitude is not separated from the previous attitude; but architecting from nature enables us to reach more sustainability in buildings (1).

**Bionic architecture types:**

Bionic architecture in a general classification can be divided into 6 main categories:

1. **Stencils:** this is a cut-out pattern, which has been usually used for decorations and in the Art Nouveau era, its usage peaked. Today, it is used in a functional role, such as front patterns, which are variable, based on the amount of sunlight.

2. **Structure:** inspiring from the formation of organisms' structures and applying them in architecture is possible by understanding the structures and mechanisms forming these living organisms. Inspiration from the structures found in nature requires more research and study than modeling from stencils.

3. **Materials:** studying nature, researchers found that some characteristics of living organisms can be transferred to man-made artificial materials.

4. **Form:** in bionic architecture, there is not much value for pure transference of natural forms to architecture. One important issue to be considered is the relation between form, structure and material, as well as the interaction with the environment. Jerry Lebedev suggests that nature is the combination of function, form and structure, which are effective integrating with each other and interacting with the environment and adapting to it; otherwise, each alone, they can do nothing. That is why only translating the shape cannot be considered a successful experience; however, good architecture is expected with the combination of function and structure.

5. **Function:** natural organisms have evolved over hundreds of thousands of years and have been developed in terms of complexity, variety and versatility. Certain functions that humans learn from different organisms can be changed based on their needs and can be applied in architecture.

6. **Process:** inspiring from the processes found in nature that lead to the formation of phenomenon is more attractive than the form and functional modeling. Perhaps it can be said, this kind of inspiration and impression of nature is the best and most valuable type of inspiration (1).

**Lack of attention to the role of structure in bionic architecture:**

What can be seen today in architecture shows that reconciliation with nature has been only in the form of enjoyment from stencils and materials (such as Turning Torso by Calatrava (Figure 1) and the football stadium by Kurokawa (Figure 2)), or some samples of benefiting from function (such as the drawbridge in Chicago (Figure 3) and Ontario (Figure 4)), or the process also can be seen and less architecture samples can be seen that benefit from the structure. While, other sciences have paid more attention on this part and this indicates the failure of architects in recognition of structure and nature structure (10).
The human body has always been a great example for investigating the correlation to architecture. An experienced builder finds the ideal coordinated form of human body, which its functional and structural needs are estimated perfectly; thus, it is reflected in an amazing order and hierarchy. Bones, organs, muscles and tissues are organized not only to achieve the best functional status, but also to fulfill the aesthetic aspects. The human body is designed to be used with comfort and optimal performance. Hence, that is why it is known as the first combination patterns (11).

At first glance, it might be thought that the human body is very complex, but after reading about it, we find that despite our imagination, much of this structure is understandable and usable. On one hand, there is great diversity in the body's structure and but with change in the structure, we can create very different and even conflicting results. One the other hand, there are more extensive studies on the human body, both anatomical and mechanical than on other living organisms.

In this article, we have tried to explain the hip joint as a human body system and show that even the structure of the hip joint, which seems very complicated, can be used easily and create new systems (10).

**Hip joint, a considerable structure in bionic architecture:**

The hip joint is one of the largest and most important joints in the body which is from the ball and socket joints. (Figure 5)
All upper organs are transferred to the lower limbs by this joint and then transmitted to the ground.

The design of structural elements and connections of this joint based on the angle and dimension of the ball is able to implement different activities according to mobility and stability (12).

Structural design based on hip joint:

This joint has three degrees of freedom and three axes of motion.

In the axis XX’ that flexion and extension is done

In the axis YY’ that abduction and adduction is done and

In the axis Z that rotation is done. (Figure 6)

In addition to the three above axes, there are two other axes in the lower limbs:

- Mechanical axis: it is an angle equal to 5-7 degrees which is created due to the femoral neck (the angle between the axis which passes from the femoral head and anatomical axis; this axis coincides with the anatomical axis in the shank.) (Figure 7)
- Anatomical axis: it is in line with bones of the relevant organ; the axis angle of the thigh and shank is different due to the angle of the femoral neck. (Figure 8)

The mentioned angles are created after motion transferring from the state of four limbs in the standing position and lead to increased range of motion. Therefore, we can benefit from these two angles in accordance with different projects or even overlook this angle in different projects (12).

Diagram 1: We can change this angle according to the level of mobility that we want to have in our project.

**Structural design based on hip joint components:**

1- Hip joint levels:

The hip joint is made of two joint levels: acetabulum cavity and femoral head. (Figure 9)
- Femur: It is the biggest and strongest bone in the body, which is about 2/3 of a sphere with a diameter of 4 to 5 cm. The head is covered by articular cartilage, except a part of it in the center, which is the junction of ligament. This cartilage is thicker in the upper part than the environmental part. The femoral head is noticed aslant to the inwards, up and forwards through its neck. (Figure 10)

- Acetabulum: it is located on the outer surface of the pelvic bone and is about the size of a hemisphere. Only the environmental part of it, which looks like a horseshoe (due to the cartilage notch at the bottom), is covered with cartilage and is thicker in up and inside its cavity is lacking cartilage. In this cavity, an edge called ACEDALABRUM increases the acetabulum cavity depth, which leads to 1- cover of the femoral head, 2- helps to keep the femoral head inside the cavity and 3- makes the cartilage in the upper part (external) thicker than in the center. Acetabulum is towards the out, down and forward and has the angle of 30-40 degrees with the horizontal plane; the upper part of acetabulum covers the femoral head like a roof and leads to increased joint stability about 30 degrees (WIBERG angle) (12).

2- Types of hip joint:

1- The femoral head is more than 3/2 of a sphere surface, thus, the small pelvis and femur and femoral neck are thin and long; it leads to more mobility in the joint and more speed in motion, like runners.

2- The femoral head is slightly larger than ½ of a sphere, consequently, the femur is thick, the pelvis is wider and the femoral neck is short and wide. It leads to lower range of motion and minimum speed, but joint stability remains at its maximum amount, such as weightlifters. (Figure 11)
As a result, based on the amount of structure mobility, we can change their dimensions according to our need in each project (12).

![Diagram 2: We can change this percentage of sphere according to our mobility that we want to have in our project.](image)

3- Trabecular system of hip joint:

In the femur: the femoral head and neck have two major trabecular systems and two minor trabecular systems. Major Trabecular system in the femoral head and neck is in the direction of forced lines of body weight in order to resist them, which includes external and internal trabecular. Internal trabecular system has vertical force lines of pressure and the internal trabecular system is in the direction of traction power lines and it resists them. Other two minor trabecular systems act towards traction forces due to muscles contractions.

In the pelvis: consists of two major trabecular systems:

- starts from the lower region of the acetabulum and ends at the upper area of the Sacroiliac, along with the external major trabecular system of the femoral head and neck.

- starts from the upper acetabulum and ends at the lower part of Sacroiliac, along with the major trabecular system of the femoral head and neck. (Figure 12)
According to what was mentioned about the femur trabecular system, we can see that these systems of the femur and acetabulum are for transmitting the load and tolerating the tension and weight between the two surfaces.

The acetabulum is root-like, which enables the transmission of load between two surfaces well and transference to the base. We see this today in the form of nailing or building foundations and piles for transferring the loads to the soil depth.

The femur is similar to common structural systems (Figure 13) in that it transfers the load from one side to the other (13).

4-Capsules:

Hip joint capsule is very strong and thick. The joint capsule has surrounded the femoral head like a cylindrical sleeve. (Figure 14)
- This capsule consists of 4 categories of fiber:

1- It is parallel to the axis of the femoral neck and it connects the two articular surfaces to each other.

2- It is aslant in a clockwise direction and extended in femoral extension and loosened in flexion.

3- They are arc-shape and only connected to the acetabulum, which helps to keep the femoral head inside the acetabulum cavity.

4- They have no bony connection and they are mainly in capsules; they are like a ring around the femoral neck and divide the joint cavity into two internal and external areas. (Figure 15)

- Hip joint capsules are reinforced by two ligaments and thickened in the anterior and inferior parts. They are thin and weak in the posterior part and reinforced by one ligament.

Given what was informed about capsules, we understand that these capsules are there to create femoral stability in the acetabulum in order to connect the ball to the socket while increasing tensile strength in the femoral neck for strengthening the extensions.

Generally, what can be seen in the behavior of capsules are like reactionary mattresses which prevents the femur from exiting the cavity; they are exactly like a washer in that reactionary circles of bottles can prevent a part from exiting and strengthens one piece from the other piece. Thus, they are able to produce reactionary cases (pneumatic, silicon, etc.) (12). (Figure 16)
5- Hip joint Ligaments:

- There are two ligaments in forward:

1- It is like an inverted Y and the shape of a fan, 8 to 10 cm thickness and the strongest ligament of the hip joint. It leads to stability in the sagittal view; it is thick in the hip joint extension and loose in its flexion. (Figure 17)

![Figure 17](image)

2- It is thick in abduction and extension of the hip joint and it limits movement. These two ligaments are like the letter Z. (Figure 18)

![Figure 18](image)

- There is just one ligament in the posterior part. They rotate around the femoral neck in a clockwise direction; they are thick when the hip is in extension and loose during flexion and they also cause movement
to be limited. Totally, all ligaments rotate around the femur in a clockwise direction, which is the result of humans converting from all fours to standing. In addition to these three ligaments, there are also a number of ligaments inside the capsule which have no role in keeping hip joint stability, including the fear and transverse ligaments.

In extension mode: all ligaments are tightened and wrapped around the femoral neck, especially those which are in portrait mode.

In flexion mode: all ligaments are loose without exception.

In rotation mode: All the anterior ligaments are stiff, particularly horizontal ones.

Reviewing the ligaments, we can conclude that, the ligaments are embedded in different parts of the hip joint based on the tension and pressure rate, in order to prevent dislocation of the ball from the socket in tension and pressure mode. According to the tensile role of ligaments, they can be considered to be the cables that connect the cavity to the ball and cover it in all aspects equally which transfers the load in traction and prevents the ball from exiting the cavity (12). (Figure 19)

6- Hip joint muscles:

A large number of muscles help to create stability and mobility in the hip joint. Muscles that affect the hip joint can be divided into the following groups:

- Flexor group
- Extensor group
- Abductor group
- Adductor group
- External rotator group
- Internal rotator group (13)
According to what was stated about muscles, the muscles act like an engine and modifier or switcher among the vertebras; by inserting each of them, we can animate a structure in all directions. Of course, it depends on whether we want to have a movable or fixed structure (12). (Figure 20)

**Conclusion:**

Hip joints consist of several main levels, including 1- femur bone and acetabulum cavity, 2- capsule, 3- ligaments, 4- muscles. They are simulated separately in different sciences and designs; they only need to be gathered together and integrated.

To be brief, the hip joint contains two parts of acetabulum cavity and femur bone; each consists of a trabecular system which takes the loads from other members and transfers to each other. There is a capsule, besides this trabecular system, which is like a cylindrical sleeve surrounding the femoral neck so it will not exit from its cavity. This capsule is like air or silicon mattresses, which have elasticity. Ligaments are like cables that keep the cavity and bone together in different directions; they have a tension role and prevent dislocation and displacement of these two from each other. Muscles are also like messaging engines, which move and displace the whole structure in different directions. As a result, the entire design cycle related to the grounding structure of this bridge is summarized below.
Totally, the hip joint structure can be simulated as such below.

In general, stability of the hip joint is very high due to the below reasons.

1- Building and joint tissue: the acetabulum cavity is a deep cavity that keeps the femoral head completely inside itself and causes a situation of INTER LOCKING.

2- Body weight force: in the hip joint, weight force increases its stability.

3- Atmospheric pressure: in the hip joint, if all soft tissues around the joint is cut or removed, the femoral head still remains inside the cavity, but if the acetabulum is not perforated, the joint will be unlocked spontaneously without the need of force.

4- Hip joint capsule: especially the capsule which is firmly wrapped around the femoral neck helps to maintain joint stability.

5- Hip joint ligaments: it prevents dislocation of the ball from its socket in a state of tension and pressure.

6- Muscles around the joint: They are between the muscles around the joint and the ligaments of the equilibrium joint. In the anterior part, in which ligaments are strong, muscular support is low; in contrast, muscular support prevails in the posterior part due to the weakness in the ligament. The muscles which are parallel with the femoral neck can play a role in stability.

7- Direction of the femoral neck: less of an angle between the femoral head and the neck will create more stability.
Maximum instability occurs during the state of flexion, in which all ligaments of the hip joint are loose.

With this knowledge of the hip joint, there is the capability of designing these structures with different functions according to the angle of the femur bone and the femur bone's ball size. While the hip joint is only a part of the structure of the human body, there are also other capabilities in the human body and each can lead to the production of different building systems, which have been neglected until now (3).

Most attempts that have been done before to perceive from nature and apply its teachings to the field of architecture, have remained only as plans on paper and not come to fruition. Thus, the architect persists in the role of an idealist. Perhaps the reason for this is the superficial selection of complicated and non-enveloped issues due to weaknesses in scientific fields or the lack of technical facilities in which to perform (14).

Applying the lessons derived from nature in designing building structure (which is closely related to the architecture and its function) can have positive effects on authentic sense of building, as well as the net flow of forces in their transmission path, efficient structural elements, less dimensions for structural components, optimum use of making fund and as a result, less damage to the environment. Hence, the use of such concepts for designers and architects is desirable in different countries (14).

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