



# THE APPLICATION OF MATHEMATICAL STRUCTURES IN BIONIC ARCHITECTURE TO DESIGN PARAMETRIC PAVILION

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## Abstract

From the very beginning, man had sought to get inspired by the living environment and the nature surrounding him to design and construct places and tools he needed. Bionic architecture is a science that deals with modeling buildings, their behaviors, and various interrelationships between organisms. Today, man has produced realistic architectural forms based on nature. Architects maintain that bionic forms can minimize environmental damage caused by buildings to nature. Bionic architecture is also called biometric architecture or creative bioengineering. To use nature and imitate bionic forms, architects use two methods. In the first method, the architect only aims to imitate the external appearance of nature to create forms, which accordingly, buildings represent nature. In the second method, the architect or designer is inspired by the processes producing bionic forms to create his design. Also, there are laws for bionic architectural forms which can be used in modern buildings. The outcome of this type of architecture is impressive because the resulting designs combine the needs of users and aesthetic aspects.

**Keywords:** mathematical structures, bionic architecture, parametric pavilion design

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## Introduction

Representing the creativity of the best architect, God, nature has always been an endless source of creative inspiration for mankind (Sadovnikova N, et. al., 2022; Mehrzad K, et. al., 2022). From the very onset of his civilization, man had sought to use this life-giving and mysterious source to design and construct a living place and a shelter. The relationship between architecture and nature can be studied in three pre-modern, modern, and post-modern eras (Sajini S, et. al., 2022; Asfahani A., 2022). In the pre-modern era, due to human weaknesses, nature was the only reference for creating innovative and reliable works, as natural forms were used in the architecture of famous temples such as Egypt's pyramids, and Chughazanbil (Çakar S, et. al., 2022). After that, in the modern era, man's worldviews changed and that led to the rise of the Industrial Revolution and impressive advancements in sciences. Machines turned into ideal symbols and models for designing living spaces to the extent that Le Corbusier, the great twentieth century, likened the house to a piece of machine for life. This attitude led to a radical use of nature, followed by the destruction and pollution of the environment.

The term *parametric* is derived from nature and denotes using parameters and variables that can change to improve results. A parametric design is a kind of algorithmic thinking that results in expressing parameters and laws elucidating the relationship between goal and design. In digital architecture, and with the development of parametric design software to create complicated forms, architectural design entered a new phase. In digital architecture, the architect and designer are capable of using parametric software programming to produce their favorable forms.

As a discipline, bionic architecture is a science that uses the technicality of buildings to investigate the behavior and relations between organisms and to solve technical issues using biological methods. Bionic architecture is one of the top three branches of science in the world and is characterized by giving life to architectural buildings. One of the major subjects in bionic architecture is the induction of life into a building.

One of the existing problems of the city of Tehran and other metropolises with historical texture and history is the lack of a relationship or interaction between new and modern

neighborhoods and historically old areas. Meanwhile, this issue in modern countries is not only not an urban problem but also an advantage in architectural design due to its ability to attract tourists. Architecture and urban development in historical areas should be coordinated and serve existing standards, as the design of these areas before meeting the aforementioned criteria and standards is not acceptable. Studies have shown that in large modern cities across the world, like London, all people with higher cultural status choose historical and old areas of cities as their residence; moreover, in these cities, all urban facilities, available in other modern areas, are also found in these areas so that people prefer residence in these areas over other areas. This is because the most effective way to protect these areas is to help people live there. However, in our country and other similar countries, old and historical areas are already abandoned and are empty of residents due to their unattraction and old texture, thus paving the way for their destruction.

With the expansion of urbanism and stresses caused by urban commuting, it is critical to construct a resting place to create a comfortable environment for peace of mind and tranquility. Pavilions as temporary accommodations can help disappear the surrounding urban spaces, and thus transfer a sense of security and comfort to users. Inside the country, the need to design and develop parametric green pavilions is strongly felt. Parametric architecture as one of the architectural derivatives uses parametric design software to serve as a method for such subjects as aesthetics in architectural design than to serve as a discipline of architecture. For this, the goal of this study was to examine the applications of mathematical structure in bionic architecture for parametric pavilion designs.

## Mathematics in architecture

The application of mathematics in architecture is divided into four main groups:

- 1. Planning:** One of the most basic applications of math is using concepts and adapting them to characteristics of a plan's site, and the facilities and limitations inside it. The architects who concern with planning in their design work are the main users of mathematical applications. Today, evaluating and planning large architectural projects cannot be made possible without using mathematics and computer software.
- 2. Subject organization:** One of the most important duties of an architect is to design

and produce proportionate to cultural and spiritual concepts and subjects. Many mathematical structures are said to be in a set of arithmetic and geometric structures, which if used, architecture design will be made possible.

**3. Architectural design:** The most important achievement of using mathematics in architecture design is design quality promotion. Also, using the science of mathematics can be examined in the following three stages:

- A) Architectural form design and what appears to relate to building forms
- B) Efficacy optimization, proportions, and functions in architecture designs
- C) Structural system designs

**4. Utilization and main needs in this stage:** At this stage, the science of mathematics is highly capable of evaluating the needs. The architectural approach to using the science of mathematics in this stage includes the following two sections:

- A) Investigating the available samples and simulating the design's performance quality at the stage of utilization
- B) Modeling project needs and comparing its characteristics to achieve an optimal and high-effective design

### Concept of Bionic Architecture

Bionic denotes the knowledge of life and/or using artificial organs of nature; this branch of science was first developed by an American scientist in 1959. He considered bionic to be the science of systems that underlined all living systems. It has been for years since scientists sought to prove causality and the existence of this relationship so that they would investigate and explain the quality of various living system formation; it is these systems that, combined with a mix of two terms of biology and technique, created the science of bionics as a body of knowledge to resolve technical issues through biological ways.

In over 3800 billion years since the creation of the earth, nature has been a perfect designer and architect. Over the years, animals and plants have sought to overcome their living problems using bionic designs. Man has always sought to be inspired by nature and the environment surrounding him to create and construct buildings. For example, a bat's body provided

Leonard Davinci with the idea to design a flying machine. The speed of dolphins was also an idea to design submarines, and also, scientists modeled plants to create helicopters, while designing houses based on a shell called Knous. Man has constantly looked into the world around him to be inspired. For example, birds' flights have inspired countless flying machines.

As well, included in the works of Santiago Calatrava, inspired by this style (inspired by the human anatomy), are the Turning Torso Tower, Milwaukee's Art Museum, Science and Technology City and its skyscraper, with each inspired by nature in some way (Golabchi, 2020:87).

Every successful architectural work, founded on solid theoretical basics, usually remains as a model or design for some time. When a man wrote his opinions on a piece of paper for the first time and constructed a relevant three-dimensional model, he could not imagine that architectural works would be so popular in less than 20 years. Almost two decades ago, the development of technologies and computer capabilities led architects and designers, such as Lin to expand their architecture designs. Their tools were now new computers that not only provided three-dimensional works but also laid the ground for computing non-geometric forms and simulating the design of living processes along with each other. Lin is among the architects who give creative roles to computers. For him, it is these computer systems that create new architectural works based on approximate equations (Dikini & Nejati, 2017:94).

### Advantages of Bionic Architecture

The earth population in 1890 was estimated to be 1.25 billion people, which skyrocketed to over 6 billion in 2000. Over the last decade, cities changed their urban strategies into concentrating tall buildings and expanding their residential areas with centered population rates. Thus, the presence of bionic architecture and giving importance to it will be a key issue that promises good results.

### Pavilion

A pavilion denotes a camp, room, temporary residence, summerhouse, mansion, or shelter. It may refer to a structure erected not far from the main residence. Large or small, this structure usually creates a relationship between comfort and pleasure. A pavilion that provides a good landscape is called *Gazebo*, which may include a small garden outside a building, like a

summerhouse or a kiosk and a hut. Pavilions of this kind were especially common in the 18<sup>th</sup> century. Also, pavilions are equivalent to the Italian name “Casina”, roughly translated as Casino in English. Places of this kind were mostly resembling a small classic temples for entertainment. A pool house may, because of its pool, become so attractive and take on such a character that can be called a pavilion. In contrast, a pavilion can also be an even larger building like the royal pavilions in Brighton, which is a large oriental-styled palace. Anyway, like its small classic counterpart, the pavilion helps create peace of mind and an enjoyable environment for tranquility. Sports pavilions mostly refer to buildings adjacent to sports land used for clothe change and taking rest. These pavilions are usually made of a porch for spectators to protect against sunlight. Round pavilions are also used in stadiums, especially on baseball pitches, which distinguish ordinary stands, expensive roofed stands, and unroofed cheaper stands.

Another main concept of a pavilion is what is seen in a group of symmetrically-classic buildings where there is a central block, with flanks leading to a pavilion. These flanks are in some styles aimed at emphasizing an end to the building composition, just like a full stop at the end of a sentence. In Place des Visges (the name of the oldest square in Paris), constructed in Paris from 1605 to 1612, twin pavilions are seen to have distinguished centers on the northern and southern sides. These sides were called Pavillon du Roi and Pavillon de la Reine, though no royal character has ever lived there. Using their three indoor passageways, they used to operate as rooms in the adjacency of the gates, thus allowing access to overlook the square. Gate rooms in the form of such


pavilions were constructed in French styles one century ago. In rural areas, a pavilion is an architectural building used for hunting. Pavillon de Galon in Loubron, France, represents a noble hunting pavilion of the 18<sup>th</sup> century. The pavilion is located at an old Roman villa and includes à la française gardens used for welcoming guests (Farshid Farnad, 2015:72).

### Status of Pavilion in Iran’s Architecture

Iranian architecture is part of a continuous creed that pertains to an ancient Iran civilization. In traditional Iranian architecture, a pavilion referred to spaces with temporary and permanent functions. Examples of these spaces were Yazd’s Dolat Abad Garden, Kashan’s Fin Garden, and A’ali Ghapu Mansion. Therefore, these pavilions fall under pavilions with permanent functions. In terms of function and efficacy, these spaces served as passageways with restricted and temporary activities, reminding of a tavern space. These places are spaces with spaces in the city which met human needs, including drinking, etc., and sometimes included such activities as performing ceremonies of vowing and kindling candles. Taverns were spaces that connected a network of passageways and served as pause places for pedestrians to stay (Ibid, 82).

Another type of these spaces was Iranian pavilions, such as the Kaha pavilion inside the Persian Gardens. Pavilions were the most important elements of Persian Gardens with independent and semi-open spaces laid between the gardens and the main building, and seen on all four sides, thus multiplying the geometric effects of Persian Gardens. Examples of these spaces were the Hasht Behesht Pavilion of Isfahan, characterized by the interaction between humans and nature.

**Table 1: Several examples of pavilions at prominent universities in digital architecture**

| Row | Name   | Image  |
|-----|--|--|
|     | Research pavilion of the University of Stuttgart (2013-2014) |  |

|  |  |  |
|--|--|--|
|  | <p>Research pavilion of the University of Stuttgart (2015-2016)</p>                  |    |
|  | <p>Research pavilion of the University of Stuttgart (2016-2017)</p>                  |    |
|  | <p>Iran pavilion design at the 2015 Expo Fair, Milan, with a biomimetic approach</p> |   |
|  | <p>Iran pavilion design at the 2020 Expo Fair, Dubai</p>                             |  |
|  | <p>Sand Pavilion, Darak, Chabahar</p>  |  |

Design time and production costs of pavilions, like those mentioned above, have significantly reduced due to using computer modeling and  
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parametric design principles. Using parametric methods could reasonably reduce project costs. In these projects using advanced design and

modeling tools, modern material, and also observing bionic principles could open new paths for free-form shapes. However, this area warrants further research in architecture. This study also examined such issues as the number of models from a geometric point of view and modulation. Using smart parametric architecture, the process of architectural design and production improves, while the number of different forms decreases, as only their common

features are integrated. Parametric design and modern three-dimensional modeling principles are the methods used to achieve constructive solutions in design.

### Introducing and Analyzing Sites

The historical compound of Toghrol Tower in the city of Ridar with 26673 square meters has been selected as shown below (Figure 1).



Figure 1: Site's location

Around the site lay the main access points of

Nabipour Street and Mirabedini Street, and a secondary point of Saheb Zaman Alley (Figure 2).



Figure 2: Access points

The presence of a green space north of the site is suitable for this neighborhood. The site under study indicates it does not have a regularly geometric shape, as only its extension and

proportions can evoke a trapezoidal shape. The ground slope is 0%, seen by passing through the alleys around the site; the site also has an even land with some ups and downs.

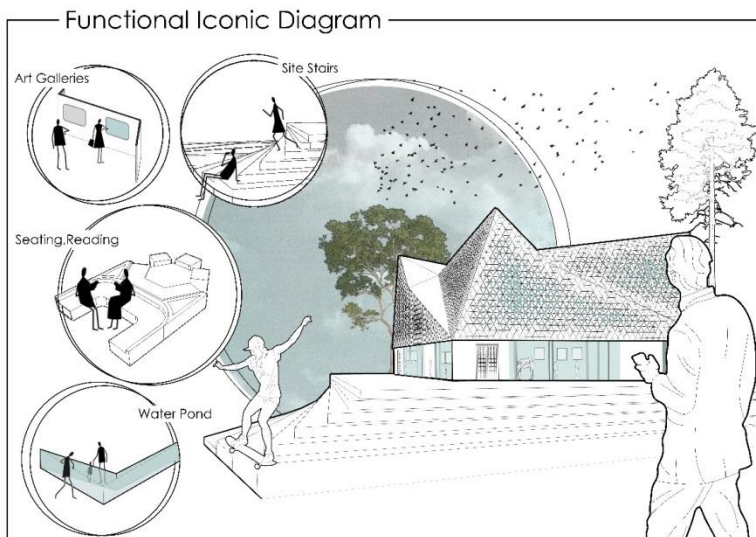


Figure 3: Functional diagram

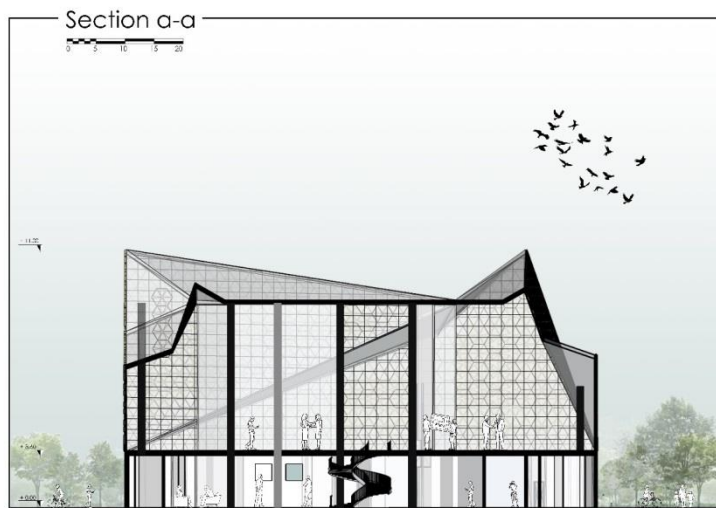


Figure 4: Section a-a

**Conclusion**

Man has always established a close relationship with nature and used it for meeting his needs. Architectural design based on natural structures, evolving for millions of years, can help solve many environmental problems, including the lack of identity in spiritless urban structures. A review of human-nature relationships reveals that in the pre-modern era, nature was thought of as the only reference for innovative and sustainable works like those of Egypt’s pyramids, while in the modern era, as

the Industrial revolution occurred, the human-nature relation was reduced to uncontrolled use of natural resources, with machines symbolizing inspiration for biological space design. In the post-modern era, with the growing environmental pollution and the crisis of global warming, nature, natural forces, and the type of organism-environment relationship were again focused on in architectural designs. The efficacy, function, aesthetics, and economy of natural forms have led architects to be inspired by nature in this era. However, inspiration from natural structures was not restricted to formative and appearance

impressions of natural forms; rather, the ultimate end of bionic architects was to use laws existing in nature to meet environmental conditions and forms. A study of bionic examples designed in recent years revealed that pavilions were one of the manifestations of inspiration from structures and rules prevailing over nature in architectural designs. Pavilions served as temporary resting places to create diversity and aesthetics in the urban visage, and to create a sense of pleasure and dynamism for the users. When entering a pavilion, urban spaces disappear and a sense of security and comfort is created. Inside the country, the empty place of using nature to construct pavilions and urban symbols is strongly felt. Thus, this study sought to investigate bionic pavilions in the world design a bionic pavilion.

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