IJBES

International Journal of Built Environment and Sustainability
Published by Penerbit UTM Press, Universiti Teknologi Malaysia
IJBES 9(3)/2022, 47-60

A Biomimetic Approach to Water Harvesting Strategies: An Architectural Point of View

Duygunur Aslan
Ministry of Environment and Urbanization, Ankara, Turkey.

Semra Arslan Selçuk
Gazi University, Faculty of Architecture Department of Architecture, Ankara, Turkey

Güneş Mutlu Avinç
Muş Alparslan University, Faculty of Engineering and Architecture, Department of Architecture, Muş, Turkey.

ABSTRACT

In the current century, due to global warming, pollution, climate change and the exponential growth of the world population, water resources are consumed at alarming rates. For this reason, sustainable methods of water harvesting have become an important research topic of today. In built environments, which are known to account for a significant share of total water consumption, places the development of alternative solutions for the acquisition and effective use of water to the forefront of the agenda. On the other hand, "nature" offers clues about how plant and animal species manage to use limited water resources with sustainable methods while also providing innovative solutions for "water harvesting". In this context, this research seeks to answer "Can water harvesting strategies of living organisms that manage to obtain water via sustainable methods be transferred to building design through biomimicry?" In this direction, considering the potentials of biomimicry in architecture, plants and animals that are successful in water harvesting have been researched. In addition, biomimetic designs inspired by these living organisms have been analyzed. As a result of this analysis, it has been concluded that, with the use of biomimetic design techniques effective water harvesting methods can be developed for buildings.

Article History

Received: *11 April 2022*
Received in revised form: *14 May 2022*
Accepted: *08 July 2022*
Published Online: *31 August 2022*

Keywords:

water harvesting, rainwater harvesting, biomimetic architecture, biomimicry.

Corresponding Author Contact:

gunesavinc@gazi.edu.tr

DOI: 10.11113/ ijbes. v9. n3.969

1. Introduction

Being the source of life that has no substitute, water should be preserved and left to future generations. The continuity of life on earth depends on the availability of sufficient and good quality water. Undoubtedly, water deprivation is one of the most critical environmental problems that are being faced today.

While almost 70% of the earth's surface is covered with water, according to the World-Wide Fund for Nature (WWF) report of 2014, approximately 1% of these resources contain potable and accessible fresh water. In the current century, the demand for water has increased continuously due to the effects of urbanization and population growth, as well as global warming, pollution, climate change, and the irreversible consumption of existing water resources. Moreover, it is expected that the world population will increase exponentially in the coming years and 2.5

billion people will be added to the existing population by 2050. According to a report of the United Nations Department of Economic and Social Affairs released in 2009, it is predicted that urbanization will continue to increase and approximately 60% of the population will live in cities.

As a result of population growth and urbanization, the growing demand and increase in water consumption in built environments is inevitable. Therefore, it is clear that the role of buildings in the perpetuation of water problems will be significant. In this direction, it is important to study and discuss alternative solutions in order to obtain, use and protect water efficiently in "built environments".

A significant portion of the worldwide consumption of water resources comes from construction and housing activities, which are necessary to meet people's basic needs for shelter. This situation increases the demands for developing water management strategies in built environments (Taskan, Mutlu-Avinç, Arslan-Selçuk). In this context, biomimetic solutions for water harvesting studies in buildings are frequently investigated in the literature. Badarnah and Kadri (2015) designed a wall surface capable of harvesting water. Similarly, Jalali, Aliabadi, and Mahdavinejad (2021) developed a water harvesting facade proposal based on water harvesting strategies in plants. Mazzoleni (2013) also investigated water collection strategies in living things in nature and presented conceptual solutions. These mentioned studies are single applications investigating biomimetic water harvesting applications. However, there is no study in the literature exposing the approaches on biomimetic water harvesting practices. In this context, this study aims to examine the water harvesting biomimetic design and application examples in the literature and to reveal the current situation.

In this context, the question that motivates this study is "Can water harvesting strategies of plants and animals that manage to obtain water via sustainable methods be transferred to building designs through biomimicry?" Within the scope of the research; strategies developed for the purpose of obtaining water needed in the buildings by using the potentials of the environment, especially rain harvesting, were investigated.

Considering the effective role of built environments in water consumption, modern solutions to the problem of water insufficiency on the basis of buildings have been researched by literature review method. As a result, for the effective use of water in modern buildings it was observed that 3 basic strategies were used, namely wastewater recycling (use of gray water and black water), water-saving installation selection and rainwater harvesting, but among these strategies, the focus was on rainwater harvesting, the variables of which are related to architectural design decisions. It is seen that there are very limited number studies on this subject in the literature. In this direction, 11 modern buildings serving different usage purposes were selected and their water efficient strategies and rainwater harvesting methods were analyzed. The building samples were selected from the buildings, which were designed and/or built for sustainability and water efficiency, and where various architectural design decisions were made in order to make rainwater harvesting in the design. Buildings with a uniform function and a certain size were not preferred, instead, a wide range of choices were made, from small-scale projects to complex projects, from single-storey buildings to high-rise buildings, from residential buildings to commercial, educational, cultural and sports structures. Thus, it is assumed that rainwater harvesting through structures will be evaluated independently of such criteria. As a result of the analysis, rainwater harvesting methods used in modern buildings were classified according to the quality of the architectural surfaces that collect rainwater, and it was revealed by which methods rainwater harvesting could be done in buildings.

In the next section, the water use strategies of living creatures in nature were examined, and the designs that could arise as a result of transferring the obtained data to the buildings through biomimetic design were questioned. Since the number of samples of biomimetic water harvesting is very limited in the literature, all samples obtained regardless of climate were examined. The designs were analyzed in terms of effective water use methods, and the differences and innovations brought by these approaches were revealed. To summarize, research has been done on traditional and modern techniques of obtaining water through structures, and then innovative methods introduced from a biomimetic perspective have been examined. Related methods were analyzed and compared with sample applications and designs, and potential architectural elements that could serve innovations and water harvesting were revealed in line with the data obtained.

2. The Relationship Between Biomimesis and Architecture

Biomimesis, which is referred to in literature by different terms such as biomimetic, biomimicry, and bionic, is the science that examines systems in nature and then mimics these systems, models, processes or strategies to solve related problems (Rao, 2014). This approach was embodied in the book "Biomimicry: Innovation Inspired by Nature" by Janine Benyus in 1997 (Rankouhi, 2012). According to Benyus, "biomimicry is a science for problem solving, which aims to use nature as a model, measure and mentor, and uses the information obtained by analyzing the models, systems and operations of nature in this direction" Benyus (1997).

Zari (2007) defines three stages for existing biomimicry applications: organism, behavior and ecosystem. The level of "organism" can refer to a holistic organism such as a plant or animal, but is also used to imitate a certain part or whole of the organism. The second stage refers to "behavior" and involves the transfer of specific / limited or broader holistic behavior of the organism. The third stage means imitating the entire "ecosystem" and this includes the transfer of its general principles. According to Zari (2007) two distinct approaches to biomimicry as a design approach exist: Problem-Based Approach and Solution-Based Approach.

Problem-Based approach was found to have different naming in various literatures such as "Design looking to biology" (Pedersen Zari, 2007), "Problem Driven Biologically Inspired Design" (Michael Helms, Swaroop S. Vattam and Ashok K. Goel, 2009) and "Top-down Approach" (Jean Knippers, 2009) all having the same meaning. In this approach designers look to nature for solutions. The Solution-Based approach is also referred to as "Biology influencing design", "Bottom-Up Approach" or "Solution-Driven Biologically Inspired Design". In this approach, biological knowledge influences human design (Nkandu and Alibaba, 2018).

Looking at the history of architecture, inspiring / learning / adapting from nature is not a new approach and has been used for many years. Having learned to live in communities, human beings have started to observe formations in nature to address the need for shelter. Human beings have not only used materials obtained from nature but have started to develop initial building techniques by consciously or unconsciously observing or imitating natural constructions (Selçuk and Sorguç, 2007).

Looking at the architecture of ancient times, it is seen that the forms, structures and proportions seen in nature are often imitated. For example, it is known that columns, the main structural element of Greek and Roman temples, were developed to support roof and beam loads inspired by the load-bearing trunk of the tree. Motifs that resemble various trees or plants are frequently found not only in the column headings of the buildings, but also on the façades and interior decorations (Rian and Sassone, 2014). It can be said that "fan vaults", one of the most important structural elements of churches, which are the symbolic structures of the Middle Ages, were also inspired by the form and structural structure of the tree branches. (Aziz and El Sherif, 2015)

With the coming of the industrial revolution in the 18th century, the nature-inspired movement in architecture also changed and developed in line with the technological advances of the period. Until the industrial period, while the movement inspired by nature generally continued with an analogical approach in line with form and structural pursuits it has developed by spreading to different areas with the production of new building materials and the emergence of new construction techniques. As a result of this development, nature started to be imitated in terms of both form and function (Gertik, 2012). The engineers and architects have benefited from the construction principles of natural formations especially in structural designs. In this regard, Horatio Greenough argued that the principles of designing a skeleton can be learned from the skeletal systems of animals and insects in a theory he put forward in 1851 (Öztoprak, 2008).

It was possible to observe this understanding in the late works of Le Corbusier, one of the pioneers of modern architecture. When speaking about the Ronchamp Chapel in Ronchamp, France in 1954, Corbusier said, "*A crab shell I found on Long Island near New York in 1946 rests on my drawing table. It will be the roof of the chapel…*" (Varlı, 2013). In the same years, Mexican designer Felix Candela started to create products by examining the pressure and breakage resistant structures of seashells and eggs. As seen through the geometric investigations of form in Los Manantiales he also frequently worked with hyperbolic paraboloids found in nature (Bozkurt, 2010). Built in 1962, the TWA airport building, in which American architect Eero Saarinen evoked the concept of flight by imagining the bird form, is among the important examples of nature-inspired architecture. Similarly, Santiago Calatrava has been inspired by the forms and structures of nature both visually and functionally in many of his buildings (Yesilyurt, 2008). The city of arts and sciences building can be cited as one of the examples.

Buckminster Fuller and Frei Otto are also among the important designers who analyze natural forms to create structurally efficient designs and thus design innovative structural systems (Öztoprak, 2008). Otto was not only concerned with what natural structures were, but also how they came together and formed. He conducted multidisciplinary research and experiments on structural efficiency by integrating the principles of biology into the design process within his institute (Institute for Light Weight Structures) in Stuttgart in 1964 (Pasic, 2014). Buckminster Fuller (1895–1983) argued that there is a technology in nature that is both dynamic and functional, and its resulting products light. He said that the optimum efficiency of natural construction contains important clues for man-made structures (Türk, 2018).

Today, architectural design perspectives have changed with the emergence of a new set of problems that have direct effects on nature such as climate change, population growth, unplanned urbanization, pollution and the depletion of natural resources. To adapt to the natural environment, sustainable architectural design strategies have started to be developed that can meet the energy and water requirements in a renewable manner within their own systems. In this sense, energy and water efficiency have become an important design criterion. In this direction, biomimesis has become one of the frequently used areas to solve the sustainability problems of the built environment (Öztoprak, 2008).

In summary, when looking at the history of architecture, it is seen that architectural ideas and practices have an absolute interaction with nature in line with the needs and possibilities of the time. Although the approach of imitating nature in architecture varied according to the dynamics of said times, nature remained the role model for many designers. The movement of learning from nature has gone beyond the formal imitation of nature as a result of the development of technology and research opportunities in the historical process. With the integration of biological information into the design process, imitating nature has gone beyond the metaphorical and analogical approach. The rules that govern natural forms have been used to solve problems in the functioning of architectural structures, and at the same time have extended over many areas such as structure, material, color, structural efficiency, energy efficiency and sustainability. Today, the movement of learning from nature, which unites under the umbrella of biomimesis and cooperates with many branches of science, continues to develop in the field of architecture. In recent years, biomimetic study centers have started to spread in universities all around the world. Some examples are "Biologically Inspired Systems Lab in Sweden, the Centre for Biologically Inspired Designs in Atlanta, and the Centre for Biologically Inspired Materials and Material Systems at Duke University, North Carolina" (Nkandu and Alibaba, 2018). According to Benyus (1997), "*if this learning process continues by spreading in different disciplines, a 'biomimetic revolution' will be experienced in the coming years*". To sum up, it is possible to state that biological data has the potential to create new paradigms in the field of architecture, as in other branches of science and design.

3. Water Harvesting in Built Environments

In the literature, there are different methods of water harvesting in built environments. These methods can be listed as atmospheric water harvesting, seawater harvesting (desalination), groundwater harvesting, and rainwater harvesting.

Atmospheric water (moisture, fog, etc.) harvesting is described as the process where water particles in the air are condensed to obtain water. Various designs and devices have been developed to obtain water with this method. For example, a system called the "foghive" with fog-catching networks was developed in South America by Dr. Cristian Suau (Suau, 2010).

The seawater harvesting method is used to separate the salt in seawater and convert it into fresh water. Although seawater treatment is considered a good water source alternative to obtain potable water, the cost of this technology is not considered as a viable option for all regions and countries that struggle with drought conditions. In addition, it is predicted that this will not be an environmentally friendly method in the long term as the desalination process creates a significant amount of waste accumulation (Bradshaw, 2008).

Groundwater harvesting is one of the methods used in regions where accessible water resources are insufficient. It is not recommended to choose this method in the long run because it is considered disruptive to the existing ecological balance by causing irreversible damages in the natural water cycle. In addition, this method is not economically sustainable as it requires the use of wells and pumps, which are very costly to develop for groundwater discharge (Bradshaw, 2008).

Rainwater harvesting is one of the most common methods to obtain water both in the past and present. According to the World Overview of Conservation Approaches and Technologies Network (WOCAT) database, rainwater harvesting is defined as the "collection and management of rainwater to increase water availability for the continuity of the ecosystem as well as domestic and agricultural use" (Liniger and Studer, 2011). A typical rainwater collection system has 4 main components which are the collection surface, the transport system, the storage system, and the distribution systems. Rainwater is collected from the collection surfaces and transported to the warehouses through a series of gutter systems and redistributed for various uses (Sahin, 2010).

As a result of extensive literature review, it has been observed that water harvesting methods, other than rainwater harvesting, are not applied in built environments today. In recent years, it has been difficult to supply good quality water with the increasing population in cities. As a solution, the approach of collecting and re-using rainwater in urban environments has profoundly increased (Badarnah, 2016). According to Kim et al. (2005), rainwater harvesting is stated as one of the most effective methods to ensure sustainable urban development and restore the natural hydrological cycle. Collecting rainwater has many advantages both economically and environmentally. In addition, in studies conducted in different countries, it has been determined that rainwater harvesting can save water significantly (Julius et al., 2013). For this reason, rainwater harvesting methods are explained in detail in the next section.

3.1. Rainwater Harvesting Methods

There are many rainwater harvesting methods in literature. Depending on the topography, land use, land cover, precipitation and demand parameters each method is specific to the application area. Consisting of a wide range from high cost to low cost, these methods vary from traditional to technologically advanced ones. In the historical process, different rainwater harvesting practices have been carried out in different parts of the world in line with the needs and opportunities of each society, and each culture has created its own traditional rainwater harvesting methods. However, when these traditional rainwater harvesting methods are examined, it has been observed that the same techniques are sometimes referred to by different names in different regions. Sometimes, although they have similar names, they appear to differ completely in practice. As a result, traditional rainwater harvesting techniques have different definitions and classifications, but the terminology used at the regional or international levels has not yet been standardized (Mbua, 2013).

Mostly water tanks, wells, cisterns, special water structures, water channels, artificial ponds or pools are seen in traditional rainwater harvesting methods. When we look at the rainwater harvesting systems used in modern buildings, we can say that traditional rainwater harvesting techniques are adapted to modern systems. The principle of rainwater collection through cisterns plays a particularly important role in the methods used today. As a basic principle, rainwater harvesting is done by collecting rainwater from building surfaces, mostly from roofs, and storing it in various reservoirs. In line with this basic principle, it is possible to see many different concepts for rainwater harvesting.

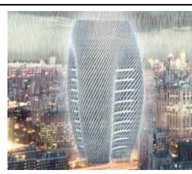
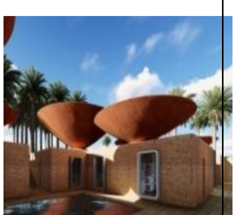
In Table 1 and Table 2, traditional and modern methods of rainwater harvesting are summarized and prominent examples of these methods are presented. Harvesting rainwater through roofs, which is considered one of the traditional methods, is also frequently encountered in modern buildings seen today. While it is understood that the applications for harvesting rainwater through specific water structures occupied an important place in the past, today these applications remain in the background. These traditional practices are now being replaced by modern and technological building designs specially developed for rainwater harvesting. Traditional rainwater harvesting applications, which are carried out through artificial ponds / pools, are used for agricultural purposes, especially in rural areas, and are generally not included in modern building designs. It is also possible to see differences in the purposes and usage areas of traditional and modern rainwater harvesting applications. As can be seen from the studied examples, traditional rainwater harvesting practices are generally carried out for replenishing the drinking water supply and agricultural purposes. In this sense, these methods are used to provide for basic vital needs. When modern practices are considered, environmental concerns come to the forefront and subjects such as water efficiency and water saving are brought to focus rather than vital needs.

Table 1 Traditional Rainwater Harvesting Methods

SAMPLE		METHOD	EXPLANATION	USAGE AREA
Tanka		through roofs	Rainwater is collected from the roof surface and stored in water tanks through a gutter	-Drinking water supply -Small-scale domestic uses
Kund/ Tanka		through special water structures	Rainwater is collected through holes in the tank or through openings on the ground.	-Drinking water supply
Chand Bori		through special water structures	Rainwater is collected from the open surface of the water well with steps and stored at the bottom of the well.	-General uses
Talab		through artificial ponds / pools	Rainwater is collected and stored in an artificial pond.	-Agricultural activities -Domestic uses -Animal husbandry
Berkad		through artificial ponds / pools	In general, on sloping lands, rainwater flow is directed by channels and collected in an artificial pond and stored.	- Domestic uses - Animal husbandry
Khadin		through artificial ponds / pools	Rainwater is collected on the land to be cultivated by directing it through canals or the slope of the land.	- Animal husbandry

Table 2 Modern Rainwater Harvesting Methods

SAMPLE		METHOD	EXPLANATION	USAGE AREA
Heifer İnternational		through roofs	Rainwater is collected from the roof and stored in the water tower that is located on the façade.	-Firefighting systems - WC
Winrock International		through roofs	Rainwater is collected from the roof of the building in the shape of a gull wing and stored in water tanks located in the basement.	- Landscape and garden irrigation works
PhilipMerrill		through roofs	Rainwater is collected from the skillion roofs of the building and stored in the water tanks that are located on the façade.	- Firefighting systems - WC - Cleaning services - Air conditioning systems
PrismaNürnbe rg		through roofs	Rainwater is collected from the skillion roof of the building and the semi-cylindrical roof and then stored in water tanks in the basement.	- Firefighting systems - Landscape irrigation - Air conditioning systems

The Solaire		through roofs	Rainwater is collected from the terraced roofs of the building and stored in water tanks in the basement.	- Irrigation of green roofs - WC - Cooling systems
Wendell Wyatt Federal Building		through roofs	Rainwater is collected from the one-sided wide canopy added to the roof of the building and stored in water tanks in the basement of the building.	- WC and washbasin - General irrigation - Air conditioning systems
Shangai Tower		through roofs	Rainwater is collected by the spiral parapet of the building.	- Air conditioning systems
The Velodrome		through roof	Rainwater is collected from the hyperbolic parabolic roof of the building and stored in water tanks located at the basement level.	- WC and washbasin
Postdamer Platz Kompleksi		through roof	Rainwater is collected from the roofs of the buildings in the complex and stored in underground water tanks.	- Irrigation of green roofs - Automatic plant irrigation systems in shopping malls - Firefighting systems
Rain Skycraper		special architectural designs	Rainwater is collected by a large funnel on the roof of the building and by the gutters on the façades.	-WC, Bath - Irrigation and cleaning works
BMDesign's Concave Roofs		special architectural designs	Rainwater is collected from the concave roofs of the building and stored between the walls of the building.	- General uses

4. Findings on Nature-Inspired Water Harvest Strategies in Buildings

In the field of architecture, in addition to rainwater harvesting applications, structures and architectural surfaces that can acquire water through condensation or concentration that are inspired by nature have been developed. In this context, below is a review of architectural designs developed through the inspiration of water collection strategies of living creatures.

Las Palmas Water Theatre

Table 3 shows the Las Palmas Water Theater building, inspired by the method of obtaining water of the Namibia Desert Beetle, which lives in arid regions. Moisture harvesting is carried out in the building based on the principles of the Namibian Desert Beetle to obtain water from fog. It contains biomimetic elements in many different design decisions from positioning to material quality. First of all, location selection and positioning decisions for the project were made with a biomimetic approach. The Namibia desert beetle fixes its body in foggy air at an angle of 45 in the direction of the air flow and obtains water by condensing moist air hitting the exoskeleton. Accordingly, the building is located along an axis in an area where the moist air flow is dense, and an angled façade is placed in line with this axis. Special condensation panels are designed for the façade of the building, referring to the bumps in the exoskeleton of the Namibian desert beetle. Water is obtained from the façade where these panels are located. In this sense, the building has achieved an innovative design by bringing the positioning criterion in water efficient design to the agenda. In addition, it represents an innovation by going beyond the traditional methods and obtaining water through a very specific and specialized façade design.

Namibia University Hydrology Center

The Namibia University Hydrology Center Building was inspired by the Namibian Desert Beetle's principle of obtaining water. Fog harvesting is carried out in the building based on the condensing principle, similar to the method of obtaining water from fog. In line with this principle, it is seen that various biomimetic elements are included in the design decisions of the building. The building stands out with its structural elements specially designed to hold the water in the air. In the design of these elements, the fog basking behavior of the insect in the fog is imitated. The structure is designed and positioned at a certain angle and height to optimally meet the misty air flow. Also, the bumps in the exoskeleton of the Namibia Desert Beetle have a hydrophilic (water absorbing) structure that increases the condensation of the water. This feature has inspired the design of a number of innovative surfaces for the building. Network surfaces supported by special structural elements are designed in the hydrophilic structure. In this direction, the building represents an innovative approach by obtaining water through a specific structure other than traditional methods and with a material proposal that supports water recovery. (Table 4)

Warka Tower

The Warka Tower was inspired by the principles of water supply of spider webs and the Namibian Desert Beetle in Table 5. In the structure, water is obtained based on the condensation principle, similar to the Namibian Desert Beetle's and spider webs' method of obtaining water. The water collection process is done by a network of surfaces within the structure of the building. To obtain water, biomimetic design elements are used especially in terms of materials. It is known that the spider webs have a micro-scaled structure, and the Namibian Desert Beetle has a similarly hilly exoskeleton, and thanks to these surface properties, it has successfully achieved water retention. Based on this, a special 3D network surface is developed for the structure, like the micro-spider web structure. Accordingly, the building represents an innovative and functional approach by presenting an example of a structure that is specialized in the collection of water and by proposing an efficient water retaining surface.

Rain Bellows

The project called Rain Bellows was inspired by the ice flower water storage principle (Table 6). The building stands out with its façade element designed in line with principles like water storage principles of the ice flower plants. The façade element has a movable mechanism that can expand until it is filled with rainwater and does not require additional storage space. In this sense, the building has uncovered an important potential for water storage in buildings with this nature-inspired mechanism.

A Surface Design

Table 7 shows an example of a multi-layered surface design inspired by the water extraction principle of the Namibian Desert Beetle and the water transport principles of the Moloch Lizard. The surface, like the Namibian Desert Beetle, obtains water by the method of condensing the water of damp air. It transmits the acquired water to the interior with pipe systems designed like the capillary channel networks on the skin of the Moloch Lizard. The outermost layer of the surface was designed with a bumps imitating the rugged structure in the exoskeleton of the Namibian Beetle. These artificial domes/mounds/bumps were supported with a hydrophilic material. The lower layer, consisting of a series of capillaries, is planned to release the collected water to indoor spaces on dry or hot days, to contribute to the ambient humidity and increase the comfort of the environment. In this sense, this surface design represents potential building envelope designs by providing a multi-layered surface sample with a specific configuration and material properties in water efficient design.

Table 3 Las Palmas Water Theatre Building inspired by the Namibia Beetle

INSPIRED ORGANISM		FEATURES OF ORGANISM	
	NAMIBIA DESERT BEETLE  		Inspirational Feature: Water harvesting Water Harvesting Method (How): -The water particles in foggy air condense on the insect's elytra and then canalize into its mouth. Advanced Biological Properties for Water Harvesting (With What): -Special Course of Action *(fog-basking behavior)* -Morphological Features (Rugged elytra consisting of hydrophilic mounds and hydrophobic grooves) -Combination of Hydrophilic and Hydrophobic Surfaces

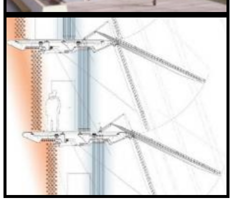
BIOMIMETIC DESIGN PROCESS

Biomimetic approach

Solution Oriented Approach	Problem Oriented Approach	
-	+	Namibian desert beetle, which can obtain and use water in a sustainable fashion, has been investigated to reduce the negative impact on water resources due to water consumption in buildings.

Biomimicry level

Organism Level	Behavior Level	Ecosystem Level	
+	+	-	-The elytra of the Namibian beetle is imitated morphologically (organism level) -Fog-basking behavior developed by the insect for water harvesting is imitated (behavior level)

APPLICATION IN ARCHITECTURE		FEATURES OF THE BUILDING	
	LAS PALMAS WATER THEATRE (Las Palmas, SPAIN)  		Feature Transferred to the Structure: Water Harvesting Water Harvesting Method: Water particles in humid air are collected by condensing through the façade of the building. Architectural Design Principles for Water Harvesting: -Special Façade Design (Façade consists of panels specially designed to condense the water in damp air) -Specific Positioning (The structure is positioned in the direction dominated by the ocean breeze)

WATER HARVESTING METHOD

Rainwater Harvesting	Atmospheric Water Harvesting	Seawater Harvesting	Groundwater Harvesting
-	+	-	-

Table 4 Namibia University Hydraulic Center inspired by the Namibia Beetle

<table>
<tr><td rowspan="3">INSPIRED ORGANISM</td><td rowspan="3">NAMIBIA DESERT BEETLE

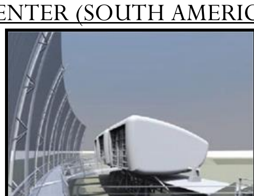
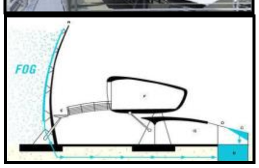
</td><td rowspan="3">FEATURES OF ORGANISM</td><td colspan="3">Inspirational Feature: Water harvesting</td></tr>
<tr><td colspan="3">Water Harvesting Method (How):
-The water particles in the foggy air condense on the insect's elytra and canalize into its mouth.</td></tr>
<tr><td colspan="3">Advanced Biological Properties for Water Harvesting (With What):
-Special Course of Action (fog-basking behavior)
-Morphological Features (Rugged elytra consisting of hydrophilic mounds and hydrophobic grooves)
-Combination of Hydrophilic and Hydrophobic Surfaces</td></tr>
<tr><td colspan="6">BIOMIMETIC DESIGN PROCESS</td></tr>
<tr><td colspan="6">Biomimetic approach</td></tr>
<tr><td colspan="2">Solution Oriented Approach</td><td>Problem Oriented Approach</td><td colspan="3" rowspan="2">Namibian desert beetle, which lives under similar conditions in nature and has solved this problem, has been investigated in order to solve the water access problem of the buildings in water scarce regions.</td></tr>
<tr><td colspan="2">+</td><td>-</td></tr>
<tr><td colspan="6">Biomimicry level</td></tr>
<tr><td>Organism Level</td><td>Behavior Level</td><td>Ecosystem Level</td><td colspan="3" rowspan="2">-The elytra of the Namibian beetle is imitated on the basis of form and material (organism level)
-Fog-basking behavior developed by the insect for water harvesting is imitated (behavior level)</td></tr>
<tr><td>+</td><td>+</td><td>-</td></tr>
<tr><td rowspan="3">APPLICATION IN ARCHITECTURE</td><td rowspan="3">NAMIBIA UNIVERSITY HYDRAULIC CENTER (SOUTH AMERICA)

</td><td rowspan="3">FEATURES OF THE BUILDING</td><td colspan="3">Feature Transferred to the Structure:
-Water Harvesting</td></tr>
<tr><td colspan="3">-Water Harvesting Method:
-The water particles in the fog are collected by condensing through a special structure placed in front of the building façade.</td></tr>
<tr><td colspan="3">Architectural Design Decisions for Water Harvesting:
-Special Structural Design (Special structural design that supports water-gathering network surfaces and imitates the angled stance of the Namibian beetle)
-Specific Positioning (The structure is positioned in the direction dominated by the ocean breeze)
-Innovative Material (Special mesh surfaces that are shaped similar to the rugged structure of the elytra to give hydrophilic properties)</td></tr>
<tr><td colspan="6">WATER HARVESTING METHOD</td></tr>
<tr><td colspan="2">Rainwater Harvesting</td><td colspan="2">Atmospheric Water Harvesting</td><td>Desalination</td><td>Groundwater Harvesting</td></tr>
<tr><td colspan="2">-</td><td colspan="2">+</td><td>-</td><td>-</td></tr>
</table>

Table 5 Warka Tower İnspired by the Namibia Beetle and Spider Webs

<table>
<tr><td rowspan="3">INSPIRED ORGANISMS</td><td rowspan="3" colspan="3">NAMIBIA DESERT BEETLE

SPIDER WEBS
</td><td rowspan="3">FEATURES OF ORGANISM</td><td colspan="2">Inspirational Feature: Water harvesting</td></tr>
<tr><td colspan="2">Water Harvesting Method (How):
-Water in damp air is collected by concentrating on the exoskeleton of the Namibian beetle.
-Water in damp air is collected by concentrating on spider web fibers</td></tr>
<tr><td colspan="2">Advanced Biological Properties for Water Harvesting (With What):
-Special rugged elytra (Namibian beetle) consisting of hydrophilic mounds and hydrophobic grooves
-Specialized mesh fibers (water harvesting) consisting of hydrophilic knuckles and hydrophobic connections in the micro-scale.</td></tr>
<tr><td colspan="7">BIOMIMETIC DESIGN PROCESS</td></tr>
<tr><td colspan="7">Biomimetic approach</td></tr>
<tr><td colspan="2">Solution Oriented Approach</td><td colspan="3">Problem Oriented Approach</td><td rowspan="2" colspan="2">-In order to ensure that people living in areas under water shortage have access to clean water, living things that can acquire water with their own methods have been investigated.</td></tr>
<tr><td colspan="2">+</td><td colspan="3">-</td></tr>
<tr><td colspan="7">Biomimicry level</td></tr>
<tr><td colspan="2">Organism Level</td><td>Behavior Level</td><td colspan="2">Ecosystem Level</td><td rowspan="2" colspan="2">-The hydrophilic structures of the spider web and the exoskeleton of the Namibian beetle are imitated.</td></tr>
<tr><td colspan="2">+</td><td>-</td><td colspan="2">-</td></tr>
<tr><td rowspan="3">APPLICATION IN ARCHITECTURE</td><td rowspan="3" colspan="3">WARKA TOWER
(Ethiopia, EAST AFRICA)

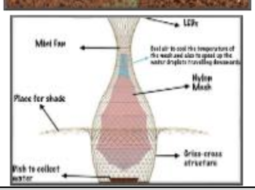
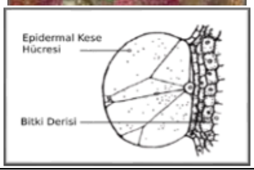

</td><td rowspan="3">FEATURES OF THE BUILDING</td><td colspan="2">Feature Transferred to the Structure: Water Harvesting</td></tr>
<tr><td colspan="2">Water Harvesting Method :
-The water particles in the humid air are collected by concentrating on the nylon network surfaces.
-Rainwater is collected directly by the open roof.</td></tr>
<tr><td colspan="2">Architectural Design Decisions for Water Harvesting:
-Special structural design (modular structure system that supports network surfaces and facilitates the collection of rainwater)
-Innovative material (nylon mesh)</td></tr>
<tr><td colspan="7">WATER HARVESTING METHOD</td></tr>
<tr><td colspan="2">Rainwater Harvesting</td><td colspan="2">Atmospheric Water Harvesting</td><td colspan="2">Desalination</td><td>Groundwater Harvesting</td></tr>
<tr><td colspan="2">+</td><td colspan="2">+</td><td colspan="2">-</td><td>-</td></tr>
</table>

Table 6 Rain bellows inspired by Ice Flower

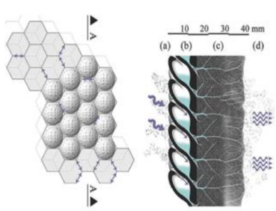
<table>
<tr><td rowspan="3">INSPIRED ORGANISMS</td><td colspan="3" rowspan="3">ICE FLOWER


</td><td rowspan="3">FEATURES OF ORGANISM</td><td>Inspirational Feature: Water harvesting</td></tr>
<tr><td>Method of Keeping Water (How?):
-Water is stored on the stem of the plant</td></tr>
<tr><td>Advanced Biological Properties for Water Conservation (With What):
• Epidermal sac cells on the plant body that expands and contracts according to the amount of water and stores it.</td></tr>
<tr><td colspan="6">BIOMIMETIC DESIGN PROCESS</td></tr>
<tr><td colspan="6">Biomimetic approach</td></tr>
<tr><td colspan="2">Solution Oriented Approach</td><td colspan="3">Problem Oriented Approach</td><td rowspan="2">The ability of the ice flower plant to hold water has been an inspiration for water storage areas in buildings.</td></tr>
<tr><td colspan="2">-</td><td colspan="3">+</td></tr>
<tr><td colspan="6">Biomimicry level</td></tr>
<tr><td colspan="2">Organism Level</td><td>Behavior Level</td><td colspan="2">Ecosystem Level</td><td rowspan="2">The function of the epidermal sac cells in the body of the ice flower is imitated</td></tr>
<tr><td colspan="2">+</td><td>+</td><td colspan="2">-</td></tr>
<tr><td rowspan="3">APPLICATION IN ARCHITECTURE</td><td colspan="3" rowspan="3">RAINBELLOWS
(Seattle,USA)

</td><td rowspan="3">FEATURES OF THE BUILDING</td><td>Feature Transferred to the Structure: Water conservation</td></tr>
<tr><td>Water Preservation Method:
-Rainwater collected through the roof is guided through various channels and stored in storage areas integrated into the façade.</td></tr>
<tr><td>Improved Architectural Design Decisions for Water Conservation:
-Special Façade Element Design (Kinetic front elements that can expand and contract according to the amount of rainwater collected by imitating the flexible epidermal sac cells of the ice flower)</td></tr>
<tr><td colspan="6">WATER HARVESTING METHOD</td></tr>
<tr><td colspan="2">Rainwater Harvesting</td><td colspan="2">Atmospheric Water Harvesting</td><td colspan="1">Desalination</td><td>Groundwater Harvesting</td></tr>
<tr><td colspan="2">+</td><td colspan="2">-</td><td>-</td><td>-</td></tr>
</table>

Table 7 A surface design inspired by the Namibia Bettle and Moloch Lizard

<table>
<tr><td rowspan="3">INSPIRED ORGANISMS</td><td rowspan="3" colspan="2">Namibia Bettle

Moloch Lizard
</td><td rowspan="3">FEATURES OF ORGANISM</td><td>Inspirational Feature: Water harvesting (Namibian Beetle)-Water transmission (Moloch Lizard)</td></tr>
<tr><td>Method of Keeping Water (How?):
-The water particles in the foggy air condense on the exoskeleton of the Namibian beetle and channel into the mouth of the beetle (water harvesting)
-Water is transported through capillary channel nets in the skin of the Moloch lizard.</td></tr>
<tr><td>Advanced Biological Properties for Water Conservation (With What):
-Special Behavior Form (fog-basking behavior)
-Morphological Properties (Special rugged elytra consisting of hydrophilic mounds and hydrophobic grooves)
-A series of capillaries in the skin that overlap on a micro scale.</td></tr>
<tr><td colspan="5">BIOMIMETIC DESIGN PROCESS</td></tr>
<tr><td colspan="5">Biomimetic approach</td></tr>
<tr><td colspan="2">Solution Oriented Approach</td><td colspan="2">Problem Oriented Approach</td><td rowspan="2">Water management strategies of the Namibian beetle and Moloch lizard inspired an effective water surface design</td></tr>
<tr><td colspan="2">-</td><td colspan="2">+</td></tr>
<tr><td colspan="5">Biomimicry level</td></tr>
<tr><td>Organism Level</td><td>Behavior Level</td><td colspan="2">Ecosystem Level</td><td rowspan="2">-The capillary structure of the skin of the Moloch lizard and the elytra of the Namibian beetle are imitated (organism level)
-Special behavior developed by the insect for water harvesting is imitated (behavior level)</td></tr>
<tr><td>+</td><td>+</td><td colspan="2">-</td></tr>
<tr><td rowspan="3">APPLICATION IN ARCHITECTURE</td><td rowspan="3" colspan="2">Surface Design by Kadri and Badarnah (2015) (Concept)

</td><td rowspan="3">FEATURES OF THE BUILDING</td><td>Feature Transferred to the Structure: Water harvesting and Water transmission</td></tr>
<tr><td>Water Preservation Method:
Water particles in damp air are collected and transported by condensing on the building envelope.</td></tr>
<tr><td>Improved Architectural Design Decisions for Water Conservation:
-Specialized Building Shell Design (the outermost layer of the building shell is designed with a dome, like the exoskeleton of the Namibian beetle. The lower layer is designed by imitating the capillary skin of the Molochlizard to transmit the collected water to the interior spaces and distribute it on the surface)
-Material Selection (hydrophilic material)</td></tr>
<tr><td colspan="5">WATER HARVESTING METHOD</td></tr>
<tr><td colspan="2">Rainwater Harvesting</td><td colspan="2">Atmospheric Water Harvesting</td><td>Desalination | Groundwater Harvesting</td></tr>
<tr><td colspan="2">-</td><td colspan="2">+</td><td>- | -</td></tr>
</table>

5. Evaluation and Conclusion

Within the scope of this article, traditional structures, modern structures and biomimetic designs in the context of "collecting water through buildings" are examined, and the water harvesting methods and architectural elements used in these methods are compared and evaluated (Table 8). In this regard, it has been observed that rainwater harvesting has been adopted as a common strategy within the scope of water harvesting methods. It is seen in the examples that have been examined throughout the study that rainwater harvesting practices contribute significantly to both the elimination of urgent water needs and the reduction of water consumption in modern buildings and traditionally developed water collection structures. It is possible to see rainwater harvesting applications in the water obtaining strategies of biomimetic designs. In addition, atmospheric water harvesting, including fog and moisture harvesting practices, have been brought to the forefront, and ways to obtain maximum water through structures have been investigated. In this sense, it is predicted that atmospheric water harvesting applications can create an effective water resource, especially in climatic regions where annual rainfall is low or seasonal. In addition, water harvesting strategies of buildings should be suitable for different climate types.

On the other hand, more architectural design elements have been included in the water harvesting process in biomimetic building examples compared to the water harvesting strategies used in traditional and modern buildings. For example, in traditional and modern buildings, water harvesting is generally limited to roofs; however, in biomimetic designs, facades, building shells, structures, walls and various surfaces are utilized. Accordingly, biomimetic designs offer a wider framework for efficient use of water. It also clearly demonstrates the potential of buildings for rainwater harvesting and atmospheric water harvesting.

For example, in the designs inspired by the Namibian desert beetle, it is seen that positioning and material are emphasized. In this direction, it is predicted that the issues of positioning and material use in the structures to be designed in regions with a climate similar to the climatic conditions in which the Namibian desert beetle live will increase the efficiency in water harvesting. In addition, it is thought that extensive research can be made on hydrophobic and hydrophilic materials, which are emphasized in case studies, innovative materials and surfaces can be developed and used in facade designs.

In the design inspired by the ice flower, an innovative approach is put forward for storage areas, which is an important component of water harvesting systems, and kinetic structural elements are highlighted. At this point, it is thought that kinetic building elements can be included in building designs or kinetic building structures can be developed for water harvesting.

From the surface prototype inspired by the Moloch lizard and the Namibian desert beetle, a study has been put forward to show that water harvesting can be done not only through certain architectural elements but also through the building shell, and in this sense, it is thought that progressive building shells can be developed for water harvesting.

In summary, examining nature for the development of water collection methods in built environments has been effective in revealing a variety of potentials, including the potentials for obtaining water from the air. In this context, it is recommended that building design processes be carried out with a multi-disciplinary approach and research in this field. Nature should be examined and investigated as a solution factor. In addition, it is suggested that the information obtained from the research conducted on nature and living organisms are evaluated and transformed into architectural teachings within the framework of biomimetic design to inspire the building design process.

Table 8 An evaluation on water harvesting methods in built environments

Water Harvesting Methods in Built Environments					
Water Harvesting Methods	Architectural Elements Used		Traditional Structures	Modern Structures	Biomimetic Designs
Rainwater Harvesting	Roofs		+	+	+
	Artificial Ponds / Pools		+	+	-
	Facade / Facade Elements		-	+	-
	Special Architectural Designs	Specific Constructions	+	+	+
		Structures	-	-	+
		Surfaces	-	-	-
Atmospheric Water Harvesting	Roofs		-	-	-
	Artificial Ponds / Pools		-	-	-
	Building Envelope		-	-	+
	Facade / Facade Elements		-	-	+
	Special Architectural Designs	Specific Constructions	-	-	+
		Structures	-	-	+
		Surfaces	-	-	+
Seawater Harvesting			-	-	-
Groundwater Harvesting			-	-	-

As a result, in this study, since the number of samples is extremely limited, all samples obtained regardless of climate were examined. Future research can explore climate-oriented solution proposals and further researches are needed to produce effective, and economical prototypes.

Acknowledgments

This article was produced from the thesis named "A biomimetic approach to rainwater harvesting strategies through the use of building" made in the architecture program of Gazi University Graduate School Of Natural And Applied Sciences.

References

Arslan Selçuk, S. ve Gönenç Sorguç, A. (2007). Mimarlık Paradigmasında Biomimesisin Etkisi. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 22(2): 451-459.

Aziz, M. S., El sheriff, A. Y. (2015). Biomimicry as an approach for bio-inspired structure with the aid of computation. *Alexandria Engineering Journal*, (55)1: 707–714.

Badarnah, L., Kadri, U. (2015). A methodology for the generation of biomimetic design concepts. *Architectural Science Review*, 58(2): 120-133.

Badarnah, L., (2016). *Water management lessons from nature for applications to buildings*, Master Thesis, Department of Architecture, Massachusetts Institute of Technology, Cambridge.

Bozkurt, C. (2010). *Kinetik Sistemlerle Çalışan, Biyomimetik Bir Kentsel Donatı Tasarımı Urbancot*, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

Bradshaw, A. J. (2016). *Water Harvesting Methods and the Built Environment: The Role of Architecture in Providing Water Security*. Master's Thesis in University of Nevada, Las Vegas.

El Ahmar, S. ,(2011). *Biomimicry as a tool for sustainable architectural design: Towards morphogenetic architecture*. Unpublished Master's thesis, Alexandria University, 2011.

Gertik, A. (2012). *Biyomimesis Anlayışı ve Bu Bağlamda Günümüz Kuzey Kıbrıs Mimarisi'ne Eleştirel Bir Bakış,* Yüksek Lisans Tezi, Yakın Doğu Üniversitesi Fen Bilimleri Enstitüsü.

Ceylan Arslan, N. (2015). *Yeşil Bina Projelerinde Tasarım Süreci İçin Bir Yaklaşım: LEED V4 Sertifikalandırma Süreci Modeli*, Master's Thesis in University of Istanbul Yıldız Teknik, Istanbul.

Jalali, S., Aliabadi, M., & Mahdavinejad, M. (2021). Learning from plants: A new framework to approach water-harvesting design concepts. *International Journal of Building Pathology and Adaptation*, 2398-4708.

Julius, J. R., Angeline Prabhavathy, R., Ravikumar, G. (2013). Rainwater Harvesting (RWH) - A Review. *International Journal of Innovative Research & Development,* 2(5): 925

Liniger, H., Mekdaschi Studer, R., Hauert, C. and M. Gurtner. 2011. Sustainable Land Management in Practice. Guidelines and Best Practices for Sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO).

Mazzoleni, I. (2013). Architecture follows nature-biomimetic principles for innovative design 2. Crc Press.

Mbua, R. L. (2013). *Water Supply in Buea, Cameroon: Analysis and the Possibility of Rainwater Harvesting to stabilize the water demand,* Master Thesis, Von der Fakultät für Umweltwissenschaften und Verfahrenstechnik der Brandenburgischen Technischen Universität, Cottbus.

Nkandu, M. I., Alibaba, H. Z. (2018). Biomimicry as an Alternative Approach to Sustainability. *Architecture Research*, 8(1): 1-11.

Öztoprak, Z. (2018). *A Biomimetic Perspective on (retro)Fitting of Building Envelopes*, Master Thesis, The Graduate School of Natural and Applied Scıences of Middle East Technical University, Ankara.

Pasic, A. (2014). *Rethinking Technical Biology in Architecture*, Master Thesis, Technical University Graduate School of Science Engineering and Technology, Istanbul.

Rankouhi, A. (2012). *Naturally Inspired Design Investigation into The Application of Biomimicry in Architectural Design*, Master Thesis, Graduate School Department of Architecture, The Pennsylvania State University.

Rao, R. (2014). Biomimicry in Architecture. *International Journal of Advanced Research in Civil, Structural, Environmental and Infrastructure Engineering and Developing*, 1 (3): 101-107

Rian, M. I., Sassone, M. (2014). Tree-inspired dendriforms and fractal-like branching structures in architecture: A brief historical overview. *Frontiers of Architectural Research,* 3(3): 298-323.

Suau, C. (2010, July). *Fog Collection and Sustainable Architecture in Atacama Coast.* Paper Presented at the 5th International Conference on Fog, Fog Collection and Dew Münster, Germany, 25–30 July 2010.

Sahin, N. İ. (2010). *Binalarda Su Korunumu*, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

Taskan, M. M., Mutlu-Avinç, G., & Arslan-Selçuk, S. (2022). Canlıların Su Dengesi Saglama Stratejileri ve Biyo-Bilgili Yapı Kabuğu Tasarımı. *Online Journal of Art and Design,* 10(1): 129-152

Türk, Z. B. (2018). *Sürdürülebilir Mimarlik İçin Doğadan Öğrenilen Yaklaşimlar: Doğa Esinli Fikirlerin Bina Kabuğuna Etkisi,* Yüksek Lisans Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara.

Varlı, E. (2013). *Geleneksel ve Dijital Tasarım Yaklaşımlarının Okunulabilirliğinin İncelenmesi*, Doktora Tezi, Trakya Üniversitesi Fen Bilimleri Enstitüsü, Edirne.

Yeşilyurt, E. (2008). *Biyoloji Temelli Bilimsel Kuramlar ile Mimari Tasarım İlişkisi*, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

Zari, P. M. (2007, November). *Biomimetic Approaches to Architectural Design for Increased Sustainability*. Paper Presented at the Sustainable Building Conference, Wellington, New Zealand.