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Optimizing Computation: A Biomimicry Design Spiral Approach to Algorithm Development

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Abstract:

The increasing focus on biomimicry in the built environment shows that designers are becoming more conscious of the opportunities that nature presents for enhancing human and systemic functions. The field of advanced material technology has extensively used biomimicry. Nevertheless, there has been little in-depth discussion of its possibilities in environmentally conscious building practices. Numerous branches of the social and natural sciences have had an impact on the field of architecture; at the present time, biological principles are finding their way into design processes. From the earliest days of bio-architectural movements to the most recent ones, bioinspiration has shaped architectural practices towards a wide range of new methods. Nevertheless, the line between architectural bioinspiration that just mimics natural forms and the genuine comprehension of biological principles—the bedrock of sustainable development—is blurry when it comes to biomimicry. One of the biggest obstacles is the lack of cross-disciplinary cooperation between architects and biologists, which is exacerbated by the vast knowledge gap that exists between the creative process of building design and the scientific disciplines that pertain to biology. All sorts of spiral pathways, their properties, and how to use them to build and enhance other optimisation methods are described in great detail.

Keywords: Biomimicry, spiral approach, algorithms

1. Introduction

Biomimicry is a method of design that takes cues from the structure and function of living things, particularly ecosystems and organisms. Researchers argue that bio-mimicry develops novel and environmentally friendly design solutions by studying and imitating natural processes. Additionally, they define biomimicry as an academic discipline that looks to nature as a role model and teacher in the design process [1]. Biomimicry is a design philosophy that takes cues from nature for its aesthetics, functionality, and ecological footprint. It uses ecological benchmarks to evaluate sustainability and generates vernacular designs. Biomimicry, according to some academics, is a scientific discipline that seeks to meet human needs by studying and emulating natural systems, processes, and designs. Biomimicry is an interdisciplinary study of product design that combines elements of biology and engineering with knowledge from other disciplines (such as philosophy, computer science, physics, and chemistry) to produce durable goods. With the current rate of climate change and environmental deterioration, biomimicry has become more important planet, where environmental degradation and climate change are happening at a fast pace [2].

Biomimicry has a long and storied history that begins in 500 B.C., when Greek philosophers drew inspiration from the forms, systems, and functions found in nature to develop the classical concept of beauty via harmonious design. Leonardo da Vinci later, in 1482, created the flying machine by mimicking the way birds fly; he called this an early example of biomimicry. While his flying aircraft failed to take flight, it did pave the way for his brother's prototype to become an aeroplane in 1948, thanks to his innovation. By its original definition, "the science of natural systems or their analogues," the word bionics was coined in 1958. Having said that, biomimicry was not coined until 1982. 'Biomimicry: Innovation inspired by Nature', written by Janine Benyus in 1997, elaborated on the idea of biomimicry. After that, she and Schwan founded the Biomimicry Institute. Chris Allen became a part of the team in 2007 to establish "Ask Nature," the first digital library of its kind. The library provides natural answers and ideas for design practice and study.

Bionics and biomimicry are not the same thing. Bionics refers to the field that studies how biological systems work in order to build engineering systems, particularly electrical ones, while biomimetic refers to the field that studies how live things work in order to create materials or products via reverse engineering. It is not a new habit to study and imitate nature in order to find practical answers that meet human requirements. Nature often served as a source of inspiration for humans in the past, who had to come up with creative solutions to meet their basic needs like food and shelter. The modern built environment, medical research, defence, agriculture, and industrial processes have all made use of these creative technologies. The ability of the natural environment to regenerate and adapt to climate change may be enhanced by creating a constructed environment that is resilient, sustainable, and adaptive, much like the natural environment and ecosystems. While the final product may differ in appearance from the original organism or ecosystem, the underlying functional principles are the same, and biomimicry provides considerate answers to human problems by applying these principles to human contexts. Natural processes and their roles have long been the subject of extensive research by early scientists. Design, architecture, and structural engineering are just a few of the many fields that have benefited from the data they have gathered. Therefore, the purpose of this research is to examine biomimicry's role in creating a resilient and sustainable built environment by reviewing its applications in structural engineering and architecture.

2. Motivation for Algorithm Developments Using Biomimicry’s Spiral Approach

Biomimicry is a way of thinking that draws on natural phenomena to find sustainable solutions to human issues, therefore bringing contemporary ideals in line with nature. By studying, copying, and learning from nature, biomimicry brings the built environment closer to nature. We will be more likely to be welcomed on this home that is ours, but not ours alone, if our surroundings more closely mimic the natural world, according to this strategy's premise. The biomimicry design spiral was developed by Carl Hastrich in 2005 [3-4]. Following this methodical procedure will help you turn the concepts found in nature into cutting-edge, long-term architectural solutions. First, identifying; second, translating; third, discovering; fourth, abstracting; fifth, emulating; and sixth, evaluating are the six steps that make up biomimicry [5]. As a first step, the identification process determines which design tasks are necessary. Developing a dynamic façade that can adapt to different levels of sunlight was the primary objective of this research. In order to go on with their plans, the researchers need to identify a natural identity that can react to sunlight in a physical and ecological sense [6-8].

A lot of the complex and highly useful designs that nature has come up with are still beyond what human engineers can do. The non-random, cumulative process by which these designs have developed over millions of years has been illuminated by the core ideas of Dawkins and Darwin, which centre on evolution and cumulative selection [4]. Figure 1 shows the broad variety of geometrical patterns that have evolved into a complex tapestry of natural designs. The image is originally available at [47,48,49,50]. These patterns range from fractals and spirals to tessellations and symmetries. These geometrical examples show how different patterns have been optimised for efficiency by natural selection and how they might be directly applied to engineering [9-11].

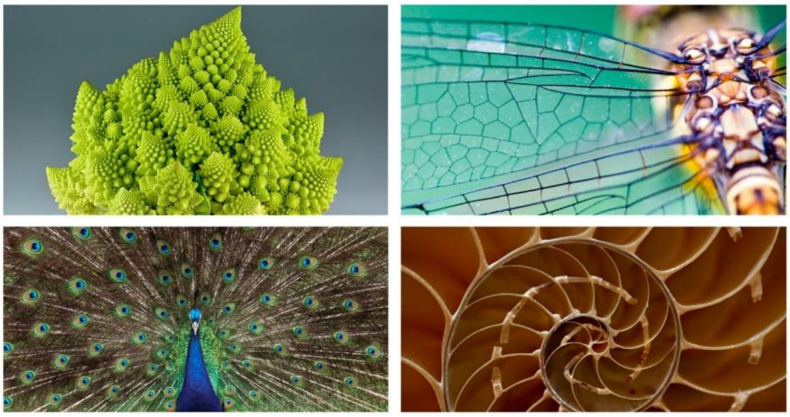

Figure 1. Natural tapestry or some of the natural patterns that can be observed in nature. From fractals, tessellations, different kinds of symmetries and spirals. [4]

Sometimes, the best human-made things are those that mimic the most efficient methods in nature. This method has been described using a number of different words, each with its own unique connotation. Both "biomimetics" (first used by Otto Schmitt) and "biomimicry" (first used by Janine Benyus) describe the practice of drawing inspiration from nature to create technological solutions; biomimicry goes a step further by highlighting the importance of long-term viability [12-15]. The term "bionics" is more often used in relation to prosthetics and robotics, although it does overlap with these ideas. In this research, we will zero in on "bio-inspired design," a catch-all phrase for drawing ideas from nature while using technological advancements. Instead of outright mimicking nature, this method seeks to improve technological solutions by incorporating designs inspired by natural phenomena. Here, the technique is based on the central idea of "Bio-inspired design," which also serves as the basis for the study [16-17].

3. A bio-inspired algorithm based on metaheuristics

Metaheuristics are optimisation methods that find solutions to complicated problems in several fields by mimicking natural processes [18-22]. When dealing with nonlinear, high dimensional, or multimodal situations, these algorithms provide strong tools that classic optimisation approaches may not be able to handle. Several metaheuristics stand out from the crowd due to their innovative methods and useful applications [5, 22a, 23-24]. Because of their track record of success in optimising agile team sizes across complicated, multidimensional search spaces, we choose to base our research on bio-inspired algorithms. To make sure our method was both innovative and resilient, we used both old and modern algorithms. Because of the dynamic nature of agile projects, factors such as computing efficiency and the speed with which they converge were critical [25-26]. The fact that these algorithms act in a way that is similar to how agile teams work together made them even more useful to our study. So, in one "lap" around the Biomimicry Design Spiral, you'll do the following:

- Identify one or more functions you want your design to perform
- Translate those functions into biological terms
- Discover strategies that nature uses to perform those functions
- Break down those strategies into technical terms
- Incorporate those strategies into your design solution
- Evaluate your design against the design brief and Life's Principles; and then decide how to use the next lap.

3.1. Whale Optimization Algorithm

Whale optimisation is a new optimisation method that draws inspiration from the distinctive way humpback whales hunt. One of the most advanced hunting techniques used by marine animals is the bubble-net feeding tactics, which these whales use for their amazing kind of foraging. With this method, the whales travel in a spiral pattern and surround themselves with a "net" of bubbles to catch their food, which is often krill or tiny fish.

This intuitive approach is translated by WOA into a mathematical framework that effectively searches and optimises solution spaces across a range of computing issues. By shifting the locations of prospective solutions—which are envisioned as whales—in the direction of prey or the optimal solution found during the search, the algorithm mimics the approach of whales.

WOA is especially renowned for its proficiency in navigating complex and multi-modal environments. It does this by updating the locations using a variable-shape spiral movement, which enables it to accurately resemble the circular approach of humpback whales. The algorithm's investigation and extraction phases are often improved by this spiral update formula when combined with linear movement, which speeds up the algorithm's convergence to the best solution.

WOA has been extensively used in many different fields, such as structural design[6], power dispatch[7], industrial design, and parameter optimisation. It is a vital tool in situations demanding strong optimisation solutions because of its capacity to tackle nonlinear in nature non-differentiable, continuous, and discrete optimisation issues. Additionally, WOA is an easy-to-use and practical option for academics and practitioners dealing with challenging optimisation problems due to its straightforward implementation and little need for parameter modifications [27].

3.2. Lighting

The influence of lighting on human well-being and lifestyle is well-established. Le Corbusier and Tado Ando emphasised the basic function of lighting in buildings and the three ways it affects humans: radiation, circadian rhythm, and visual systems.

A wide range of options and ideas for lighting design in architecture projects are provided by biomimicry. Two elements are used by nature: colour and light. Thus, while creating a project that draws inspiration from biomimicry, lighting has to be taken into account.[8]

The collecting and focussing of light is one biomimetic design principle that may be used to lighting design. An anthurium, for instance, has several intriguing features for gathering light in dispersed environments. Similar to this, the concept of including a symmetrical pair of mirrors in the atrium areas to reflect light into the internal sections of the building was inspired by spookfish [9].

Pawlyn, for instance, took inspiration for her most recent creation, The Biomimetic Office, from the spookfish's (Figures 2 and 3) ability to concentrate in dim light. When creating architectural designs, architects may imitate the spookfish's abilities. This vertebral spookfish was once thought to have four eyes, but it was eventually discovered that its eyes focused light via mirrors rather than lenses. (1) uses reflecting crystals (b) to focus light on the retina (a). The primary eye (2) centres light on the retina (d) via a lens (c) (Left). The extra eye structures on the brownsnout spookfish allow it to view below. Every eye has two linked components. The other points downward, while the first points upward and towards dawn. Bioluminescence produces low-intensity light, which is focused using a mirror. Using the spookfish's mirroring technique, Pawlyn increases occupant well-being, lowers energy use, and distributes natural light throughout his building [28].

Figure 2: The Biomimetic Office of Exploration Architecture resembles the anatomy of the spookfish's eye. [11, 20]

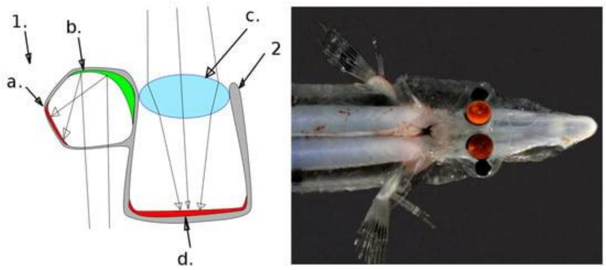

Figure 3: The brownsnout spookfish's downward-facing eye (Credit: Florida Atlantic University (Right, (Source: https://asknature.org/strategy/extra-eyes-direct-light/).

The spookfish eye's tilted mirror plates form a curved shape that maximises reflected light and produces the clearest picture possible. It is anticipated that the fish would adjust the mirror's location so that it centres on things at different distances [11a, 29].

Reducing the amount of natural light that enters a structure is another popular idea in lighting design. Reduced self-shading from the building itself is another biomimetic lighting design idea. This idea is mostly seen in plants having phyllo-tactic geometry, and it is often used in building illumination design. Their shape captures the light profoundly. This Fibonacci rule on the ratio of series of repeating spirals was used in these projects [30].

3.3. Tuna Swarm Optimization Algorithm (TSO)

Tuna Swarm Optimisation (TSO) is a population-based global optimisation metaheuristic approach. The TSO algorithm mimics two of the tuna school's foraging techniques. Two methods of fish foraging are described here: Fish use two methods of foraging: spiral foraging, which explains how fish travel in a spiral pattern to direct prey into shallow seas where they may eat, and parabolic foraging, which includes a fish swimming in a parabolic shape and following its tail of the fish in the direction that allows it to surround the school of tuna. TSO reaches worldwide optimisation with these two foraging strategies. An innovative based on populations metaheuristic algorithm that mimics tuna schools' helical and parabolic feeding patterns. [31]

Tuna swarm optimisation method stands out for having fewer adjustable parameters and strong exploratory capabilities. The tuna algorithm is being used in a wide range of industries [32]. Fan et al. addressed the issue of economic operation in hydropower plants by using an improved tuna swarm approach. Fu et al. proposed a novel and improved tuna optimisation particle filter method that successfully handles the power system harmonic estimation issue. Gou et al. developed an upgraded tuna swarm technique to solve parameter estimation problems in the Jensen model. Nanda et al. maximised the forecast of solar power generation using an ELM model based on an upgraded tuna swarm approach. Sheeja et al. presented an adaptive black hole–tuna swarm approach for multi-objective optimisation of energy saving in wireless sensor networks. [11]

Each individual in the community is compared to a tuna, and although they are all impacted by each other's foraging activities, each tuna uses a different foraging technique to get the best answers. This is the main concept of the method known as the tuna swarm optimisation (TSO). Every tuna improves its environmental adaptation and pursues the global optimum by modifying its location in response to changes in its own fitness and that of other tunas in each algorithm iteration [33].

Through spiral foraging, tunas improve their ability to search their environment for the best solutions. Whenever all tunas spiral around food sources to forage, they show a remarkable capacity to effectively search the search region. However, blindly following the top performer in the event that they are unable to locate food might result in a drop in the group's overall search efficiency. Consequently, a random individual location is provided as a reference point for spiral searching in order to improve the tuna swarm algorithm's global search capability. This facilitates each tuna's exploration of a larger region. The tuna swarm method improves local search capability and search accuracy by progressively moving a point of reference enabling spiral hunting from the ideal person's location to that of a randomly chosen individual as the number of algorithm cycles grows.[11]

4. Types of Spiral Paths in Bioinspiration

4.1. Spiral Paths

Trees, spirals, waves, and other forms in nature are examples of patterns known as apparent consistencies. Natural visual patterns may be modelled using fractals, spirals, chaos theory, etc. Spirals and fractals may be found together in some natural designs. For example, the Fibonacci spiral is a variation of the logarithmic spiral that relies on the Fibonacci numbers and the golden ratio. Because the curve is logarithmic, it looks the same at every size and is fractal in nature. One such example of a fractal spiral is romanesco broccoli. Researchers were motivated to create optimisation algorithms by the aforementioned trends. The following are some examples of the many spiral trajectories that were employed in the study: Archimedes spira, Cycloid spiral, Epitrochoid spiral, Hypotrochoid spiral, Logarithmic spiral, Rose spiral, Inverse spiral, and Overshoot spirals [10]

Below is a thorough explanation of the five spirals that are most often used: Archimedes, logarithmic, rose, epitrochoid, and hypotrochoid [34].

4.2. The Logarithmic Spiral

In nature, logarithmic spirals are often seen as in Figure 4. For example, the arms of tropical cyclones, galaxies, the nautilus slice, and Iceland's low-pressure region often have a logarithmic spiral structure. Because the spiral distance grows in a geometric manner, the logarithmic spiral is often referred to as an equiangular or growth spiral [34a, 35-38].

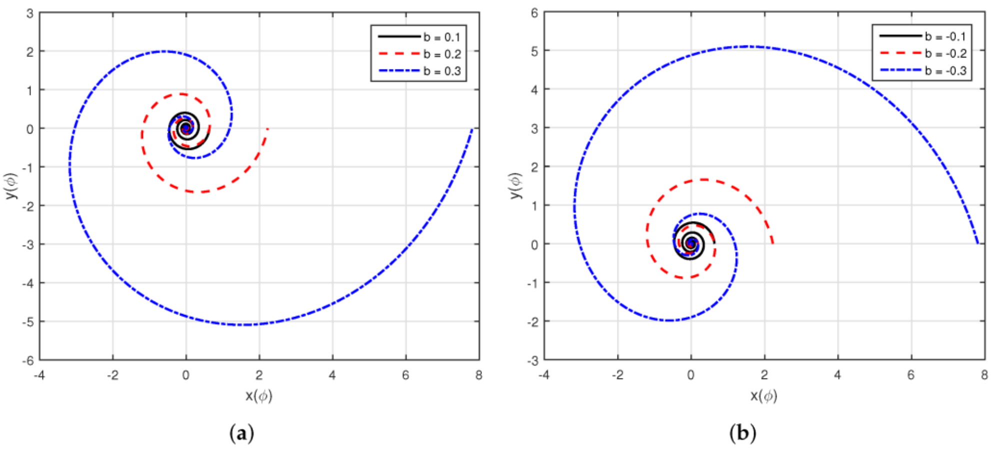

Figure 4: Logarithmic spiral [10]

4.3. The Archimedean Spiral

Another well-known spiral that has found extensive use in biology, engineering, and other fields is the Archimedean spiral as in Figure 5. The mathematical spiral is another name for the Archimedean spiral. In nature, this spiral is present in human fingerprints [39], ferns [40], and millipedes [41-42]. The location of a point as it travels away from a fixed point along a line that spins at a constant angular velocity is known as its spiral trajectory [43-46].

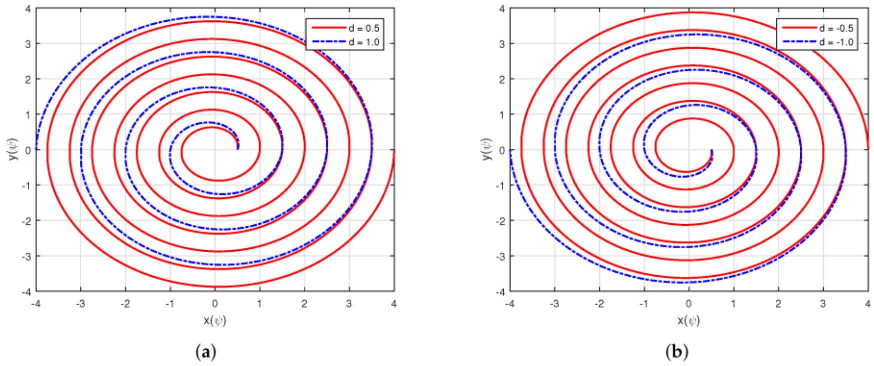

Figure 5: Archimedean Spiral [10]

4.4. The Rose Spiral

As the name implies, the rose spiral has periodic and symmetric arc curve characteristics and is often seen in the unfolding of rose petals as in Figure 6

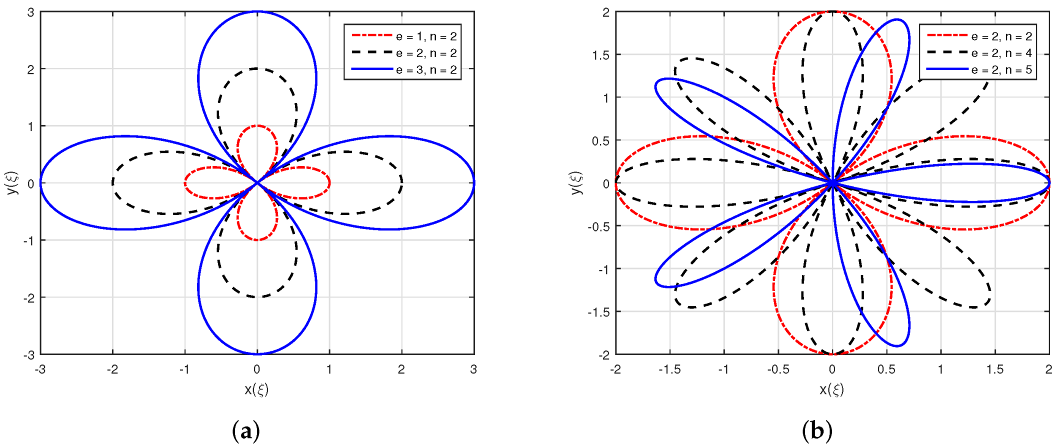

Figure 6: Rose Spiral [10]

5. Conclusion

Designers' increased cognisance of nature's possibilities for enhancing human and system function is reflected in the rising popularity of biomimicry in the built environment. The field of advanced material technology has extensively used biomimicry. Nevertheless, there has been little in-depth discussion of its possibilities in environmentally conscious building practices. Biological principles are increasingly finding their way into architectural design, one of many fields that have been impacted by the social and natural sciences. From the earliest days of bio-architectural movements to the current day, bioinspiration has influenced architectural techniques, leading to a proliferation of novel ideas. Nevertheless, the line between mimicking natural forms and really comprehending biological principles—the bedrock of sustainable development—becomes blurry when discussing biomimicry and bioinspiration in the context of architecture. The biggest obstacle still isn't bridged between the creative process of architecture and the extensive understanding of biology and associated scientific domains; this includes the need for architects and biologists to work together across disciplines. There includes an extensive presentation of several spiral trajectories, their features, and how these spiral techniques have been used to create and enhance other optimisation algorithms.

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