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Product Design

BIOMIMICRY

DESIGN OF WATER COLLECTION STRUCTURES INSPIRED BY SUCCULENTS.

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Abstract. Biomimetics has now become a key tool for addressing challenges such as climate change adaptation and biodiversity loss. This project explores the application of biomimicry in regenerative urban design. The main objective is to analyze whether it is possible to create a biomimetic-inspired surface to improve water harvesting from the environment without chemical or molecular interventions. Following the Biomimetic Design Spiral methodology, the water strategies of succulents and their structural characteristics were studied. Based on these principles, 3D prototypes were designed and evaluated in a controlled experiment. The results show that the biomimetic design collected less water than the neutral model, with a difference of 27%. This unexpected finding suggests the need to explore new methodologies to evaluate water harvesting and retention. Despite the variation in results, the research opens new possibilities in the study of succulent-inspired design and its application in water harvesting surfaces.

Keywords: Biomimetic design, biomimética, recurso hídrico, captación de humedad, water saving, succulent plants.

Resumen. En la actualidad, la biomimética se ha convertido en una herramienta clave para abordar desafíos como la adaptación al cambio climático y la pérdida de biodiversidad. Este proyecto explora la aplicación de la biomimética en el diseño urbano regenerativo. El objetivo principal es analizar si es posible crear una superficie inspirada en la biomimética para mejorar la captación de agua del ambiente sin intervenciones químicas o moleculares. Siguiendo la metodología de la Espiral de Diseño Biomimético, se estudiaron las estrategias hídricas de las suculentas y sus características estructurales. A partir de estos principios, se diseñaron y evaluaron prototipos 3D en un experimento controlado. Los resultados muestran que el diseño biomimético recolectó menos agua que el modelo neutro, con una diferencia del 27 %. Este hallazgo inesperado sugiere la necesidad de explorar nuevas metodologías para evaluar la captación y retención de agua. A pesar de la variación en los resultados, la investigación abre nuevas posibilidades en el estudio del diseño inspirado en suculentas y su aplicación en superficies de captación hídrica.

Palabras clave: Diseño biomimético, biomimética, recurso hídrico, captación de humedad, ahorro de agua, plantas suculentas.

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1. INTRODUCTION. OBJECTIVES AND HYPOTHESES

This study stems from the article *Product Design and Biomimetics: Research and Development of a Water Resource in Harmony with Architecture* (Cáceres Jijishvili, O., 2023), which explores the application of biomimetics in regenerative urban design.

The present research ranges from the study of these mechanisms to the physical development of products suitable for experimental testing, following the Biomimicry Design Spiral methodology (*Biomimicry Toolbox*, 2019).

Through this approach, the aim is to provide innovative solutions in biomimicry that optimise the use of natural resources.

1.1 JUSTIFICATION

This project seeks to expand knowledge on the integration of design processes inspired by nature. This approach strengthens the connection between theoretical research and its practical application in products or services.

The theme is based on the need to **develop sustainable methods for water collection and management**, which would contribute to preserving water resources and mitigating the effects of climate change in specific communities and urban environments.

1.2 OBJECTIVES

1. **Investigate natural organisms and their biological strategies for water collection, focusing on their structural and formal characteristics.**
   - 1.1 Gather information on organisms that perform water collection functions.
   - 1.2 Identify characteristics related to the structure, shape, surface, and spatial composition of organisms.
2. **Speculate on the applications of organism research to design a water collection element.**
   - 2.1 Conduct a formal analysis of biological references.
   - 2.2 Generate mock-ups and 3D models.
2. **Develop a prototype to test and evaluate results.**
   - 3.1 Manufacture 3D prototypes using 3D printing.
   - 3.3 Develop the experiment to validate the design.

1.3 HYPHOTESES

It is possible to design a surface formally created using biomimicry to improve water collection from the environment, without the need for molecular or chemical intervention.

By researching the formal elements and structural details of organisms, water collection can be improved. With the results obtained, more specific applications can be explored in the future.

1.4 STATE OF PLAY

In the project published in *Nature Communications* entitled 'Integrated Fog Harvesting System Inspired by Cacti' (Ju et al., 2012), researchers investigated how cacti capture and transport water from fog using specialised structures. Based on these findings, they developed artificial systems that improve water collection efficiency in arid environments.

On the other hand, the project 'Directional Water Collection in Wet Spider Silk' (Zheng et al., 2010) analysed the mechanisms of water collection and transport in spider silk. This study reveals how the asymmetrical structure and moisture gradient properties of silk allow for the directional collection of water droplets. In this case, solutions have been developed to improve water collection efficiency in high humidity conditions.

Research such as that mentioned above demonstrates the capacity of biomimetics to generate efficient and specific solutions in the field of water use, both in high humidity conditions and in arid environments.

Two areas of research have been identified in relation to water use, depending on the focus of analysis:

1. **Those that use biomimetics as a starting point.**

Within the first strand, we can find studies that investigate the Namib desert beetle and its biological strategy (Park et al, 2013), applying it to the meshes used in disadvantaged communities to obtain drinking water. (Out Of Thick Air, 2011). On the other hand, researchers at the University of Waterloo developed systems that capture water from the air, inspired by both Namib desert beetles and spider webs, using biomimetic surfaces such as sponges or membranes (Researcher Finds Inspiration From Spider Webs And Beetles To Harvest, 2023). With regard to the study of filtering membranes, known as aquaporins, those studied by Aquaporin Inside (A Selective Membrane Inspired by Aquaporin Channels Filters and Purifies Water — Innovation — AskNature, n.d.) are particularly noteworthy.

Another related study is that carried out by Cáceres Jijishvili (2023). This author suggests a type of building designed with regenerative principles and systems for collecting, purifying and reusing rainwater, integrating biomimetic techniques into sustainable architecture.

From this first approach, we extract the possibility of using structural and surface elements of organisms, applying them both on a membrane, surface or product scale, and at an architectural level.

2. **Those that focus on the physical-chemical properties of the environment and materials.**

In this second strand, we find studies such as the 2011 paper entitled 'Atmospheric humidity as an optional source of water for domestic use', which investigates water collection at the macroscopic level through the condensation of atmospheric vapour, and addresses the need for drinking water in cold climates by incorporating the use of an artificial hygrometer to condense atmospheric vapour.

On the other hand, 'Chitosan-Based Composite Materials for Adsorption of Cu(II) and As(V) from Aqueous Solutions: Synthesis and Adsorption Studies' (Park et al., 2013) investigates the ability of certain polymers, such as chitosan-based compounds, to absorb and release water in low humidity conditions. This makes it possible to regulate humidity in environments such as food packaging, providing an effective solution for maintaining the quality of stored products. In this field, the development of new polymer materials, such as the polymer-MOF (PC-MOF) mixed matrix (Yilmaz et al., 2020), is noteworthy.

2. METHODOLOGY

The biomimicry methodological process is structured into several key phases, which guide us from identifying a problem to implementing solutions inspired by nature. According to the Biomimicry 3.8 tool (2019), the biomimicry process is organised into the following stages: Define, biologise, discover, abstract, emulate and evaluate.

For the development of this research, this approach has been followed, organising the project according to these phases and with the active participation of the two team members in all stages:

- Phase 1: Research (October - November 2023)
- Phase 2: Experimentation and Evaluation (November 2023 - May 2024)
- Phase 3: Conclusions and Results (May–June 2024)

Phase 1: Research

- **DEFINE PHASE:** Definition of the objectives and functions of the water collection device.
- **BIOLOGISE PHASE:** Biologisation of the identified functions and proposal of a biological context to serve as a reference for the design.
- **DISCOVERY PHASE:** Research and discovery of biological strategies that can be applied to the design, identifying organisms that have interesting capabilities in terms of water collection.
- **ABSTRACTION PHASE:** Abstraction of biological strategies to the design, creating models and 3D representations that emulate these strategies.

Phase 2: Experimentation and Evaluation

- **EMULATION PHASE:** Application of the knowledge acquired in the abstraction phase to the design. Through the prototyping of the chosen designs.
- **EVALUATION PHASE:** Exploration and testing of biomimetic ideas. In this phase, the results obtained are analysed, the data is recorded and possible improvements to the design are proposed.

Phase 3: Conclusions

2.1 PHASE 1: RESEARCH

2.1.1 DEFINE

How could we design a device that efficiently captures water from the air without resorting to chemicals or molecular interventions using a specific object?

After defining the design challenge, a study of natural organisms is carried out; in this case, succulents are the focus of the research. They could answer the question posed. The results of this analysis are presented in the following table:

Figure 1
Summary of biological strategies study.

Leaves of certain bromeliads (Bromeliaceae family) The leaves of some bromeliads are convex in shape with upward-curving edges, allowing them to collect and channel water into a central reservoir. Trichomes, which are small protuberances with tiny hairs, cover the leaves and, together with hydrophobic wax crystals, direct water into the reservoir without it adhering to the leaf surface. This mechanism allows the plant to accumulate nutrient-rich water for long-term use (Leaves Capture Water — Biological Strategy — AskNature, n.d.).	
Rosette succulent leaves The smooth, waxy leaves of rosette succulents effectively capture water from fog and light rain. These leaves are arranged in layers that act like a funnel, directing water towards the base of the plant for storage. In higher altitude areas, succulents have developed narrow, flexible leaves that optimise water collection from fog, improving their ability to capture moisture (Leaves Capture Water From Fog — Biological Strategy — AskNature, n.d.).	

Note. Own work. (2025). Illustrations of different biological references [Illustration]. ESADA.

2.1.2 BIOLOGISE

In this phase, the context and key functions that the design must address are analysed. Questions are raised about how nature solves these problems, in order to better understand biological solutions and transfer them to the project. How does nature store liquids in areas with low rainfall? How does nature capture, absorb and filter liquids? How does nature repel liquids? This section is completed using the 'Function Taxonomy' resource, which identifies biological functions and strategies related to water management inspired by succulents:

Figure 2
Study of the taxonomy of functions.

	Capture, absorb and filter liquids	Store liquids	Repel liquids
Functions	- Capture moisture from the air. - Absorb water into storage fabrics. - Filter particles from the collected water.	- Store water in specialised tissues. - Maintain water retention during dry periods.	- Prevent water loss through evaporation. - Repel excess water to prevent oversaturation.
Biological strategies	- Succulents capture and absorb moisture from fog and dew through specialised leaf surfaces. - They have waxy coatings and trichomes that help collect and direct water efficiently.	- Store water in thick, fleshy leaves or stems. - Swell when hydrated and contract when water is scarce, ensuring water availability during droughts.	- Some succulents have a powdery surface that repels water, preventing excessive moisture build-up.

Note. Own work. (2024). Table analysing biological functions and strategies [Table]. ESADA.

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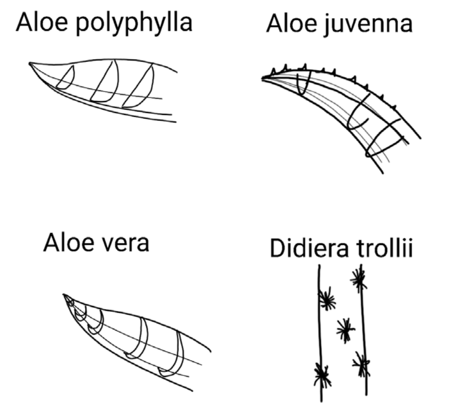
2.1.3 DISCOVERY

Once the design of the succulents had been analysed and confirmed as a good model for the project, research was carried out to investigate and explore in depth how the different families of these plants work, using formal analysis. As a conclusion to this analysis, it was decided to interpret the structural and surface forms of the succulents shown in Figure 3.

Figure 3
Elements selected as inspiration for the formal study.



Note. Own work. (2024). Selected illustrative examples [Illustration]. ESADA.

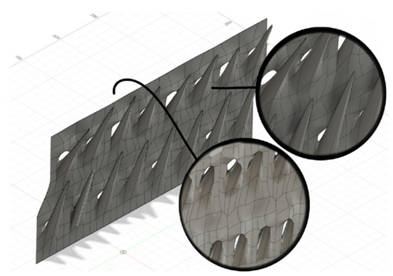
In addition to these physical characteristics, possible interventions such as the use of hydrophobic elements on the surface are being considered.

2.1.4 ABSTRACTION

In this section, biological strategies are interpreted and abstracted into design.

Next, the first 3D sketch is presented, which proposes the most suitable shape for the product. In the model in Figure 8, the front layer mimics the collecting leaves, while the internal rear hole channels the collected water.

Figure 4
Primeros bocetos del estudio de la forma.



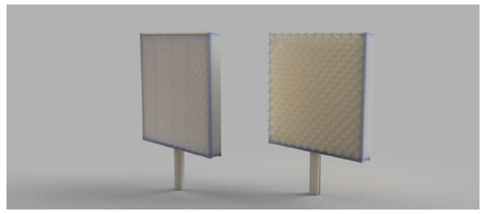
Note. Own work. (2024). Modelling carried out with Autodesk Fusion 360º, with educational licence [3D model]. ESADA.

2.2 PHASE 2: EXPERIMENTATION AND EVALUATION

2.2.1 EMULATION

In this phase, the 3D printing models and prototypes created for evaluation are presented.

Figure 5
3D visualisation of the final model.

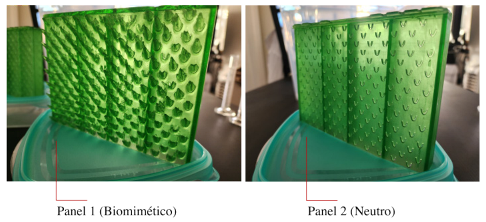


Note. Own work. (2024). Rendering created with Autodesk Fusion 360º, with educational licence [Render]. ESADA.

2.2.2 TOOLS FOR MANUFACTURING THE TEST MODEL

For a comparative analysis of the proposed design, two collection plates were created with the same general shape and the same number of channelling holes. The difference between the plates lay in the biomimetic design of the collection and channelling surfaces, which was only present in plate 1, as shown in Figure 6.

Figure 6
Panels to be evaluated.



Note. Own work. (2024). SLA (Stereolithography Apparatus) 3D printing prototypes [Prototype]. ESADA.

Description of the experiment:
A controlled environment was created, where the panels were placed in conditions of 99% humidity for 4 hours.

2.2.3 EVALUATION

To evaluate the collection capacity, the panels were placed on two sealed containers. Once the exposure time had elapsed, the lids were removed and the contents were poured into two separate test tubes. See Figure 7.

Figure 7
Recording of the experimentation and measurement process.

Note. Own work. (2024). Infographic of tools for the experiment [Infographic]. ESADA.

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The data collected on the behaviour of both plates is shown below.

Figure 8
Assessment of water uptake from plate 1.

Panel 1 (Biomimetic Design)			
Time	**Temperature**	**Humidity**	**Collected water**
4 hours	16.5 ºC	99%	8 ml

Note. Own work. (2024). Data record for Experiment 1 of Prototype 1 (Biomimetic Design) [Table]. ESADA.

Figure 9
Assessment of water uptake from plate 2.

Panel 2 (Neutral Design)			
Time	**Temperature**	**Humidity**	**Collected water**
4 hours	16.5 ºC	99%	11 ml

Note. Own work. (2024). Data record for Experiment 1 of Prototype 2 (Neutral Design) [Table]. ESADA.

3. RESULTS

The experiment showed negative results in relation to the hypothesis, as the panel with a succulent-inspired surface design (Panel 1) collected less water than Panel 2 (neutral design). Panel 2 collected 27% more water than the biomimetic panel.

Does the experiment provide information on the design's collection and harvesting capacity?

Although the experiment addresses both collection and harvesting, the data obtained only reflect the capacity to collect and channel water into the container. It is possible that Panel 1 captured water in the protrusions on the surface, but did not channel it completely into the container. Therefore, the results are only objective in terms of water collection and channelling, but do not allow for an evaluation of the total collection capacity.

Are there any biases in the process that may have influenced the results?

It should be noted that the finish of the prototype may have partly influenced the results. It is possible that the holes in Panel 1 are not completely perforated or do not have the same level of perforation as in Panel 2, due to the manufacturing method used. However, the difference in the results is so considerable that it is unlikely that this bias could have altered the results.

4. CONCLUSIONS

Most of the objectives set have been achieved, both in terms of preliminary research and biological references, and in the process of experimentation, emulation and evaluation of biomimetic design proposals. A water collection model inspired by succulents has been prototyped, and it has been demonstrated that the difference in surface shape directly affects the behaviour of water particles on it.

However, with regard to the evaluation of water collection, we must conclude that the objective has not been achieved. Biases have been identified in the type of experiment that affect the interpretation of the results.

4.1 PERSONAL ASSESSMENT

This project has provided insight into the difficulties and limitations of research in the field of design. It has helped to better understand how to apply experimental design methodologies to complement traditional scientific research. It has also been a valuable experience in identifying possible biases and subjectivities inherent in the design research process.

Furthermore, the research has reinforced interest in biomimetic methodologies, which represent a meeting point between the scientific field and design thinking. This allows for the generation of applied innovation, with a market-oriented vision focused on society and users.

We believe that this research can be just the starting point for further exploration into the design of biomimetic surfaces with applications in water resource management.

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