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An Introduction to Bionic Designing: Matching the Design with the Form and Function Pattern

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Abstract: In the methodology of the Bionic design of products, the form and function mechanism has been a totality that guided the user to understand the object since a long time ago. The existence of form together with the function in the structure of an object or organisms is inevitable and has been differently defined by various theoretical perspectives. The manner and the extent of coordination between the two indexes have been one of the challenges in the bionic design methods. Different perspectives in the design methodology tried to redefine the totality of how and why the form and function has a relation with each other. The current study aimed at analysing the requirements, nature of the main functions and their relationship with forms. Accordingly, the study provided a document-based methodology using the rules of form and functions governing the organisms in the nature. Furthermore, it provided the recognition of the main factors determining the existing configuration of organisms to adapt with the successful man-made products. The matching between form and function has been observed in the investigation of natural and artificial samples through obtaining fixed pattern in the processing. The study followed an analytic-comparative research method. The results indicated that based on the bio-morphological and bionical analysis, every organism has a potential to shape its final form based on the body configuration. This potential was a motor generating vector of the organism and defined as an axis. Therefore, the main lines of the design were determined by analysing the generating vectors in the organisms. It was concluded that designing the main lines of the object configuration (based on the initial generating vector) and determining the form and function (simultaneously and step by step together), would lead to a type of product that was as efficient and successful as the organisms regarding functionality and aesthetics.

Key words: Generating vector, bionic design, biomimicry, designing, form, function

INTRODUCTION

The design of the products has been influenced by several efficient factors during the time span. The factors included the taste of clients, culture, tradition, social, political and economical requirements of the society. Besides, the factors should fulfil the functional and aesthetical needs of the consumers (The designing style has been changed through the history. The idea of human being about "correct design" has changed fundamentally and it is obvious in different styles. The change in one style or the change to other style is done through the modification in governing laws or thorough the use of new or modified elements. This can help us understand the different approaches in comparing the styles (Gruther, 1996). Then, the utilization of the visual elements such as form, material, colour, texture and decoration together with the concepts delivered to the consumers determined the final form of the objects in their design. Now a days, design has been defined as ideation and planning for all man-made products in many parts of the world. Basically, the designs can be viewed as a tool for improving the life quality (Goseili, 1993). Accordingly, the nature of form as one of the key elements in product design, establishes the structure of aesthetic in the product. Therefore, the relationship between how and why a form has been defined with regard to the content in both aesthetic and other analytical art studies (Azhdari, 2013). Satisfaction of the consumer with the product has also been emphasized.

However, considering the methods and schools of laws in the current era has no logic to guarantee that the quality of the form is comparable with the organisms created by God. The criterion for the design has referred to the nature and the relationships within to copy and represent the natural elements. The study investigated the cases of the forms in the nature, body of organisms and the man-made objects all from Bionic perspective. In addition, the relationship between the forms and their functions has been analysed to determine the initial and

the main structure of the form (identified as line or main vector). The study addressed two research questions: How did the form of products in the nature basically develop considering the Bionic approach in designing What are the factors affecting the successful natural and man-made products?

It was hypothesized that a criterion for recreating the simultaneous relationships between form and function in organisms could be used for the common methodology of the product design. The data collection method was documentary and library based and the analytical discussions included comparative studies.

Literature review: There has been many studies about the designing inspired by nature. Also large number of studies focused on the definition of form and function relationship in the field of product design. A considerable number of studies introducing the styles and methods related to bio-design (Bio-design is a kind of design based on the realities in organisms through using the system and function of natural elements) and organic designs (The form and colour of natural elements are mostly used in the organic design) have been conducted in Bionic design field. Arazm (2010) conducted a case study research to introduce a business brand product from organic design or Bio-morphism (The form and colour of natural elements are mostly used in the organic design) design. Furthermore, regarding the design elements, form and function have been defined in different ways.

Sarafioon (2010) redefined the form as: 'the element for making an object and it is understood clearly. Accordingly, form is considered as one of the most fundamental issues in designing. While in the past, the form and shape of anything were derived from the functional considerations'. In this regard, there are many studies with different views influenced by the schools of thoughts in art. Papanak (2005) stated that "during the history of designing, there were major conflict between the proponents of form and function in designing the daily objects and products. The common belief that form follows function was discussed in the beiginning of 21st century by one group. While the idea of function following form was provided by the other groups'. In the definitions of designing methodology for the objects, Mortazaee (2011) stated "designing is a process that refers to set of conscious decisions made by the designer or designer-creator. The study by Benyus about the recent findings in biomimicry and the book "Design for the Real Worl"by Papanek (2005) are very close to the definition of designing methodology mentioned earlier. Moreover, many form studies investigated the natural forms referring mostly to the form behaviour in relation to certain function mechanism in design, architecture or ergonomics of the product. For instance, such studies included the knowledge of Bionic and its subsets in the field of technologic design inspired by the nature (Pohl and Nachtigall, 2015). The recent analytical studies in the field of dominated forms in nature have been conducted by the well-known designer of Bionic, Luigi Coughlan, in that the findings were used as a theory in designing. However, there was no recorded study with form and function matching approach aiming at analysing and discovering the sources of Bionic, main lines of form and their relation to the function. The purpose of this study was an interdisciplinary investigation of this relationship in order to provide a novel redefinition of the form and function matching approach.

Bionic approach[4] along with the interaction between form and meaning: Following the Second World War, the studies provided a reconsideration with biological science and the use of technical knowledge. In this process, the technicians of different scientific fields achieved growing success in designing military equipment to implement mechanisms of body and behaviors of organisms against environmental stimulus. They achieved a designing methodology and introduced it to the US Bionic conference in 1958.

Bionic is considered as an interdisciplinary subject and one of the three top knowledge helping to improve the human life. The combination of the words biology and technique indicates that the beginning of 21st century presented new orientations in designing with the development of technology in the field of engineering. The Bionic technicians make an attempt to solve the technical problems by users, systems, mechanisms and comparable forms that are discoverable in the nature. Therefore, they develop objects and tools to copy or simulate the reactions and behaviors that match the living organisms (Harris, 2012). Bionic is a science in which simulation systems are designed to answer the human needs by scientific investigation of form and function mechanism in organisms. There are three approaches for designing a product:

- Inspiration from the natural organisms
- Inspiration from functional mechanism in natural organisms
- Using production and development processes of natural organisms in the products

Applying natural organisms in the structure, derived from the nature, needs technical knowledge to be used during the process of product design. The designers consider some cases in designing procedure with the Bionic approach that provided approximate methodology

of this field. Using the laws governing form and function in the nature and recognition of the main factors that determine the existing body, one can match them with the successful hand-made products. Based on the body configuration, every organism has a potential that helps them to make the final form. This potential is concealed in the patterns that are observable in the form of organisms. If the main lines of the object body is designed based on the initial form patterns, the form and function will be determined simultaneously together step by step. Finally, there will be a product that is as successful and efficient as the organisms in functionality and aesthetics. Such a design has been achieved by human beings through the mediation of patterns in nature in that the form is affected, developed and shaped by the main axis of pattern to obtain its function (Pye, 2002).

The mechanisms in nature are determined in a way that the system can operate efficiently. In the anticipated approaches from the function, the mechanisms contain complex connections with the interaction between the organisms and nature. The analysis of such mechanisms requires the technical knowledge of scientific engineering, biomechanics, aerodynamics, informatics, biomimicry, biology, metallurgy, anatomy and environmental science. It is obvious that the imitation and copyingare not adequate and logical to create the convenient methods in designing. Although, nature is full of inspirational sources for designers, it is not able to fulfil human beings' physical and psychological needs. It is oversimplification to see nature as the perfect model for fulfilling the needs without any change in the mechanisms and the forms.

MATERIALS AND METHODS

Bionical analysis of the generating vector in product design: According to the studies about elements and totalities of form in nature, the successful products in nature and the human life have a vector and foundation. The analysis of the vector can help us achieve the structures for designing based on form and function matching. They have been observed as a force and the potential concealed in the natural organisms. One or more vectors can be drawn in the body of every organisms that influence the form and function simultaneously. This vector and axis were called "generating vector" in this study due to the influence on creation of form and function. The term "generator" was selected since it defined the visual force in the form and function of the organ's body. Furthermore, the generator was efficient in the creation of form and shape. For instance, human beings move on two feet and have a vertical movement, so vertical generator could be defined for human beings. As shown in the simple line analysis (Fig. 1), every organism had different generating vectors based on the

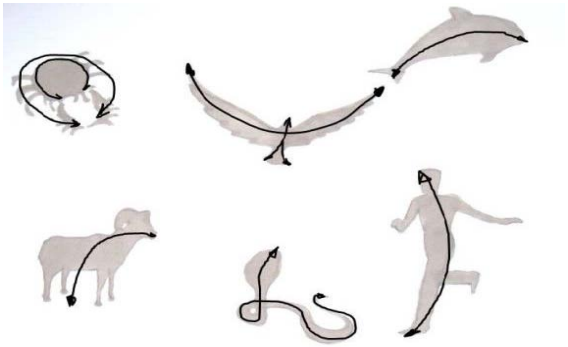

Fig. 1: Different vectors in organisms

Fig. 2: Three stages of formation from the main and initial

type of body structure. For example, a four-leg creature had different generating vector than crawling animals.

During the step by step identification of an object design, the potential vectors of the object in the main design built the structure and configuration of the main pattern. If the belief of the designer considered a pre-determined framework as the pattern in his design, there would be an unsuccessful product. The form would be multiplied in the creative thought derived from the attention to potential vectors and the design generator. This increase in form was affected by different ideas believing the changes in shape, thickness, material and texture. Such a view rejected the existence of the background information during the design. The designer increased the number of ideas based on the generating vector. As the generating vector had connection with the functionality of form in organisms, it was necessary to draw a completely correct 2D line (in the initial stage of the designing process) acting as spinal cord of the object. The initial line was the generating vector of the object which was free of complexities and details. The investigation of successful objects in designing indicated that in the creation of ideas at next stages, one could move from 2.5 D (the stage in that the form did not have an obvious full size and it was moving toward the 3D stage) to 3D stage. In the 3D stage, the full size was revealed and more details, such as colours and patterns were included (Fig. 2).

The generating vector could be seen in organisms like shark. The visual feeling derived from the body type

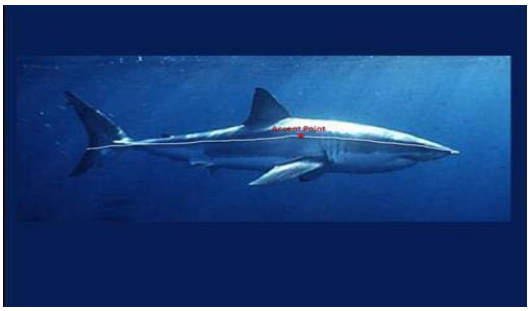

Fig. 3: The generating vector in the body of shark

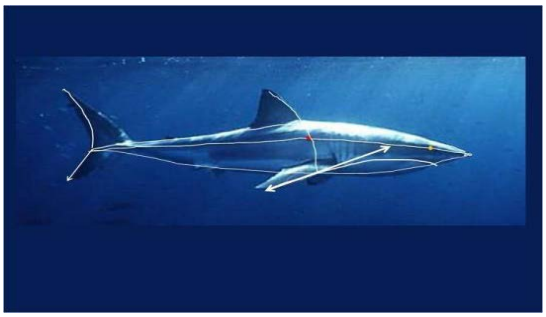

Fig. 4: The relationship between the body form of the shark toward the generating vector

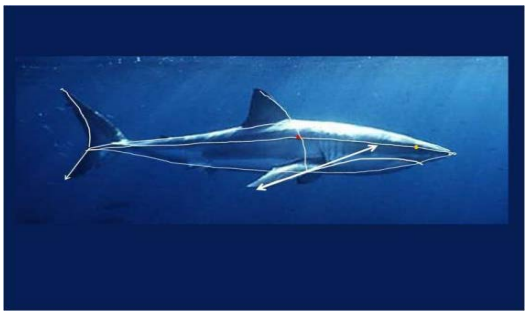

Fig. 5 The relationship between the upper and lower fins with emphasis point and generating vector

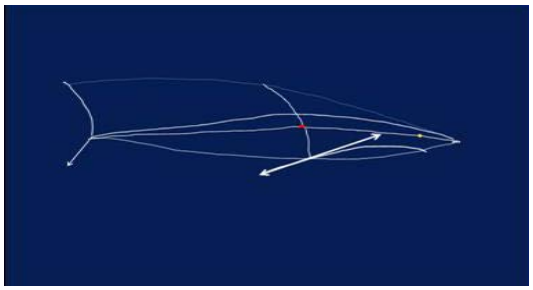

Fig. 6: The body form lines of the shark indicating the forward movement

of shark, was the flowing speed and agility. As shown in the Fig. 3, the form structure of the shark body was designed for fast movement.

Through drawing the generating vector of shark from the tail to the peak, a straight line with a curve was observed. The details were shown in Fig. 4-6. The turning point in the curve was located in the widest and muscular part of the shark which was named "emphasis point". The generating vector was also moved on the most observable part of the shark-the eyes. There was a connection between the fins and the emphasis point; the center of one part was connected to the next fin (Fig. 4).

A complex body was seen on the shark which was successful in aerodynamics, because such shapes broke the water evenly in relation to each other. Visually, the eyes of the audience were used to find the central points. In addition, three points were observed on the line drawn on the shark: beginning, end and the middle. The audience could draw the diameters of each drawn level in his mind. It was assumed that during the designing, the size lines had appropriate contact with each other through the points. In the Fig. 4, the upper line with a slope forward was connected to the centre of the second line with a slope forward. If the slopes were vice versa, they won't be in coordination with the shark movement.

Moreover, they would be in contrast with the forward movement. However, if the next line was drawn through the middle of the next fin, it would contact with the space between the emphasis point and the eye of the shark. There was also a forward slope in the tail of the shark. Consequently, all lines and points were there to move the shark forward. The relationship between the mouth line and the line under the fin was obvious. The eyes of the audience unconsciously connected the lines together in the integrated body. Accordingly, the line above the shark's body also followed the main generating of its structure which was also true for the lines beneath the body. The main generator was followed if the upper fins were connected to each other and it was observable again in the connecting line of fins beneath the shark (Fig. 5).

The linear analysis of the Fig. 6 indicated that the audience may not know the object if he saw it first. However, he would give a positive response to the movement of the object. If the audience was asked about the movement direction, he would agree that it was moving right. The next organism for analysis was the product which had a great dignity and visual influence. This feeling is due to the strength and symmetry used in Iranian architecture. The face of a lion was analysed in Fig. 7. The main generating vector was the symmetry line that passed through the middle of the face. The curve line was coordinated with the line under the nose. Besides, the return of the lips also determined the same line.

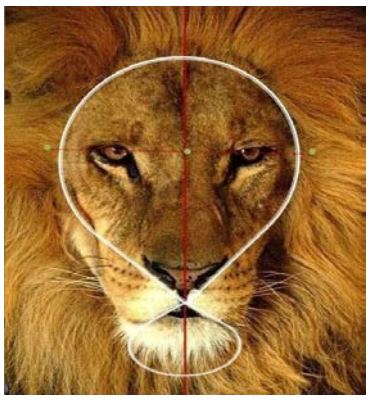

Fig. 7: The generating vector in form of symmetry line in the face of lion

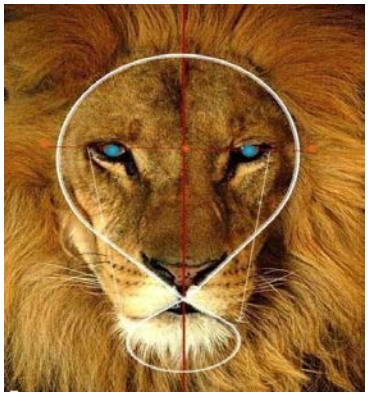

Fig. 8: The emphasis point between the eyes of the lion

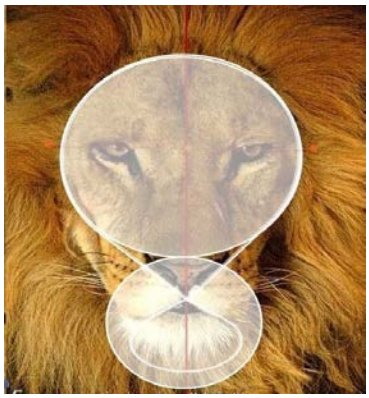

Fig. 9: The division of the lion's face into analytic sections of environment and operation

Although, the lines did not exist in the reality, the audience saw it unconsciously. The emphatic points located on the two curves created a point on the main generating vector that is the main emphatic point moving exactly through the eyes. If an imaginary circle above was drawn in front of each other, there would be two circles with two different functions. Accordingly, the upper circle is the thought section responsible for the operating section. Actions like smelling and hunting were the responsibility of the upper circle (Fig. 8).

Careful consideration of the proportions created a feeling of dignity and splendour in the face of the lion. In Fig. 8 and 9, the lines have moved through the eyes and this form of the nose itself has a return line that referred to the eyes on the emphatic point mentioned earlier.

The whole view of the observer was focused on the eyes and their centre. When the audiences saw the lion, they concentrated on the eyes and the aggressive form in the eyes which looked like a triangular form. The visual reflection of the triangle made fear in the heart of the observer.

RESULTS AND DISCUSSION

Biomimicry relation and the generating vector in the bionic product design: The systematic relationships between mechanisms defined complex processes that were related to the function of several reactions together in the body of an organism. This process responded to a stimuli in an overall composition harmoniously together. The measurement of the forces and the intensity of the pressure in complex mechanisms required numerical calculations and the use of physics and mechanics beside the knowledge of space and aerodynamics. Moreover, the numerical data resulted in sectional answers and the experiments of simulated models were analysed via technical software and building scaled models. In this case, the Bionic constructivists have designed the products and spaces based on the organisms' mechanism (Braga, 2006). The relationship between form and mechanical functions created a process in that the environment was analysed and matched. The growth and evolution of organisms occurred when the form and function were coordinated. Therefore, the measurement of the environmental situation and the standards of building are the important factors in the analysis.

The understanding of science and materials and their application in the designing process was significant. The analysis of the texture and the building mechanism in the organisms would determine the selection of the material and the method of use in the design. The understanding of the cellular and molecular structure in the body of organisms and the physiologic and morphologic growth of them are practical in designing of smart systems, light-sensitive cells, sound and radars, robots and the human simulation computer systems. This approach was known as biomimetic biomimicry science which was based on the physiologic studies of the living organs (Pohl and Nachtigall, 2015).

The form and function mechanism of the birds have been illustrated for gaining a better result. In the first

example, the product design was the copy of form and function in the opening-closing mechanism and lever mechanism to crush an object. The generating vector in this example was the lever that looked like the Chalipa beak bird.

The forms were created when their shapes justified the function. This functions occurred under certain conditions. The process was smart and appropriate considering the determined angle in the structure of form or combination of forms. The softwoods and coniferous trees had conical fruits that include rich nutrients for the body of birds and animals. These organisms should have teeth, beak or systems for breaking the hard crust fruits. Chalipa beak bird was an example of this type. The bird ate the seed inside the fruit through its scissors shaped beak. The form of the beak was made up of two intersecting lines that made angles together. This angle helped the beak of Chalipa to break the crust of pine cones for eating the oil seeds inside the pine (Fig. 10).

The next example had a biomimetic view toward the flight style and used the flight mechanism to from the final product. In the principle of wings flapping, the constructivist Bionic was in line with formation and the procedure of designing required more precise analysis of the physical and environmental calculations.

The wings of the birds followed the four main patterns within a normal period of flight namely, flapping wings, reverse movement swing and wing folding. Wing flapping was a kinetic movement done around the axis that has the same direction with the flight angle. The reverse movement was an angled movement around the central line of the wings and the swing was an angled movement around vertical axis of the body. The movement structure acted as the flight system engine. The wings were parallel with the movement structure and swung forward and backward during the flight. The folding included stretching and bending of elbows longitudinally.

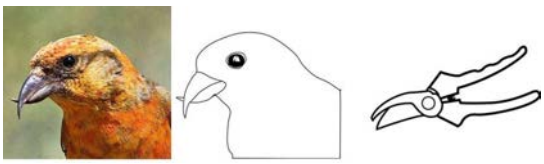

Fig. 10: The angled form of the beak in Chalipa beak bird that acts as scissors

Liang *et al.* (2011) indicated the movement angles in the four patterns (Fig. 11). Moreover, the action of elbows in the wings and the opening-closing of wings were illustrated with simple lines.

The two swing and reverse angles were defined in small scale in the birds with larger bodies. But, the stretch-backward movement in the folding of the birds were observed clearly because the difference in the size of birds demanded for different wing length and angled movements during the flight. The swing movement of the wings caused shift and rotation with two degrees of freedom in movement as the main factor in aerodynamic movements. The flight principle was different in birds and insects. A round of wing flapping in the birds could be divided into some parts. In a simple diagram, the wings of a bird could be divided into two flat levels and the period of one wing flapping could be indicated. These two flat levels included three sections: the section close to the root or the meeting point of the wing with body, the internal level of the wing and the external level of the wing. The internal level of the wing provided the tangential movement and thrust for flight. This level was capable to produce the driving force in the natural flight. On the other level, wings had a high capacity in upper and lower movement and the change of reversal angle. The lift and thrust movements (both upward and downward) made the speed and swing smooth. Although the airplanes today use the aerodynamics to decrease the air friction, they have quite simple structure compared with the quality of birds' flight. The lift and thrust system is indicated in Fig. 12.

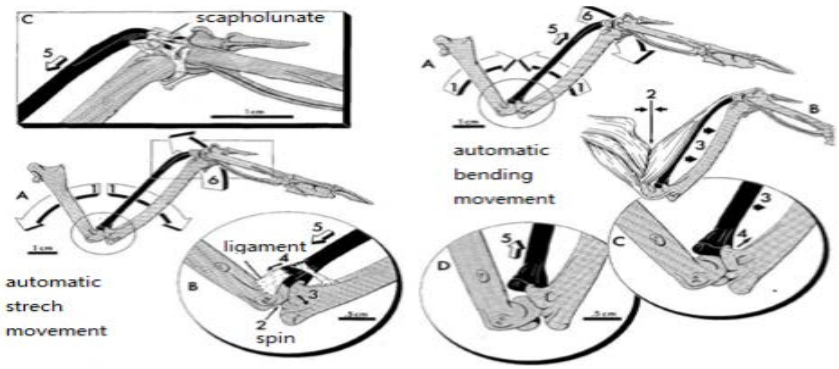

Fig. 11: The analysis of wings movement mechanism during the flight

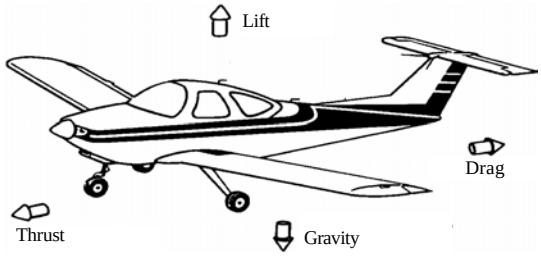

Fig. 12: The lift, thrust, drag and gravity in airplane systems

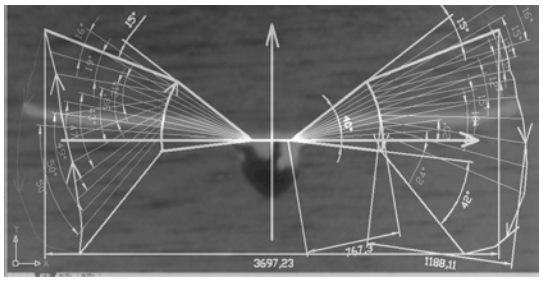

Fig.13: Two directions of wings flapping: upward and downward

According to the simplified model (Fig. 13), the range of angles in one period of wings flapping was indicated and the difference between the highest level and the lowest internal point. The angle in the highest point was about 40°. While the angle went to zero in the lowest point. Moreover, the measurement of one downward wings flapping period was indicated on the right and the measurement of one upward wings flapping period was indicated on the left.

The results of the measurement indicated that the different movements of the wings during one wing flapping cycle was influenced by the bending and stretching angle. In the recent condition, the decrease in opening of the wing would adjust and decrease the lifting force. In addition, it would balance the speed to prepare for the landing.

Apart from the speed and change in movement angle, there were other factors affecting the quality and type of the flight, such as weight and size of the body, the formation of the wings and its size. The findings of the modeling and simulation mechanism indicated the capability of the wings flapping mechanism for fulfilling the human demands in airplane and flight structure design in near future.

CONCLUSION

The findings of studies about the components relationship from different views: the Bionic design, matching between form and function in nature and the man-made products were summarized below: The matching between the form and function in the creatures indicate that appearance configuration and the body of the organisms are developed simultaneously with their function and also developed together to overlap the functionality-aesthetics needs. Therefore, forms of the products in the nature are planned according to the simultaneity of form and function together. It is concluded from this simultaneous growth that the so-called generating vector is the factor for shaping the design.

The generating vector is related to the initial line and the main column design along with the biological and formal capabilities of the organisms. So, the vector can be cited as the starting point of design in the analysis of objects. According to the results from the generating vector analysis in the case studies of organisms, all proportions referring to the form aesthetics, all intersections (the change in the shape or direction of form) and the functions have occurred on the generating vector.

The findings can be generalized to the man-made products. Based on the case study of flight function, it is found that the factors shaping the main form to reach certain function have created a direct attention to the generating vector used by the designer imperceptibly. Therefore, the factors could explain the success of both products in nature and the products made by human.

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