BIOMIMETIC DESIGN PRINCIPLES AS AN INSPIRATIONAL MODEL: CASE STUDY ON URBAN FURNITURE

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ABSTRACT
In today's world the amount of design examples generated by computational methods are increasing every day. Especially it is very significant to study the design opportunities that nature offers for humans considering its capabilities which help to solve human problems in aesthetic, economical and sustainable way together with the help of computational methods that offer engaging design solutions. Nature has time-tested forms, structures and solutions all around us, and Biomimesis is the study and application of natural solutions to design challenges through research and design, this article seeks to answer two questions: what is biomimetic design principles and how can it benefit the field of industrial design particularly urban furniture design? This article examined the relationship between biomimetic design principles and designing the urban furniture with parametric modelling. To show how biomimetic design principles being used by architects and designers some case studies included in this article. Utilizing parametric methods and tools, a design proposal was created to prove that the use of the natural characteristics (organism, behaviour, and ecosystem) and natural typology (form, construction, material, process, function) in designing urban furniture will improve the efficiency and expression of architectural objects in terms of sustainable, aesthetic and economic design ways. Considering the implications of biomimicry for solving human problems, this research aims to incorporate this approach into the design process of urban furniture and to create ergonomic public place in urban areas for temporary relaxing and for meeting points of people.
Key words: urban furniture, biomimicry, parametric modelling, computational design

1.Biomimicry

1.1 What is Biomimicry

Biomimicry can be defined as imitating or taking inspiration from nature's forms and processes to solve problems for humans (Benyus, 1997). Janine Benyus, a biologist and leader of the emerging discipline of Biomimicry says that for a more sustainable future we need to imitate nature (Benyus, 1997). According to Benyus, forms in nature are the obvious element for imitating; however, it is not enough to learn from nature. That's why Benyus emphasizes that fully learning from nature includes basic three levels: form, process and ecosystem (Benyus, 2008, p. 40). As Benyus writes in her studies that firstly is needed a close examination of an organism or ecosystem. After that, the design principles that are found in that organism or ecosystem should be find a way to logically apply these design principles. Learning about nature is one thing and learning from nature is another. Benyus (2008) also claims that "Nature is imaginative by necessity, and has already solved many of the problems we are grappling with today."

1.2 Biomimetic Design Approaches

Approaches to biomimicry as a design process typically fall into two categories. First is defining a human need or design problem and looking to the ways other organisms or ecosystems solve this. The other one is identifying a particular characteristic, behavior or function in an organism or ecosystem and translating that into human designs (Biomimicry Guild, 2007). Maibritt Pedersen Zari, an academician at Victoria University in Wellington, studied biomimetic design principles and proposed a list of requirements for the basic theories and ideologies of Biomimicry. She made a connection between biology, nature and architecture and was able to explain Biomimicry in three different categories and/or levels. The first level is **organism**, this refers to mimicking a specified organism. The second level is **behavior**, this refers to mimicking a specific type of behavior. The third level is **ecosystem**, which refers to mimicking a specific ecosystem and how it functions successfully (Zari, 2007). The next chapter of the paper explains and exemplifies these categories and/or levels with selected case studies.

1.3 Examples of Biomimicry

1.3.1 Organism Level

This level of Biomimicry learns the innovative ideas from the entire organism or a portion of the organism and then mimicked it to solve human problems by giving sustainable solutions. The world's fastest railway lines operate in Japan, famously called as "bullet trains" can be given as an organism level of learning from nature (Figure 1). A bullet-shaped nose was designed to maximize the high speed movement of these trains. As the speeding train exited a tunnel, it was building up a pressure wave that produced a loud booming noise. The noise was clearly a problem for the environment and a new design became necessary to fix it. To find a solution to the problem a birdwatcher on the team, turned to nature and discovered a kingfisher, diving into the water from the air without disturbing the surface. The streamlined shape of the kingfisher's beak acting as a wedge plied the surface for a low-splash entry. As shown in figure1 The team applied a beak design to the bullet train that not only helped to eliminate the booming sound but also made it more aerodynamic reducing the energy demand. Now it travels 10% faster and uses 15% less electricity. (Shinkansen Train, 2011).

Figure 1 Kingfisher Bird and Bullet Train [URL.01]

1.3.2 Behavior Level

Behavior level can be explained like an act that the organism does to survive in the nature by providing daily innovative solutions. *The Eastgate Centre, the* largest shopping *complex* and office block in *Harare Zimbabwe* is one of the most famous architectural example of biomimicry designed by Mick Pearce. The maintenance of traditional air conditioning system for the building was costly in Harare's climate, and thus required ecologically sensitive adaptations. The creation of self-controlled ventilation system to adjust the temperature at a comfortable level for workers and residents were necessary. Pearce was inspired by models of internal climate control in termite mounds. Termite mounds could sustain internal temperature stability by having a physical structure which enables passive cooling. Termites build huge mounds inside which they cultivate fungus for food. The fungus must be kept roughly at 30 degrees C, while the external temperature fluctuate from 1 degrees C at night-time to 40 degrees C during the daytime. The termites repeatedly open and block series of heating and cooling vents all over the parts of the mound during a day. The follows the same cycle with termites digging new vents and plugging up the old ones to control the temperature (Doan, 2012).

Figure 2. Termites mound and The Eastgate Centre building. [URL.02], [URL.03].

The ventilation system works in the same route. The materials used in the construction of the building has a high thermal capacity that help to keep and release the heat generated from the surroundings. Fans functioning on a cycle time serve to enlarge heat storage throughout the warm day and release heat during a cool night. Various openings across the building further enables wind driven airflow. As shown in figure 2, these design features work in collaboration to minimize changes in the temperature level inside the building while the external climate ranges (Doan, 2012) (Figure 2).

1.3.3 Ecosystem Level

To learn from existing ecosystems in nature and mimic them we should first know how it functions successfully and what principles and factors are needed for it to function in that way. The Zira Island Master Plan appears to be a perfect illustration of this form of biomimicry. It was developed by Bijarke Ingels, founder of BIG Architects. The Zira Island is situated on the Caspian Sea, within the crescent bay of Baku, the capital of Azerbaijan. The project aims to be a Zero Energy resort and entertainment city on the island. Although it may seem unattainable to create a zero energy resort that consumes a 1,000,000 m island, BIG found a solution for its successful implementation. It was Azerbaijani minister who brought this project to BIG. Encouraged by the previous projects that BIG had proposed, the minister deemed it great to recreate mountains out of architecture, since Azerbaijan is regarded as the Alps of Central Asia. According to Bijarke Ingels's (2009) words, the proposal for Zira Island rests on an architectural and the natural landscape of Azerbaijan (Bijarke, 2009). It is not only the iconic silhouettes of the seven peaks that this new architecture allows to create, but more importantly, an autonomous ecosystem enabling the flow of air, water, heat and energy to be channeled in most natural ways. As shown in figure 3, a mountain is able to create biotopes and econiches, to channel water, to store heat, as well as to provide beautiful sceneries, valleys, access and shelter. The Seven Peaks of Azerbaijan cannot be called a metaphor only. In fact, it embodies living models of the mountainous ecosystems of Azerbaijan (Basulto, 2009).

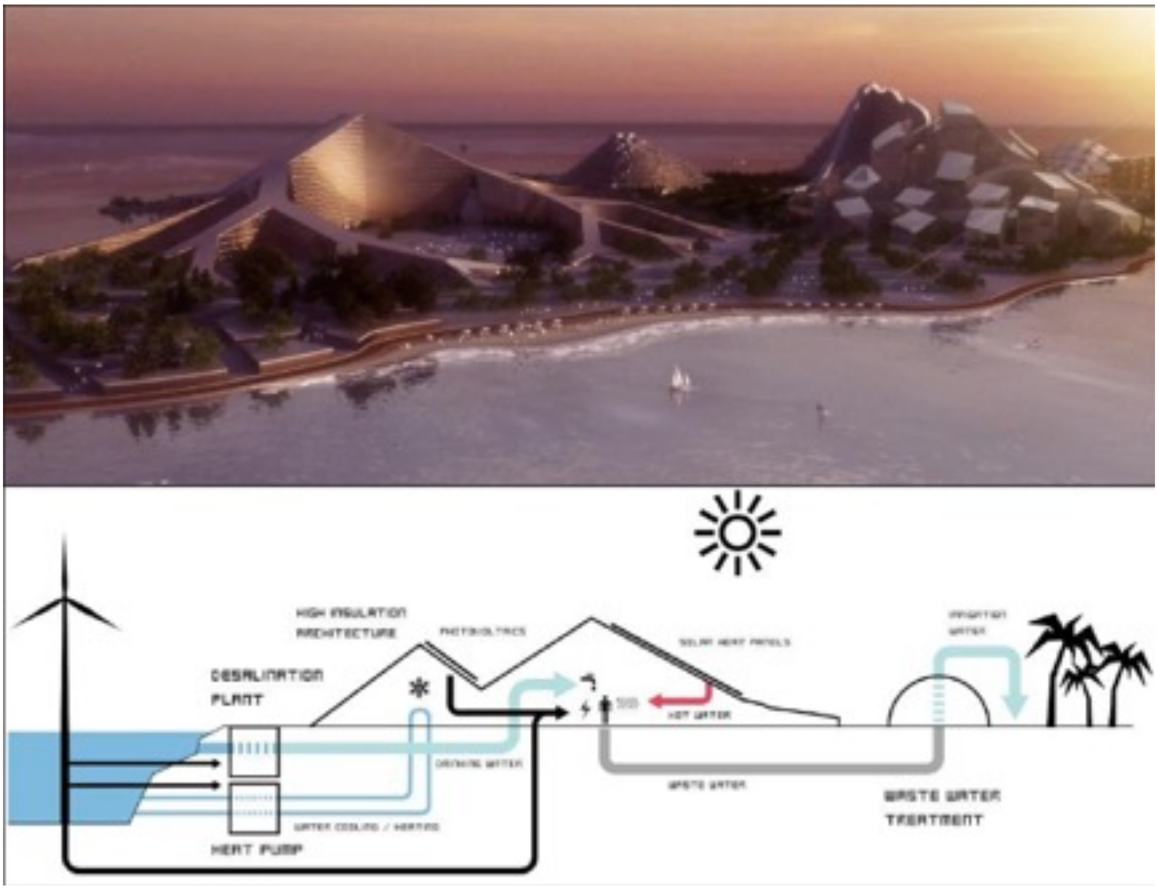

Figure 3. Zira Island concept view and ecosystem working principle. [URL.04]

2. A New Design Paradigm

In the course of the last a quarter century, computers have turned out to be to a great degree pervasive in the architecture and design fields. Initially utilized as an approach to draft all the more rapidly, progress in technology has permitted computers to be a significant design tool for architects (Jester, 2014).

2.1 Parametric Design and Related Tools

Since computers were developed, they have been interwoven with the profession of architects and engineers. Starting in the 1960's with the innovation blast taking after World War II, it was obvious that architecture and all design would be influenced by developing technology. Industrial design had as of now started using advanced digital design tools to make and refine industrial products. In 1970, digital design research moved forward and started focusing on delivering advanced 3D. These models were structures produced by content based code and script entered by the user. A disadvantage of this information procedure was that the models couldn't be immediately controlled. One noteworthy development of these 3D examinations was the innovation of NURBS (non-uniform rational basis spline), made by Ken Versprille for his PhD research (Cohn, 2010). NURBS was another method for programming a line inside the computer programming. It was less escalated on the computer equipment and more instinctive for the designers to draw (American Institute of Architects, 2012)

As computers and technology keep progressing, architects started exploring different forms and structures using 3D modeling and parametric design. By the mid 1990's, computer progression permitted designers to tectonically control standard shapes and forms such as blocks, chambers, circles and pyramids. Also, by the 21st century, computers had sufficiently grown to permit designers to control and produce more advanced shapes in a digital realm. This took into modeling and experimentation of all structures and materials. Parametric design helped permitting designers to set limits and points while generating advanced/complex shapes and structures. As a result of this, digital design tools cause discovering o a new way from computers to digital fabrication and helped designers, engineers and architects to design what cannot be done by hand/traditional methods (Cohn, 2010).

Digital age brings new tools for parametric modeling. The nature of parametric modeling is that all attitudes of design are interlinked with each other. With aid of parametric software this design components can influence each other when one of this parameters are changed. Such approach caused to born of new paradigm and design theory, parametricism.

There are many tools and computer programs which support parametric modelling. Maya, CATIA and Rhinoceros are one of this computer programs. As advances occur in this programs in terms of supporting parametric modelling many designers and architects began to use this software in order to explore and generate new forms, structures and designs. McNeel Company is the founder of Rhinoceros3D (Rhino). Rhino uses NURBS modelling which is the Non-Uniform Rational Basis Spline and was first developed in 1970's and 1980's (Cohn, 2010). Generally, Rhino used for jewellery, marine and industrial design and in recent years this software has been used by architects. Its easy human interaction, low cost in comparison to other modelling programs and diverse usage in different fields of industry make Rhinoceros3D popular among users in creative industry (Jester, 2014).

As it mentioned Grasshopper is a plug-in for Rhino. This plug-in works directly with Rhino components using graphical algorithms (Figure 4). The objects that are generated in Rhino can linked with the Grasshopper algorithm components. In other words, Rhino models can be easily manipulated in geometric ways based on the designed parameters in Grasshopper. For the easy user interface developers designed scripting way of Grasshopper by using visual icons.

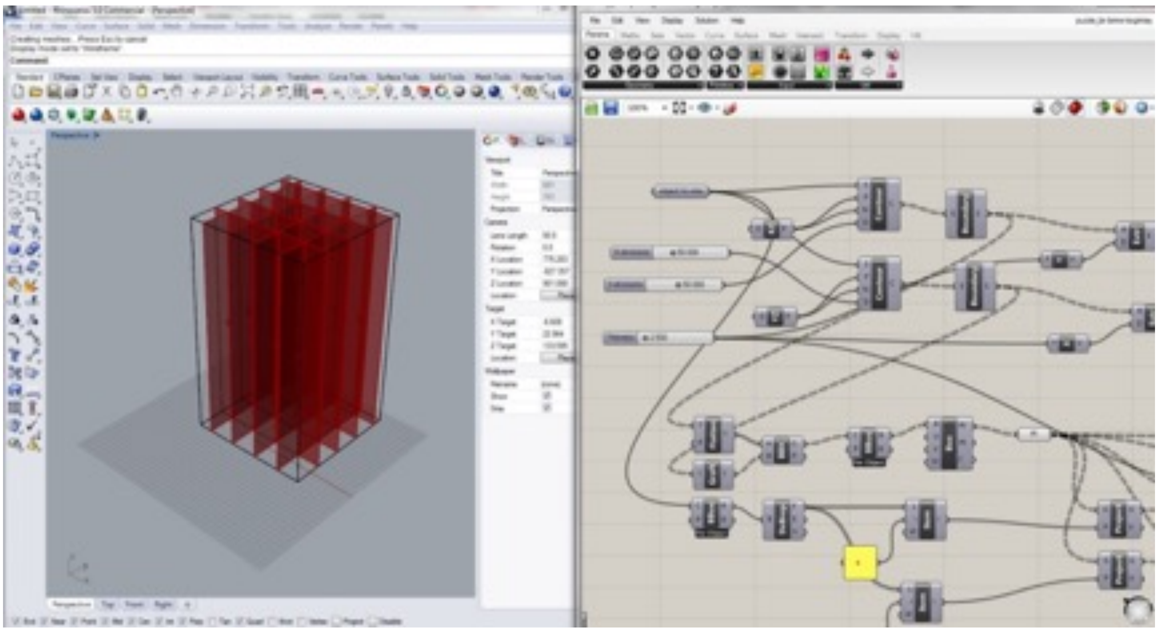

Figure 4. Rhino and Grasshopper interface; Example of Rhino and Grasshopper relation (Graphics by Ujal Abbasli)

Relationship of Biomimetic and Parametric design

In nature where natural systems created with minimal material input have a high degree of morphological variation and fulfill their functions in maximum performance (Natchtigall 2004). On the other hand, due to manufacturing constrains architectural systems have long been to be constructed with a large number of similar elements. Moreover, it was almost impossible to imitate natural forms and structures using minimal construction materials. However, thanks to advances in computer aided design and computer aided manufacturing, using parametric modelling principles for digital fabrication opened new way to architects and designers to realize their nature inspired form and structures with high level of morphological differentiation. Therefore, through the application of digital fabrication methods by using parametric modelling tools biomimetic design approach for new forms and structures can be generated (Krieg, et.al 2009). In addition to that, thanks to advances in digital fabrication methods precision in manufacturing has rapidly increased which lead to diminishing mistakes in fabrication and to increment quality in manufacturing.

3. Urban Furniture

Street furniture can be described as objects and facilities which function is to service to the public. Street furniture is one of the decisive elements in the image of city, its quality and environment even though it has relatively small scale compared with other elements of urban landscape (Krauel, 2007). Street Furniture concept was developed in mid 19th and it is considered the element of urban landscape with the most closeness to people (Figure 5). It is defined as being both private and public because not only residents of the urban landscape enjoy it, but also visitors of that urban landscape (Wan, 2007).

a) steet furniture in past

b) modern urban furniture

Figure 5. Urban furniture in the past times (a) and contemporary one (b) [URL. 05-06]

Urban furniture is a complex system and an important element in urban landscape which aims satisfying needs of users while considering total landscape design. In fact, Identity of urban Landscape is established by street furniture. That is why it is important to understand how street furniture will coordinate with not just with one another, but also with surrounding objects (Eckbo, 2001).

Because street furniture is a complex system with many functions, it is grouped into 4 main functions to be analyzed. First function is called **Basic** which covers core features of street furniture like convenience, safety, protection, etc. Second function is called **Environment**. This function enhances surroundings by its appearance, quantity, quality and etc. Third function is **Decorative** and it emphasizes form, color, style, etc. Forth and last function is called **Complex**. This is about how street furniture can be combined to achieve complex goals in urban landscape (Wan, 2007).

As shown in Table 1, several Design principles exist in Street Furniture design like functional, technical, aesthetic, environmental, humanist. Functional and technical principles come into effect when for example, selecting function of street furniture for locations and considering dimensions, distance. There are different technical design standards established by British Standard Institute. Aesthetic principle increases value and attraction of street furniture and incorporates form, color and material. Starting since mid 19th, Humanist approach gained new popularity. People became top priority in the design of street furniture. These design principles aim to assist humans to interact with environment. Uniqueness of street furniture should accompany localism and regionalism. It also has to assist to support barrier free environment so humans can enjoy street furniture regardless of their background (Wan, 2007).

DESIGN PRINCIPLES OF URBAN FURNITURE

FUNCTIONAL	TECHNICAL	AESTHETIC	ENVIRONMENT	HUMANIST
• Locations • Distance	• Standards • Dimensions	• Form • Colour • Material	• Coordination of street furniture with other elements	• Users are the top priority in design • Ergonomics • Accompany localism

Table 1. Design Principles of Urban Furniture (Graphic by Ujal Abbaslı)

4. Case Study

Inspiring from Cocoon for Designing Urban Furniture and Structural Skin

In order to understand how biomimetic design principles can contribute to the designing process of the urban furniture a case study should be done. Therefore, the cocoon of the Urodid Moth which has the unique structural skin can be the inspirational source for the study.

Figure 6. The Urodid Moth Cocoon [URL.07]

In Figure 6 is shown the cocoon of the Urodid Moth, and it is unlike to other cocoons in the nature. This cocoon is like a building of 3D net. The cocoon's open structure hangs in mid-air for keeping the pupa from drowning in a rain shower and prevents it from being destroyed by ants or insects. Using this structure as an inspiration model for designing urban furniture by using parametric modelling can be feasible. After referring back to the metaphor behind the cocoon's structure and how it is designed in response to needs of the pupa, there was further investigation on how the structural skin of urban furniture could be designed in such a way. In order to continue this investigation, it is needed to determine which biomimetic design principle is more proper for this case. Since this cocoon can be explained like an act that the organism does to survive in the nature by creating this innovative structure; **Behavior** level of biomimicry is selected for analysing this structure and then applying it to the design process of urban furniture. Thus, to design the urban furniture it is needed to determine the needs of the users in public areas and set parameters for further design process because the pupa acting in the same way to design its cocoon. In other words, a set of parameters and forces which are mentioned in previous paragraph cause pupa to build such structure. Hence, the matrix table with parameters and forces was generated with needs of users in public areas to shape the structure (Table 2).

Parametrs / Forces	Width	Structure	Height	Material
Density of people	The width of the structure should be according to the density of the people			
Seating		The structure should allow people to seat		Material of the structure should be relevent in terms of seating
Standing		The structure should create spaces for standing		
Position of the sun		The structure should designed to partially prevent people from the sun light	The height should be high enough to create shadow spaces	

Table 2. Matrix table representing parameters and forces that shaped the structure of urban furniture. (Graphics by Ujal Abbaslı)

After setting the parameters and forces in matrix table the relation of them was taken to determine the design brief. Hence, the width of the structure should be according to the density of the people and the height should be high enough to create shadow spaces and partially prevent people from the sun light. Moreover, the structure itself should create spaces for users to stand freely and providing seating for temporary relaxing with the relevant material in terms of seating. This design brief is used to generate 3D model in Rhinoceros and structural skin in Grasshopper for designing urban furniture (Figure 7).

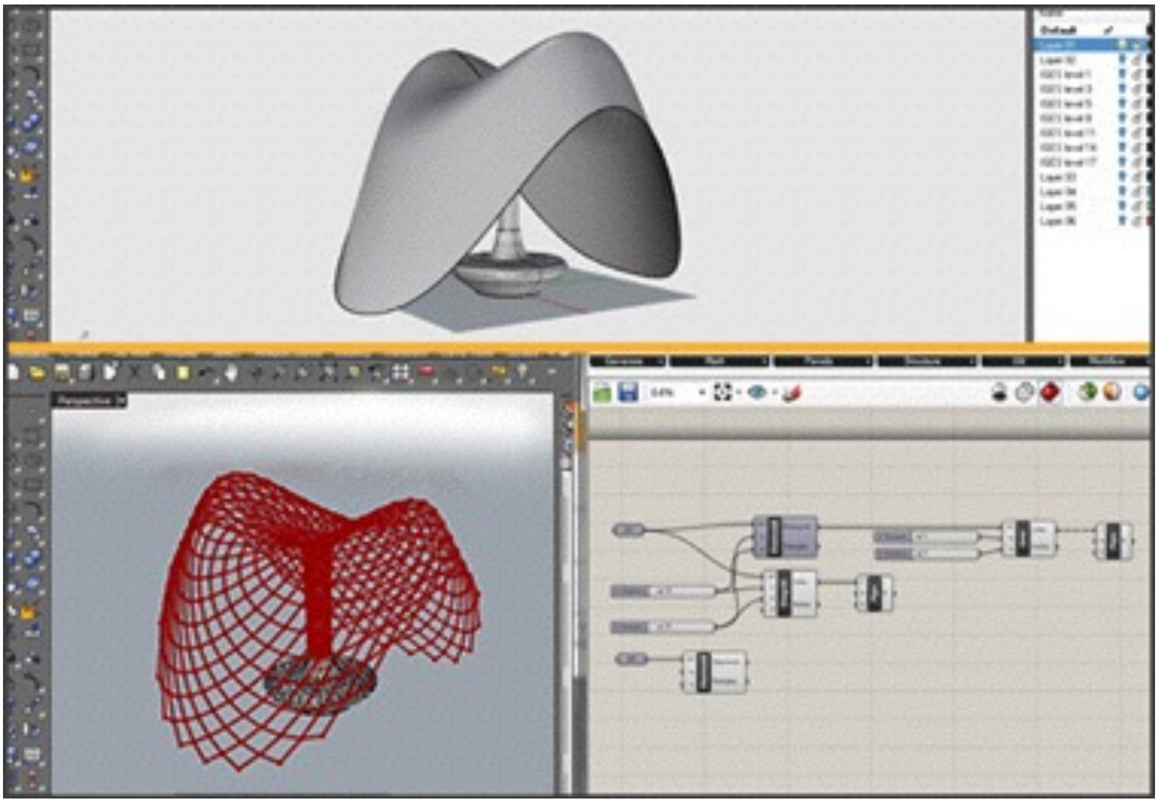

Figure 7. Rhinoceros model and applied structural skin in Grasshopper (Graphics by Ujal Abbasli)

FINAL DESIGN AND CONCLUSION

After the structural skin applied based on the matrix relations and cocoon's structure metaphor the final design concept was generated and visualized. Considering the implications of biomimetic design principles, cocoon's structure used as inspirational model for this study and incorporated this approach into the design process of urban furniture to create public place in urban areas for temporary relaxing and for meeting points of people. The structure prevents people from direct sun lights by creating partially shadowed spaces. Considering the uses of **bamboo** in sustainable building both in ease of usage and because of economic factors (Reubens, 2010), bamboo is selected as a construction material for the structure. To sum up, using **“Behavior”** as natural characteristic and **“form”** and **“function”** of cocoon as a natural typology proposed urban furniture was designed to show how nature can be model for urban furniture design in terms of sustainable, aesthetic and economic design ways (Figure 8).

Nature always gives us innumerable inspirations. Designers just need to look at nature and ask for solutions that can use in their designs. The aim of the article was to answer two questions: what are biomimetic design principles and how can it benefit to the field of industrial design particularly to urban furniture design. This article examined the relationship between biomimetic design principles and street furniture and designed the urban furniture with parametric modelling.

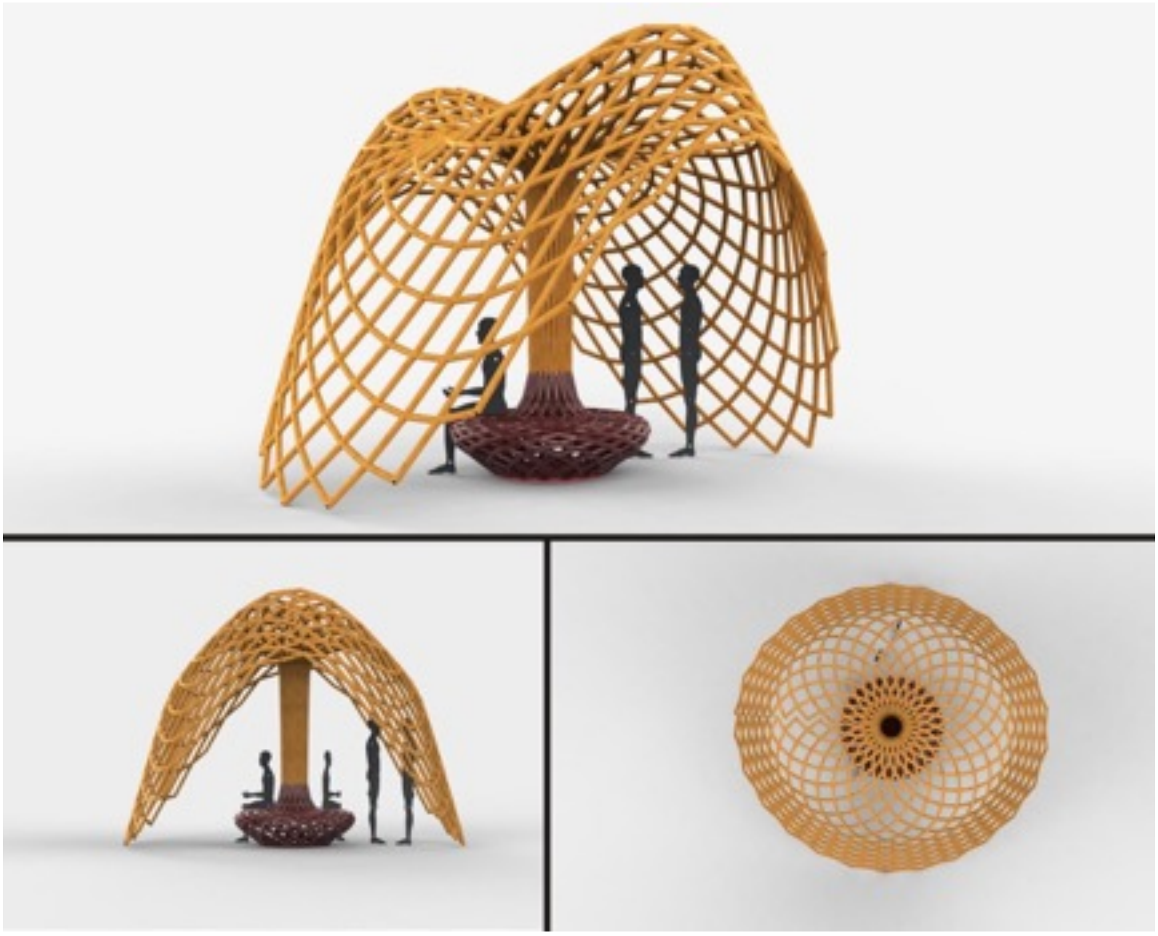

Figure 8. Final proposed design (Graphics by Ujal Abbasli)

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