

**An Approach to Incorporate Generative Artificial Intelligence
as a Means to Include Biomimicry within Industrial Design**

by

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Abstract

Biomimicry is most commonly defined as “innovation inspired by nature.” Biomimicry has the potential to make industrial design more sustainable, but has yet to be fully realized within the industrial design process and community. There are defined approaches to using biomimicry, but none specifically dedicated to applying biomimicry in industrial design, and this thesis aims to address this challenge. Typically, industrial designers begin with a design brief, move onto the research phase, and then ideate and test design solutions from there. However, in many biomimetic design solutions, inspiration precedes the brief, possibly posing a challenge to industrial designers looking to nature for solutions post-design brief. Combining aspects of existing biomimetic methods, industrial design methodology, and considering growing AI workflows, a new approach to biomimetic design is developed that incorporates generative artificial intelligence technology to strategically include biomimicry in industrial design.

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1.1 Problem Statement

Biomimicry has the capacity to help industrial designers create innovative and sustainable solutions, but has not come to full fruition within industrial design. There are defined approaches to using biomimicry, but none specifically dedicated to applying biomimicry in industrial design. Oftentimes, biomimetic design solutions are happened upon by chance or driven by inspiration, *not* a design challenge. Industrial designers are typically given a design brief when beginning a project, and look to find solutions to their presented design challenge by finding inspiration through various forms of research and ideation techniques. However, biomimicry often inspires design *before* a design brief or challenge has been presented. This dichotomy can pose a challenge for industrial designers looking to nature for solutions post-design brief. It could be argued that to make biomimicry more pervasive throughout the industrial design community, there should be a more systematic, developmental approach to incorporating biomimicry into industrial design. This thesis will examine existing biomimetic methods, industrial design methodology, and growing AI workflows, proposing a new approach to strategically include biomimicry in industrial design.

1.2 Need for Study

This study is important because there needs to be a systematic approach to using biomimicry in industrial design. Biomimicry has the capacity to help industrial designers develop innovative and sustainable solutions, but has yet to reach its full potential in industrial design. There are defined approaches to using biomimicry, but there is not currently a biomimetic approach tailored specifically to industrial design. As the demand for sustainable solutions increases, biomimicry offers significant potential to support these efforts. However, its effectiveness is limited if there are usability challenges in industrial design applications, which this thesis addresses. Furthermore, another aspect that makes this thesis important is that generative artificial intelligence [generative AI] is utilized. Generative AI is a powerful, impactful tool that arguably has the potential to greatly alter the industrial design space. By incorporating generative AI into this thesis' approach, readers are educated about this emerging technology and understand how to better use it to their benefit. With the use of generative AI, industrial designers are able to better integrate biomimicry into their current design practices.

1.3 Objective of Study

The objective of this thesis is to provide industrial designers with an approach to better include biomimicry within industrial design by incorporating generative AI. This study will examine existing biomimetic methods, industrial design methodology, and generative AI. This thesis will also discuss sustainability in relation to industrial design. By combining aspects from these topics, a new approach to using biomimicry for industrial design will be established. A design project will be completed to demonstrate the approach developed from this thesis. The development and demonstration for the approach will be documented.

1.4 Assumptions

It is assumed that the developed approach from this study will educate designers about biomimicry and how to apply it by using generative AI. It is assumed that all books, journals, videos, and other cited publications have been validated.

1.5 Scope and Limits

This study is focused solely on the role of biomimicry in industrial design, not other design fields. The two major biomimetic approaches and their corresponding ideologies discussed in this study are from similar sources, so some overlap should be expected. Generative AI technology is being advanced every day, causing some information published in this study to be changing quickly. This study does not examine every generative AI technology. It specifically concentrates on ChatGPT, a release by OpenAI, which is widely considered a frontrunner in the field of artificial intelligence. The ChatGPT prompts developed in Chapter Three were designed to be used in ChatGPT's GPT-3.5, as it only responds with textual answers for designers to respond to or synthesize, rather than GPT-4 which has integrated text-to-image capabilities. This approach focuses on text-to-text generation because the developed approach emphasizes the use of generative AI in the beginning stages of the design process, primarily the research phase, as that is where the challenge for industrial designers using biomimicry lies. This thesis does not aim to change an industrial designer's process, but rather integrate and streamline the use of biomimicry in the current design process.

1.6 Anticipated Outcomes

The outcome of this study is a systematic approach for designers to better include biomimicry within industrial design by incorporating generative AI. By using the approach developed in this thesis, it is supposed that the use of biomimicry in industrial design will be more approachable and result in more successful biomimetic solutions.

1.7 Definition of Terms

Artificial Intelligence [AI]- describes machines that imitate human cognitive functions and human intelligence; “AI uses predictions and automation to optimize and solve complex tasks that humans have historically done, such as facial and speech recognition, decision making and translation” (IBM Data Team & IBM AI Team, 2023).

BIDARA- stands for *Bio-Inspired Design and Research Assistant*; “a ChatGPT-based chatbot that was instructed to help scientists and engineers understand, learn from, and emulate the strategies used by living things to create sustainable designs and technologies” (*PeTaL | Glenn Research Center | NASA*, 2023).

Biologize- term used by the Biomimicry Institute to represent the process of identifying “the essential functions and context [the] design solution must address” and then “[reframing these criteria] in biological terms, so that [designers] can ‘ask nature’ for advice” (*Biologize Function & Context*, n.d.).

Biome- “the world's major communities, classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment” (*The World’s Biomes*, n.d.)

Biomimicry- “innovation inspired by nature” (Benyus, 2002); a practice that learns from and mimics the strategies found in nature to solve human design challenges (*What Is Biomimicry?*, 2023).

ChatGPT- stands for *Chat Generative Pre-trained Transformer*; a large-language model [LLM] chatbot which was released in November 2022 by AI research and deployment company, OpenAI (Gregersen, 2023).

Classic Learning- type of machine learning model, dependent on human intervention to operate, “[solves] problems by using explicit programming,” performs well with smaller datasets (Grieve, 2023).

Deep Learning- type of machine learning (ML) model that can run with little to no human intervention to solve problems using neural networks; interprets massive amounts of data to increase the success of the algorithm’s performance and understanding (Grieve, 2023).

Ecosystem- “a geographic area where plants, animals, and other organisms, as well as weather and landscapes, work together to form a bubble of life” (*Ecosystem*, n.d.).

Generative Artificial Intelligence- a type of *deep* machine learning model, able to “generate high-quality text, images, and other content based on the data they were trained on” (Martineau, 2023).

Machine Learning- “a subset of artificial intelligence that allows for optimization” (IBM Data Team & IBM AI Team, 2023); optimizes “learning” through observing data patterns (*What Is Generative AI?*, 2023).

Organism- a living thing that has an organized structure, can react to stimuli, reproduce, grow, adapt, and maintain homeostasis... any animal, plant, fungus, protist, bacterium, or archaeon on Earth (*Organism - Definition and Examples - Biology Online Dictionary*, 2023).

Neural Network- serves as the backbone of deep machine learning (IBM Data Team & IBM AI Team, 2023); made up of nodes that communicate with one another based on specific

factors; the amount of layers in the network determines the type of machine learning model (Grieve, 2023).

Planned Obsolescence- "...a business strategy in which the obsolescence (the process of becoming obsolete, that is, unfashionable or no longer usable) of a product is planned and built into it from its conception" (Kramer, 2012).

Sustainability- "the ability to be sustained, supported, upheld, or confirmed; the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance" (*Sustainability Definition & Meaning* | *Dictionary.com*, 2020).

Chapter 2

Literature Review

2.1 Need for Sustainability

Sustainability is defined as: “the ability to be sustained, supported, upheld, or confirmed; the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance” (*Sustainability Definition & Meaning | Dictionary.com*, 2020). The need for sustainability has been increasing exponentially since the Industrial Revolution. The goal of sustainable design is to incorporate sustainability throughout the entire design process, creating products that have a reduced impact throughout products’ life cycle. These impact categories are ecological damage, human health damage, and resource depletion. Ecological damage includes: ozone depletion, climate change, acid rain, water eutrophication, habitat alteration, and eco-toxicity. Human health damage includes: photochemical smog and air pollution, carcinogens, and health damaging substances. Resource depletion includes: the use of non-renewable materials such as fossil fuels, fresh water, and minerals. Another form of resource depletion is the loss of topsoil through agricultural practices (White et al., 2013).

Some could claim that industrial designers have a pivotal role in sustainability as industrial designers are designing products and their manufacture. In *Design for the Real World*, Victor Papanek famously stated, “There are professions more harmful than industrial design, but only a very few of them (Papanek, 2019, p. ix).

A cause of negative ecological impact that the industrial design profession has a role in is “planned obsolescence.” Planned obsolescence is defined as “...a business strategy in which the

obsolescence (the process of becoming obsolete, that is, unfashionable or no longer usable) of a product is planned and built into it from its conception” (Kramer, 2012). Originally developed to stimulate the U.S. economy after the Great Depression, this practice is unsustainable and has had many negative effects, including an increased amount of harmful waste on both land and in the world’s bodies of water (Slade, 2007). While the Earth has gone through fluctuations of temperature over long periods of time, humans and their actions are main contributors to the Earth’s current rising climate (Mladenov, 2020). Another negative impact that humans have on the earth is pollution, especially plastic pollution both on land and in water. This is arguably how industrial designers are inadvertently negatively impacting the environment the most, given that designers create the products that become pollution, but it is also where industrial designers can have the most positive influence.

2.2 Biomimicry

Biomimicry is “innovation inspired by nature” and the term ‘biomimicry’ comes “from the Greek *bios*, life, and *mimesis*, imitation” (Benyus, 2002, p. xi). Written by Janine Benyus, the book *Biomimicry: Innovation Inspired by Nature* popularized biomimicry in the public eye. In the preface of the book, author Janine Benyus presents a sort of philosophy of biomimicry, which she defines as the three foundational elements of biomimicry:

1. *Nature as model.* Biomimicry is a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.

2. *Nature as measure.* Biomimicry uses an ecological standard to judge the “rightness” of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.
3. *Nature as mentor.* Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it. (p. xi)

The Biomimicry Resource Handbook: A Seedbank of Best Practices [*The Biomimicry Resource Handbook*] (Baumeister et al., 2014) also addresses the philosophy of biomimicry, which they categorize under the term ethos:

Ethos also represents our respect and gratitude for and responsibility to our fellow species and our home. It comes from a deep-seated belief that humans comprise one of many species populating the planet, each with their own inherent right to survive- yet our survival ultimately depends on their survival. By holding this element, the practice of biomimicry should lead towards solutions that create conditions conducive to life. (pp. 63-64)

While these underpinnings and beliefs are essential to biomimicry, some folks believe it is not enough to fuel the biomimetic movement. Published early 2023, *The Biomimicry Revolution* by Henry Dicks takes a deep dive into the philosophy of biomimicry. Claiming that the biomimicry movement does not have a strong enough philosophy to fully come to fruition, he states, “Lacking a cogent theoretical and philosophical basis, biomimicry has been unable to realize its revolutionary potential” (p. 1). In order to understand much of Dicks’ claims, one must understand this philosophical vernacular he utilizes in his work. The term ontology has its roots in the Middle Ages and is known as the “the philosophical study of being in general, or of what

applies neutrally to everything that is real” (Simons, 1998). Ethics “[refers] to the philosophical study of the concepts of moral right and wrong and moral good and bad... and to any system or code of moral rules, principles, or values” (Singer, 2023). Technics refers to the philosophy of technology and epistemology is “the philosophical study of the nature, origin, and limits of human knowledge” (Martinich & Stroll, 1998). Dicks explores biomimicry through the use of these philosophical pillars and concludes there must be a marriage of both biomimetic design and philosophy for the “biomimicry revolution” to be successful, stating “...to embrace biomimicry is to embrace not only a new strategy for technological innovation, but also a broader philosophical shift in both our thinking about and our relation to nature” (p. 250). While biomimicry is most commonly known as a design strategy, Dicks claims that biomimicry can also function as the foundation for a new environmental ideology that significantly changes our perception and interaction with the world (Dicks, 2023). Dicks proposes a new philosophical structure pictured below (Figure 1) to be applied to biomimicry in order to achieve this goal.

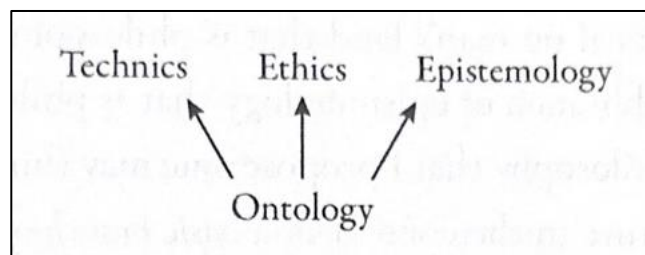


Figure 1: Henry Dicks’ (2023) New Philosophical Structure

In the book *Building for Life: Designing and Understanding the Human-Nature Connection*, author Stephen Kellert identifies eight different types of connections that humans have with nature: aesthetic, dominionistic, humanistic, moralistic, naturalistic, scientific, symbolic, and utilitarian (cited in Baumeister et al., 2014, p. 77). Many of these connections are

essential to the practice of biomimicry such as aesthetic, humanistic, moralistic, naturalistic, scientific, and symbolic. However, it can be argued that the majority of industries rely on dominionistic ideals, where the control of nature is emphasized, and utilitarian perspectives, viewing nature as an inexhaustible resource available for human benefit. Both of these connections to nature stand in direct opposition to biomimicry. Biomimicry advocates for learning from and respecting nature, emphasizing sustainability, whereas dominionistic and utilitarian views prioritize human benefit and control without considering the long-term impacts. This contrast is why *The Biomimicry Resource Handbook* emphasizes the need to “(re)connect” with nature, by which they mean that the population need to understand that nature and humans are deeply intertwined and not separate entities. In continuation of ethos, *The Biomimicry Resource Handbook* (2014) goes on to state, “The only economy that really matters is the Earth’s, and to succeed here, we have to play by our planet’s rules” (p. 70). While this sentiment is very appealing, one could argue that unfortunately this is an unrealistic ideal in America’s capitalist society and that the majority of companies consistently choose profit over sustainability. Arguably, this statement should be adjusted and recognize that there must be a way for biomimetic designers to design their products so that they maintain a high profit margin in their sustainable efforts so that their designs are attractive to both the company and the consumer.

Biomimicry became popularized in 1997, when Janine Benyus first published her book *Biomimicry: Innovation Inspired by Nature*. This book publicized the emerging field of biomimicry and provides case studies of successful biomimetic designs. It also emphasizes the need to mimic nature’s models in order to create a more sustainable and healthier planet. Often considered a torch bearer of the field of biomimicry, Janine Benyus is a biologist, author,

speaker, educator, and innovation consultant. In addition to bringing biomimicry into the public eye, Benyus co-founded two biomimetic organizations: Biomimicry 3.8 and the Biomimicry Institute. Founded in 2000, Biomimicry 3.8 is a bio-inspired design consultancy and in 2006, the Biomimicry Institute was founded with the goal to “naturalize biomimicry in the culture by promoting the transfer of ideas, designs, and strategies from biology to sustainable systems design” (*Our Mission; Biomimicry Institute*, 2022). The Biomimicry Institute emphasizes the need to look to nature for inspiration to create designs that can better sustain the environment and seeks to educate the population of this sustainable goal.

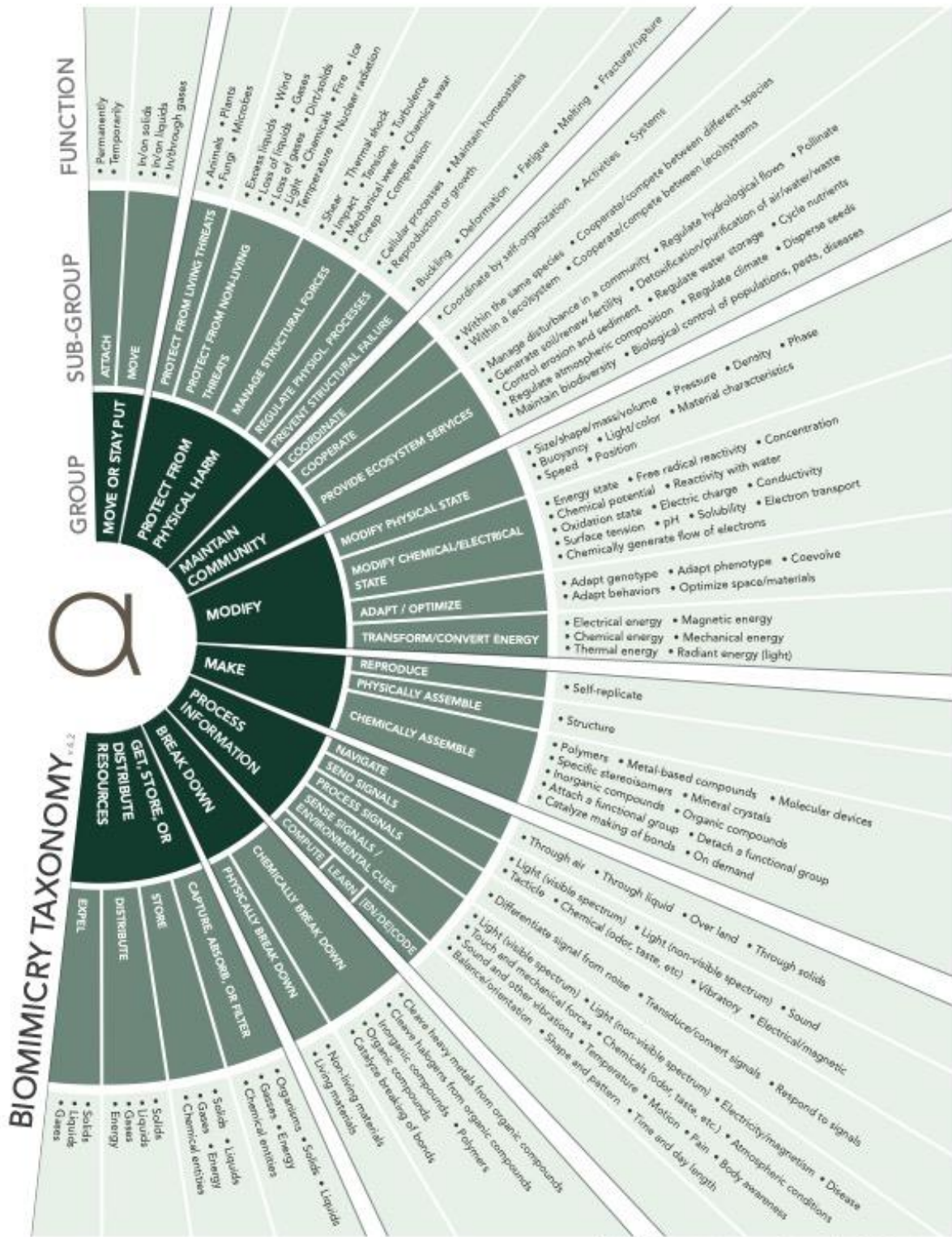
2.2.1 The Biomimicry Toolbox

The Biomimicry Institute provides many free resources, compiled into what they call The Biomimicry Toolbox for individuals to use and reference when learning how to use biomimicry. The Biomimicry Toolbox emphasizes the importance of understanding systems view, context, and functionality in the biomimetic process. Similar to biomimicry, systems view is an essential aspect of the industrial design process, as the same with nature, every aspect of the product is interconnected. The role of function in biomimicry distinguishes it from biophilic, biomorphic, and bio-inspired design movements. The Biomimicry Toolbox states, “In the context of biomimicry, function refers to the role played by an organism’s adaptations or behaviors that enable it to survive. Importantly, function can also refer to something you need your design solution to do” (*Function and Strategy - Biomimicry Toolbox*, n.d.). One can draw a parallel with biomimicry and industrial design here, as much of the industrial design process is based on addressing the function that is needed for each product. The Biomimicry Toolbox directs readers to frame “how” questions and ask nature, “how does nature... *insert function.*” After asking

these “how” questions, the toolbox points readers to look to nature for ‘biological strategies’ to address their design challenge, which are defined as, “a characteristic, mechanism, or process that performs a function for an organism. It’s an adaptation the organism has in order to survive” (*Function and Strategy*, n.d.). To aid readers in formulating these “how” questions, the Biomimicry Institute developed a classification system coined The Biomimicry Taxonomy.

2.2.2 The Biomimicry Taxonomy

The purpose of the Biomimicry Taxonomy is to help users approach their design challenge using biomimicry. The Biomimicry Taxonomy organizes biological strategies by function- by what the strategy does for the organism or living system. Organizing biological content by function is valuable because it allows us to look for potential solutions to similar challenges we face as humans. However, some may claim that the Biomimicry Taxonomy is hard to decipher and apply to biomimetic design. The Biomimicry Taxonomy is pictured on the following page (Figure 2).



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Figure 2: The Biomimicry Taxonomy

The following diagram from the Biomimicry Institute explains how a user can apply the Biomimicry Taxonomy:

Organism	What is the organism?	Namib desert beetle
Challenge	What challenge must it address?	Capture water in a very arid climate
Strategy	How does the organism address this challenge? (strategy)	The beetle's wing covers gather water from the air using nanoscale bumps and body position. *View this strategy page on AskNature.
Function	Why does the organisms need this strategy?	To capture liquid This is represented by the Biomimicry Taxonomy as: <ul style="list-style-type: none"> ▶ Group: Get, store, or distribute resources ▶ Sub-group: Capture, absorb, or filter resources <ul style="list-style-type: none"> • Function: Capture, absorb, or filter liquids

Figure 3: Using the Biomimicry Taxonomy

However, this process is explained by beginning with the organism, but the real challenge is where to look for organisms in the first place that possess applicable biological strategies. The Biomimicry Taxonomy also acts as a framework for AskNature, an online biological database created by the Biomimicry Institute. However, the main limitation of AskNature is that it has 1,754 biological strategies compiled, yet there are estimated to be 5 to 10 million different species on the planet that all have different ways of living in all sorts of ecosystems and environments (*How Many Species Are There?*, 2022). Given this, it can be argued that AskNature is barely scratching the surface. This issue will be addressed in the development of the approach in Chapter Three by incorporating the use of generative artificial intelligence program, ChatGPT.

2.2.3 Nature's Unifying Patterns

The Biomimicry Toolbox also provides a list called Nature's Unifying Patterns, which have been slightly updated since they were first released in Benyus' book in 1997. Nature's Unifying Patterns are listed below, their explanations summarized from descriptions provided from the Biomimicry Toolbox ("Nature's Unifying Patterns," 2021).

1. "Nature only uses the energy it needs and relies on freely available energy."
 - a. Organisms conserve energy due to its costly nature, using it sparingly to survive. Nature utilizes "free" energy sources, such as sunlight, wind, minerals, or organic materials, allowing organisms to minimize energy expenditure. Organisms also employ low-energy processes such as using modular structures, and utilizing multi-functional designs, thereby reducing the energy needed for growth and maintenance.
2. "Nature recycles all materials."
 - a. In nature, organisms utilize the waste from and decomposing bodies of other organisms as a source of food and materials, a process similar to "upcycling," rather than mere recycling. It is similar to upcycling because when organismal detritus becomes an energy or material source for other organisms, it is being turned into something considered of higher value. These "upcycling" processes occur within local, regional, and global ecosystems.
3. "Nature is resilient to disturbances."
 - a. Resilience, concerning nature, involves the ability to recover after disturbances or significant changes in the environment, such as natural disasters or injuries.

Nature achieves this through diversity, redundancy, decentralization, and self-renewal/self-repair mechanisms- ensuring appropriate responses, multifunctional systems, scattered vital functions, and the ability to regenerate cells and heal damage.

4. “Nature tends to optimize rather than maximize.”
 - a. As previously stated, materials and energy are “freely” available, but also scarce, so organisms must utilize both wisely. Therefore, organisms look to find balance between the amount of resources, both material and energy, they utilize and take in.
5. “Nature provides mutual benefits.”
 - a. Interactions between organisms within ecosystems can often provide mutual benefits. One example is sharks and remoras. Remoras are a small fish that attach themselves to sharks while swimming through the ocean. Both sharks and remoras benefit from this relationship: the remoras eat the scraps from the shark’s meal and gain protection from predators, whereas the shark stays clean and healthy, as remoras feed on harmful parasites off the sharks skin and mouth (The Shark and the Remora Fish– a Unique Relationship!, 2019).
6. “Nature runs on information.”
 - a. In order to survive, organisms and ecosystems must be able to receive and respond to information, including signals from other organisms or signals within an organism's body. This adaptive process, honed over millions of years of evolution, involves constant monitoring and appropriate responses. Every system operates within different optimal ranges utilizing feedback loops, which is

essential in natural systems for monitoring and adapting to environmental conditions.

7. “Nature uses chemistry and materials that are safe for living beings.”
 - a. Organisms rely on chemistry within and around their cells, emphasizing the need for chemicals, processes, and materials that support life. Life's chemistry is water-based and involves specific chemical elements organized into precise 3D structures. This enables self-assembly, guidance of chemical processes, and biodegradation to occur. However, not all of nature’s chemistry is safe to living beings. The publication does not mention the fact that many organisms conduct chemistry within themselves, causing them to be poisonous to other organisms as a form of individual protection.
8. “Nature builds using abundant resources, incorporating rare resources sparingly.”
 - a. As mentioned previously, organisms must conserve and optimize material and energy use. Given this, organisms utilize abundant resources, as they are easier to access, reducing energy expenditure. Rare resources are utilized only when they can be found locally in the environment and easily accessible.
9. “Nature is locally attuned and responsive.”
 - a. Organisms must be in tune with and responsive to their environment and ecosystem for the reason of survival. Organisms and ecosystems evolve to respond to local environmental conditions, such as predictable cycles like tides or seasons, as well as gradual changes over time. Adapting to these patterns allows organisms to fill specific niches, providing opportunities for them to thrive and

have an advantage over others. The ability to respond to changing conditions enables organisms and ecosystems to thrive.

10. “Nature uses shape to determine functionality.”

- a. Nature relies on shapes and forms instead of additional material and energy to fulfill functional needs, enabling organisms to achieve tasks with minimal resources. In nature, observed forms almost always have functional reasons behind them, emphasizing efficiency and purpose in design.

The objective of these “patterns” is to transform these lessons into specific design guidelines, criteria for quality control, decisions on materials, and various choices related to manufacturing or processes. However, this often easier said than done. These principles also come with a type of warning label, stating:

Our intent is not to present this as a definitive and exhaustive list. Rather, it is a work in progress that we hope will be informed and enhanced by the growing community of biomimics who are practicing applying nature’s lessons to their designs (“Nature’s Unifying Patterns,” 2021).

2.2.4 Life’s Principles

Biomimicry 3.8, a bio-inspired design consultancy, published a book in 2014 titled *The Biomimicry Resource Handbook: A Seedbank of Best Practices* [*The Biomimicry Resource Handbook*] (Baumeister et al., 2014). This book was created in response to people voicing that after being inspired by talks or stories about biomimicry, many did not know how to actually

utilize biomimicry in practice. Given this, *The Biomimicry Resource Handbook* is a compilation of the consultancy’s methods to utilizing biomimicry to help the reader use biomimicry.

The Biomimicry Resource Handbook presents a backbone of their work which they titled Life’s Principles. Much like The Biomimicry Institute’s Nature’s Unifying Patterns, Biomimicry 3.8’s Life’s Principles are nature’s commonalities: strategies and characteristics that are found across the board (Figure 4).



Figure 4: Life’s Principles (*The Biomimicry Life’s Principles Explained*, 2022)

When introducing Life's Principles role in the design process, the book emphasizes the role of inspiration as the precedent by stating, "During design, Life's Principles can be inspirational and provide a framework for choosing among design options. After a design is completed, Life's Principles can be the basis for continuing assessment on the final outcome of a project" (Baumeister et al., 2014, p. 20). The diagram lists "Earth's Operating Conditions" in the dark gray section, listing common conditions that all of nature is affected by (Baumeister et al., 2014):

- Sunlight, Water, and Gravity
- Dynamic non-equilibrium
- Limits and boundaries
- Cyclic processes (p. 25)

The bullet points in the light gray sub-sections represent how each of Life's Principles, listed in the green section, achieve the goal of "Life creates conditions conducive to life" located in the center of the diagram. The phrase "Life creates conditions conducive to life" is representative of the idea that one should not bend nature to their will, but that people should make their lives, practices, and technologies fit into nature's systems- which the book argues should be a non-negotiable in design. The book states that the purpose of Life's Principles is to "gauge the success of [a] design" and to "use Life's Principles as aspirational goals to aim towards" (Baumeister et al., 2014, p. 26). Life's Principles are also exemplary of Benyus' trio of biomimetic ideology: nature as mentor, model, and measure. Life's principles are listed below (Baumeister et al., 2014, pp. 33-34).

1. *Evolve to Survive*

- a. "Continually incorporate and embody information to ensure enduring performance."

- b. Replicate Strategies that Work
 - c. Repeat successful approaches
 - d. Integrate the Unexpected
 - e. Incorporate mistakes in ways that can lead to new forms and functions
 - f. Reshuffle Information
 - g. Exchange and alter information to create new options.
2. *Adapt to changing conditions*
- a. "Appropriately respond to dynamic contexts"
 - b. Incorporate Diversity
 - c. Include multiple forms, processes, or systems to meet a functional need.
 - d. Maintain Integrity through Self-Renewal
 - e. Persist by constantly adding energy and matter to heal and improve the system
 - f. Embody Resilience through Variation, Redundancy, and Decentralization
 - g. Maintain functions following disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together
3. *Be Locally Attuned and Responsive*
- a. "Fit into and integrate with the surrounding environment"
 - b. Leverage Cyclic Processes
 - c. Take advantage of phenomena that repeat themselves
 - d. Use Readily Available Materials and Energy
 - e. Build with abundant, accessible materials while harnessing freely available energy.
 - f. Use Feedback Loops

- g. Engage in cyclic information flows to modify a reaction appropriately.
 - h. Cultivate Cooperative Relationships
 - i. Find value through win-win interactions.
4. *Integrate Development with Growth*
- a. "Invest optimally in strategies that promotes both development and growth"
 - b. Self-Organize
 - c. Create conditions to allow components to interact in concert to move toward an enriched system
 - d. Build from the Bottom-Up
 - e. Assemble components one unit at a time
 - f. Combine Modular and Nested Components
 - g. Fit multiple units within each other progressively from simple to complex
5. Be Resource Efficient (Material and Energy)
- a. "Skillfully and conservatively take advantage of resources and opportunities"
 - b. Use Low Energy Processes
 - c. Minimize energy consumption by reducing requisite temperatures, pressures, and/or time for reactions
 - d. Use Multi-Functional Design
 - e. Meet multiple needs with one elegant solution
 - f. Recycle All Materials
 - g. Keep all materials in a closed loop.
 - h. Fit Form to Function
 - i. Select for shape or pattern based on need

6. Use Life-Friendly Chemistry

- a. "Use chemistry that supports Life's Processes"
- b. Break Down Products into Benign Constituents
- c. Use chemistry in which decomposition results in no harmful by-products.
- d. Build Selectively with a Small Subset of Elements
- e. Assemble relatively few elements in elegant ways.
- f. Do Chemistry in Water
- g. Use water as solvent.

There is overlap between Nature's Unifying Patterns from the Biomimicry Institute and Life's Principles from *The Biomimicry Resource Handbook*. However, they all have the ability to be streamlined and applied to the industrial design process in a systematic manner, which will be demonstrated in Chapters 3 and 4.

2.2.5 Biomimetic Design Strategies

The Biomimicry Resource Handbook (Baumeister et al. 2014) acknowledges the challenge of using biomimicry:

In its most basic definition, biomimicry may be as simple as "imitating Life," but the actual practice of biomimicry is less straightforward. There is no linear sequence or instructions a biomimic can follow and be rewarded with a perfect biomimicry solution... biomimicry is more than an abstract, or even tangible practice. Succeeding at biomimicry requires a kind of mindset, a connection to nature, and a guide.

Many can agree there needs to be a mindset shift concerning design and production in order to fully realize biomimicry's potential. However, some could argue without a specific

methodology, the practice of biomimicry can be overwhelming and inaccessible to the designers who may not have a biology-focused or scientific background. In continuation, without a clear and concise approach to using biomimicry, industrial designers could get discouraged trying to figure out the best path for using biomimicry in their design practice. Therefore, the most prominent existing biomimetic design strategies will be discussed and synthesized in this section.

2.2.5.1 The Biomimicry Design Spiral

Another tool that the Biomimicry Institute provides is the Biomimicry Design Spiral. Pictured below (Figure 5), the Biomimicry Design Spiral was created to act as a methodology for using biomimicry.

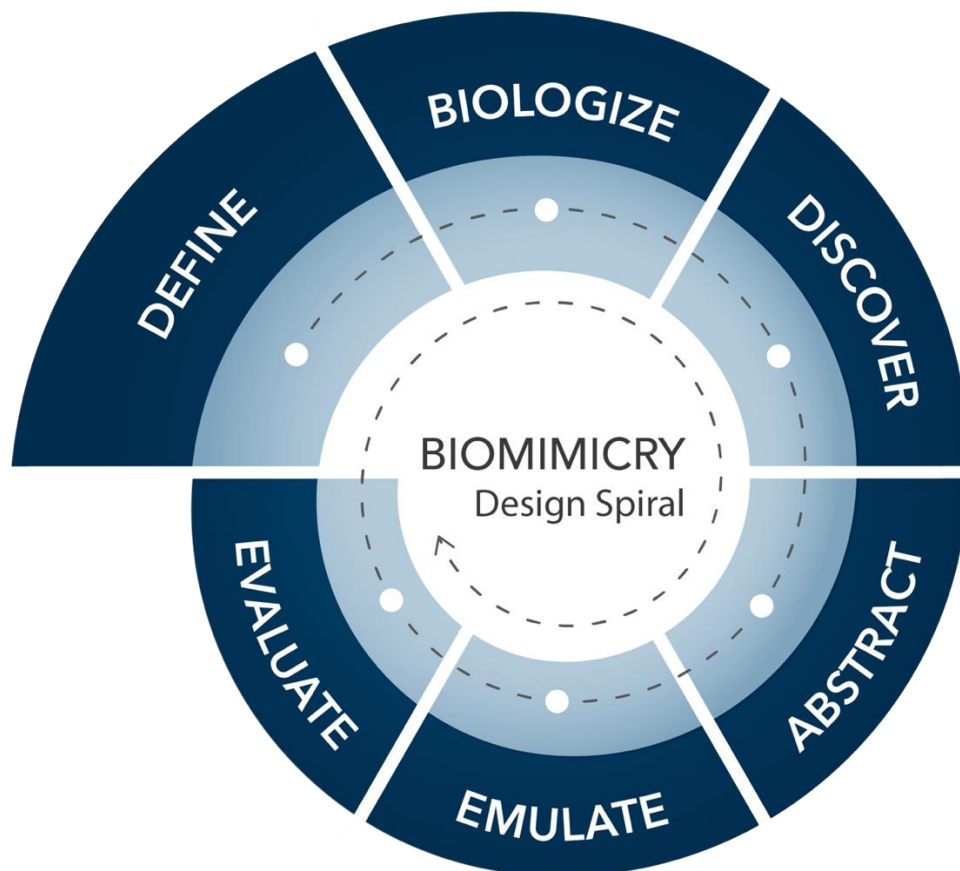


Figure 5: The Biomimicry Design Spiral

1. *Define*

- a. Articulate the problem you want to solve
- b. Identify constraints

2. *Biologize*

- a. Identify the necessary functions and context for your design solution.
- b. “Reframe [these criteria] in biological terms, so that you can ‘ask nature’ for advice” (*Biologize Function & Context*, n.d.).

3. *Discover*

- a. “Look for natural models (organisms and ecosystems) that need to address the same functions and context as your design solution. Identify the strategies used that support their survival and success” (*Discover Biological Strategies*, n.d.).

4. *Abstract*

- a. Take found biological features and identify what makes them successful
- b. “Restate [biological features] in non-biological terms, as ‘design strategies’” which are defined as, “a statement and/or sketch that articulates the function and mechanism without using biological terms” (*Abstract Design Strategies*, n.d.).

5. *Emulate*

- a. “Look for patterns and relationships among the strategies you found and hone in on the key lessons that should inform your solution. Develop design concepts based on these elements” (*Emulate Nature’s Lessons*, n.d.)
- b. Create visual aid, revisit your design question, explore many ideas, consider nature’s unifying patterns.

6. *Evaluate*

- a. “Assess the design concept(s) for how well they meet the criteria and constraints of the design challenge and fit into Earth’s systems. Consider technical and business model feasibility. Refine and revisit previous steps as needed to produce a viable solution” (*Evaluate Fit & Function*, n.d.).

While the Biomimicry Design Spiral may serve as a jumping off point to using biomimicry for an inexperienced designer, there are both challenges and limitations within the Biomimicry Design Spiral. For example, the *Discovery* section of the Biomimicry Design Spiral provides a list of “Tips and Suggestions” which are listed below (*Discover Biological Strategies*, n.d.):

Go outside and look around

Keep a nature journal

Explore AskNature

Read scientific literature

Talk to biologists and naturalists

Track your sources

To an industrial designer looking for a concrete way to discover biomimetic solutions for their project, who are both familiar with the design process and experienced in design research, many of these “suggestions” and steps may feel obvious, contrived, or even impractical. One could argue there needs to be a streamlined approach to using biomimicry in design, which will be developed in Chapter 3.

2.2.5.2 The Biomimicry DesignLens

The Biomimicry Resource Handbook also presents a visual representation identifying their approach to using biomimicry which Baumeister et al. (2014) call the Biomimicry DesignLens.

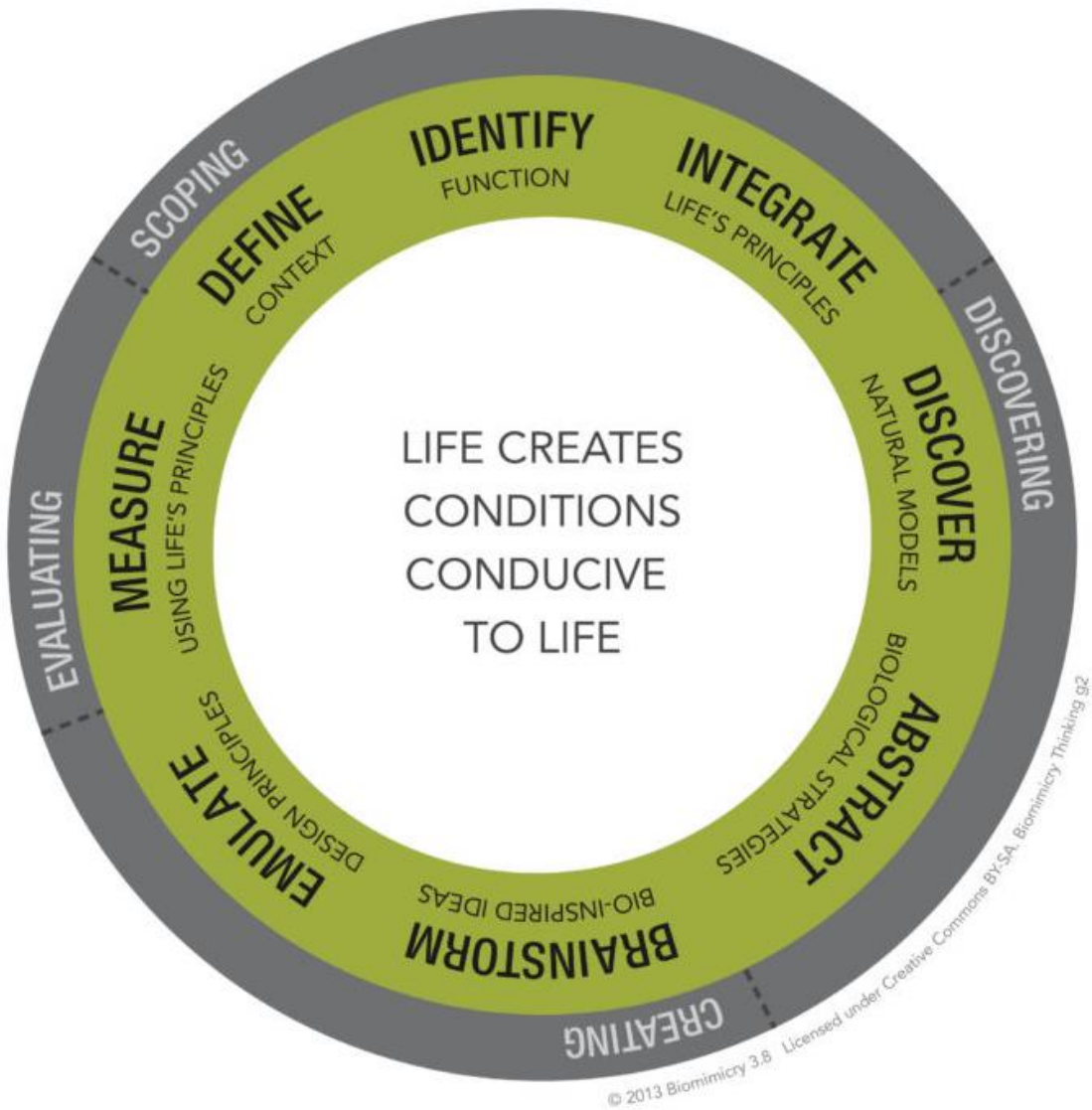


Figure 6: The Biomimicry DesignLens

The Biomimicry Resource Handbook (Baumeister et al., 2014) introduces their biomimetic approach as follows:

...there is not just one methodology, start to finish, that works for all industries and all applications...we no longer teach a methodology per se, but rather share a framework with which one can learn how and when to incorporate biomimicry thinking into design.
(p. 85-86)

The diagram pictured above (Figure 6) does not denote a specific starting or stopping point, which goes back to their approach not following a strict sequence, allowing people using their approach to jump around through the steps. However the book states that typically the process follows the following order (Baumeister et al., 2014):

1. *Scoping*
 - a. **Define** context of the scope of work
 - b. **Identify** the function(s) of the challenges
 - c. **Integrate** life's principles in the design brief

2. *Discovering*
 - a. **Biologize** the question
 - b. **Discover** natural models
 - i. Walk outside
 - ii. Comb the literature
 - iii. Brainstorm with biologists
 - c. **Abstract** biological strategies into design principles

3. *Creating*
 - a. **Brainstorm** ideas

b. **Emulate** design principles

4. *Evaluating*

a. **Measure** using life's principles (p. 89)

Their process emphasizes to always come back to Life's Principles and try to integrate them as much as possible in order to create the most sustainable design solution and to use them to evaluate at the end of the process. The process also emphasizes the role of function and context in biomimicry, just like the Biomimicry Institute's approach.

The Biomimicry Resource Handbook (Baumeister et al., 2014) talks about the design process in a general sense, describing it as nonlinear and likening the lack of structure in the DesignLens to the fluid-ness of design. However, as will be discussed in the design methodology section of the literature review, there are many successful attempts at standardizing the approach to design that have high success rates. The goal should be to incorporate biomimicry into a more traditional design structure in order to achieve its full potential, which is what this thesis aims to achieve. The book goes on to state:

Even if the project continues along a more traditional design course- relying on adapting existing ideas, human cleverness, or that rare flash of creative genius to find innovative ways to meet the functional needs of design- by having planted the seed for inviting biomimicry to the design table, the project may still return to seek solutions from Life in the discovering phase. (p. 102)

This statement could be seen as problematic because it can imply that without biomimicry in the process, human creativity to develop innovative solutions is in fact "rare," even though a plethora

of innovative products have been developed without the use of biomimicry. Furthermore, the book goes on to state:

In many ways, biomimicry thinking best serves radical innovation because natural models generally aren't standard sources, yet nature's strategies can provide very compelling future visions and brilliant insights, proven by 3.8 billion years of R&D. (p. 103)

Some could claim that this statement places limits on biomimicry, implying that a biomimetic design approach is unable to be used to design everyday solutions, and primarily can be used for “radical innovation” and “future visions,” which is in direct opposition of the philosophical statement earlier in the book, “The real ideal is to create a biomimetic culture that looks to nature for advice in all endeavors, including but not limited to inventions” (p. 69). Perhaps, instead of creating warring factions between current design practices and biomimicry, a more integrated approach of the two should be promoted. This approach should take the best of both processes to streamline and simplify the use of biomimicry in the design process, which the developed approach addresses in Chapter 3.

2.2.6 Biomimetic Case Studies

In many biomimetic design examples, inspiration precedes the design challenge or brief, rather than being presented a design brief, then looking to nature to research and find solutions that address their brief. Biomimetic solutions are also often happened upon by chance, even when a design challenge is present. Some of these case studies also illuminate that while biomimicry was popularized in the late 1990's, imitating nature's function has been prevalent

throughout human history, just not under the formalized title of “biomimicry.” Some case studies are listed below:

Umbrella & Saw, 5th century BCE

Perhaps the earliest examples of biomimicry were conducted by Chinese carpenter Lu Ban in 5th century BCE. Lu Ban is credited with inventing both the umbrella and the saw during his lifetime. It is claimed that his invention of the umbrella was inspired by a giant lily leaf (*The Complete History of Biomimicry (With Examples)*, n.d.). The story also goes to say that Lu Ban stumbled across the idea to invent the saw when he cut his hand one day on a leaf with a spiny texture and was inspired to design a tool for cutting wood.



Figure 7: Lu Ban with saw, (*Lu Ban, the Ancestor of Craftsmen*, 2023)

Flying Machines, 1452-1519

One of the most famous figures of the Italian Renaissance was Leonardo Da Vinci, who was considered an “expert scientist, inventor, artist, architect, [and] mathematician” (Schriener & The Department of History at Ohio State University, 2018). Da Vinci often looked to nature for inspiration, especially in his development of multiple flying machines. Da Vinci studied both birds and bats, being “fascinated by flight and drew out schematics for many flying machines

that mimicked the bone structure” of their wings (Schriener & The Department of History at Ohio State University, 2018). Da Vinci’s explorations would be considered inspiration preceding his design challenge of creating flying machines.

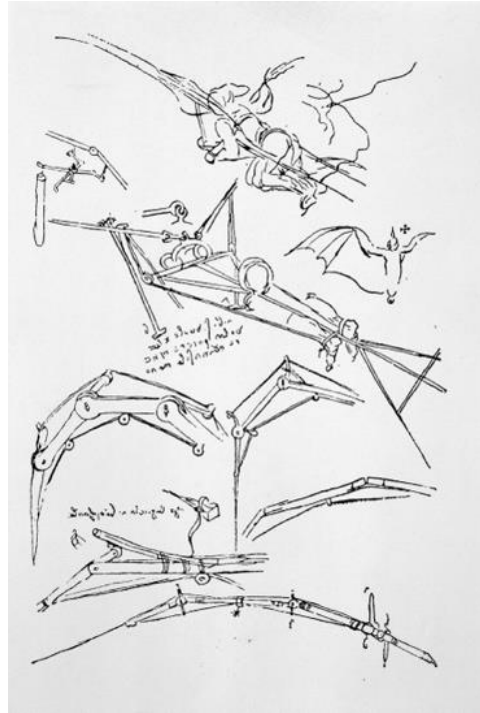


Figure 8: Da Vinci’s sketches, (*Leonardo Sketches, circa 1500, n.d.*)

The Airplane, 1903

In 1903, Orville Wright and Wilbur Wright, most commonly known as “The Wright Brothers,” built and flew the first successful airplane in Kitty Hawk, North Carolina. In their effort to design man-made wings for flight, they looked to the masters of flying: birds. After years of development, the Wright Brothers created a concept that was called “wing warping,” which was inspired by various birds that “angled their wings for balance and control” (*Wright Brothers, 2023*). This historic feat is a successful example of looking to mimic nature to create an innovation solution after being presented with a design challenge.

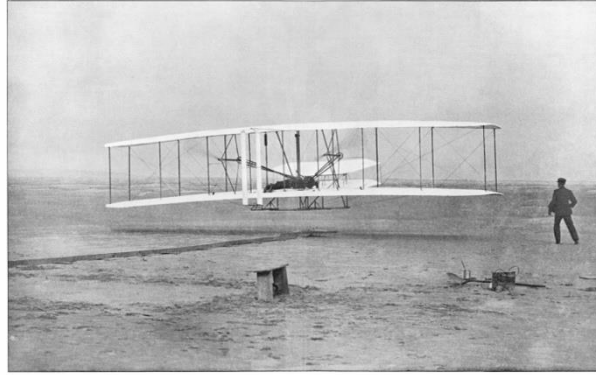


Figure 9: The Wright Brothers' airplane, (*Wright 1903 Photo. Date 1444, n.d.*)

Velcro, 1954

Velcro was invented by George de Mestral, a Swiss electrical engineer, after he was inspired by the cocklebur plant on a walk through the woods. A cocklebur is an “erect summer annual herb” that produces burs that are covered in small, hook-like hairs (*Common Cocklebur, n.d.*). These burrs often got caught on his clothing, inspiring Mestral to create hook and loop fasteners. Over time, patents for Velcro were filed worldwide and their designs were improved upon, causing Velcro to be an extremely prevalent example of biomimicry in products still to this day. Velcro is an example of biomimicry in which nature inspired a solution before a design challenge.

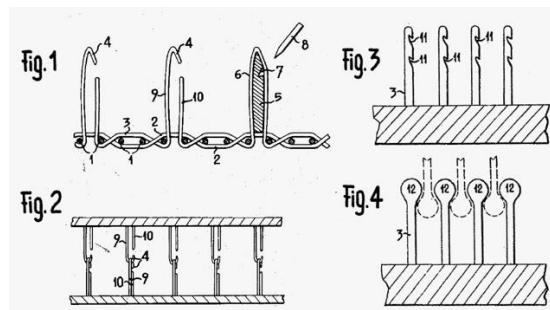


Figure 10: Velcro patent, (*Our Story- Velcro Companies History, n.d.*)

Japan's Shinkansen, 1989

One successful example of biomimicry in design is the Japanese Shinkansen train, commonly known as a bullet train. The Japanese bullet train needed to be quieted, as it was creating small sonic booms every time it exited a tunnel (Vox & 99% Invisible, 2017). One of the team members, Eiji Nakatsu, was a bird watcher, and incorporated physical characteristics from an owl, penguin, and kingfisher into the new design. These biomimetic additions increased efficiency, speed, and reduced the train's noise (Vox & 99% Invisible, 2017). However, while this design was incredibly successful, this is an example of there being a design challenge present, but the biomimetic solution was luckily happened upon given there happened to be a birder on the team with knowledge of birds' biological strategies.



Figure 11: Artistic representation of the Shinkansen, (Biomimicry Institute, 2017)

InterFLOR Entropy Carpet Tiles, 2000

In 2000, InterfaceFLOR and designer David Oakey developed non-directional tiled carpet, its patterning inspired by the inconsistent pattern of the forest floor during a biomimicry workshop. They created this flooring in order to address the waste from the carpet industry and try to make carpet more sustainable. The carpet squares can be placed in any direction during installation and individual tiles can be replaced without redo-ing the whole floor (The

Biomimicry Institute, n.d.). This case study is an example of biomimicry in which nature inspired a solution before a design challenge.



Figure 12: Entropy carpet, (*Entropy: Commercial Carpet Tile by Interface*, 2023)

Sharklet, 2002

This example is an outlier from the others, because the design challenge preceded the inspiration in this material product. Development began for Sharklet in 2002, after the U.S. Office of Naval Research tasked Dr. Anthony Brennan in researching "a way to reduce the buildup of algae on ship hulls that did not involve toxic paints and reduced maintenance and dry dock costs" (Jay et al., n.d.). To solve this problem, he decided to study the micro-topography of the skin of large, slow-moving sea creatures to see how their bodies fight against algae and bacteria growth. His research found that shark's scales, called dermal denticles, performed the best at reducing algae growth: "[their scales] are covered in enamel that is analogous to human teeth and can repel more than 85% of algae that comes in contact with the scales" (Jay et al., n.d.). Brennan mimicked their scales in the development of the Sharklet material, significantly reducing the ability for bacteria to grow on the surface. This surface micro-pattern has been used in a yoga mat design, endotracheal tube, urinary catheter, and adhesively backed film (*Products - Sharklet Technologies, Inc.*, 2022).

However, while this material innovation is astounding, Brennan (n.d.) is not an industrial designer. He impressively obtained both his Bachelor's and Master's degrees in chemistry, and earned his PhD in Materials Engineering Science. Industrial designers are able to employ innovations like Sharklet in their designs; however, one may ask how can a designer, with little to no scientific background, research nature's solutions and apply them in their work?

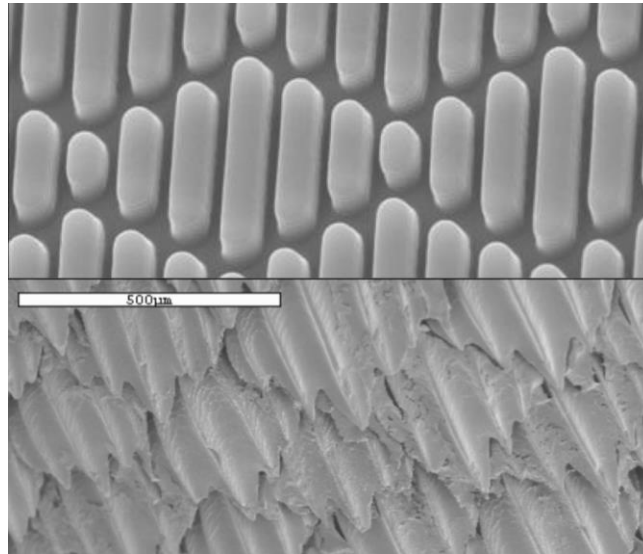


Figure 13: Microscope view of Sharklet material and dermal denticles,
(*NON-TOXIC ANTI-FOULING SOLUTIONS: SHARKLET*, n.d.)

2.3 Sustainable Design

As mentioned previously, sustainability is defined as: “the ability to be sustained, supported, upheld, or confirmed; the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance” (*Sustainability Definition & Meaning | Dictionary.com*, 2020). The need for sustainable design is growing rapidly and its goal is to incorporate sustainability throughout the entire design process, creating products that have a reduced impact throughout products' life cycle.

2.3.1 Notable Figures in Sustainable Design

There are many notable figures that have influenced sustainable design, such as Rachel Carson, R. Buckminster Fuller, Victor Papanek, and Vance Packard.

Rachel Carson was a marine biologist, conservationist, and writer who inspired designers to take action towards sustainable solutions. She authored multiple books and articles that revealed the science, importance, and beauty of the natural world to the public. Her most influential book was *Silent Spring*. Carson released it originally as a series of articles in the *New Yorker*, then published these as a book in 1952. *Silent Spring* is about the misapplication of powerful chemical pesticides and their negative impacts on humans and the environment. *Silent Spring* ignited change at the federal governmental level in the United States, and inspired the current environmental movement, showing how influential one person can be on the larger picture of society (Carson, 2002).

R. Buckminster Fuller considered himself a “comprehensive anticipatory design scientist” and worked as an architect, systems theorist, writer, designer, inventor, philosopher, and futurist (*About Fuller*, 2022). Fuller “was an early proponent of high-efficiency, environmentally responsible design” (Gorman, 2003, p. 186). In 1969, Fuller released one of his most influential writings: *Operating Manual for Spaceship Earth* in which he “emphasizes the need to conserve the earth’s resources” (Gorman, 2003, p. 186). Fuller influenced a multitude of designers in the sustainable design movement.

Victor Papanek was a designer and educator who heavily promoted sustainable design. He was influenced by individuals such as Buckminster Fuller and Rachel Carson, and “castigated practitioners of industrial design for wasting both natural and human resources on the design of unnecessary, dangerous, and environmentally harmful products.” One of his most famous quotes

is from his 1971 book, *Design for the Real World*, in which he boldly claims, “there are professions more harmful than industrial design, but only very few of them” (Gorman, 2003, p. 188).

Vance Packard was a magazine journalist and novelist who released many influential novels from 1957-1960. His most successful and well known novel is *The Waste Makers*, which analyzed and criticized planned obsolescence in American culture. *The Waste Makers* started many conversations about sustainability in the design profession, and brought the negative effects of planned obsolescence into the public eye. (Slade, 2007)

2.3.2 The Okala Practitioner

The Okala Practitioner (White et al., 2013), published by the Industrial Designers Society of America [IDSA], is a resource for designers to learn sustainable design methodology and apply it in their design practice. In the Hopi language, the word “okala” translates to “life sustaining energy” (White et al., 2013, inside cover). The creators of *The Okala Practitioner* chose this title to “[honor] the indigenous American tradition of respect for the natural environment” (White et al., 2013, inside cover). Pictured below (Figure 14), *The Okala Practitioner* (White et al., 2013) also presents the Eco-Design Strategy Wheel. This tool provides a compiled list of design strategies which are grouped based on each phase of a product’s lifecycle. The goal of these design strategies is to reduce the negative ecological impact products and services have.



Figure 14: Eco-Design Strategy Wheel, (White et al., 2013)

1. *Innovation*

- a. Rethink how to provide the benefit
- b. Design flexibility for technological change
- c. Provide product as a service
- d. Serve needs provided by associated products
- e. Share among multiple users
- f. Design to mimic biological systems
- g. Use living organisms in product system
- h. Create opportunity for local supply chain

2. *Reduced Material Impacts*

- a. Avoid materials that damage human or ecological health
- b. Avoid materials that deplete natural resources
- c. Minimize quantity of materials
- d. Use recycled or reclaimed materials
- e. Use renewable resources
- f. Use materials from reliable certifiers
- g. Use waste byproducts

3. *Manufacturing Innovation*

- a. Minimize manufacturing waste
- b. Design for production quality control
- c. Minimize energy use in production
- d. Use carbon-neutral or renewable energy sources
- e. Minimize number of production steps
- f. Minimize number of components/materials
- g. Seek to eliminate toxic emissions

4. *Reduced Distribution Impacts*

- a. Reduce product and packaging weight
- b. Reduce product and packaging volume
- c. Develop reusable packaging systems
- d. Use lowest-impact transport system
- e. Source or use local materials and production

5. *Reduced Behavior and Use Impacts*

- a. Design to encourage low-consumption behavior
 - b. Reduce energy during use
 - c. Reduce material consumption during use
 - d. Reduce water consumption during use
 - e. Seek to eliminate toxic emissions during use
 - f. Design for carbon neutral or renewable energy
6. *System Longevity*
- a. Design for durability
 - b. Foster emotional connection to product
 - c. Design for maintenance and easy repair
 - d. Design for reuse and exchange of products
 - e. Create timeless aesthetic appeal
7. *Transitional Systems*
- a. Design upgradable products
 - b. Design for a second life with different function
 - c. Design for reuse of components
8. *Optimized End of Life*
- a. Design for fast manual or automated disassembly
 - b. Design recycling business model
 - c. Use recyclable non-toxic materials
 - d. Provide ability to biodegrade
 - e. Integrate methods for used product collection
 - f. Design for safe disposal

2.4 Industrial Design Theory and Methodology

There have been a multitude of different approaches and methods developed for the design process. However, every attempt shares the same end goal, which is to create a successful design solution. The following two will be discussed: the Double Diamond and Three Functions of an Artifact.

2.4.1 Double Diamond

Popularized by the UK Design Council in the early 2000's, the Double Diamond is a visual representation of the design process that incorporates divergent and convergent thinking (*Double Diamond (Design Process Model)*, 2023). The process has roots from creatives and thinkers such as John Dewey, Osborn & Parnes, and Béla Bánáthy:

Dewey believed in bringing experience and inquiry together, and that learning should be an active process driven by problem-solving and critical thinking. Osborn & Parnes proposed divergent and convergent activities in their Five Diamond model. Bánáthy abstracted Parnes' model and compressed five diamonds into two, bringing his work to bear on systems design (*The Double Diamond Design Process — Still Fit for Purpose?*, 2023)

In 2018, UX designer Dan Nessler (2018) developed the Revamped Double Diamond Design Process Framework shown in Figure 15. Nessler's updated approach to the Double Diamond is more detailed, getting into the nitty gritty of the design process, but maintains the basics of the original approach. Some aspects of this approach will be incorporated into the new methodology developed in Chapter 3.

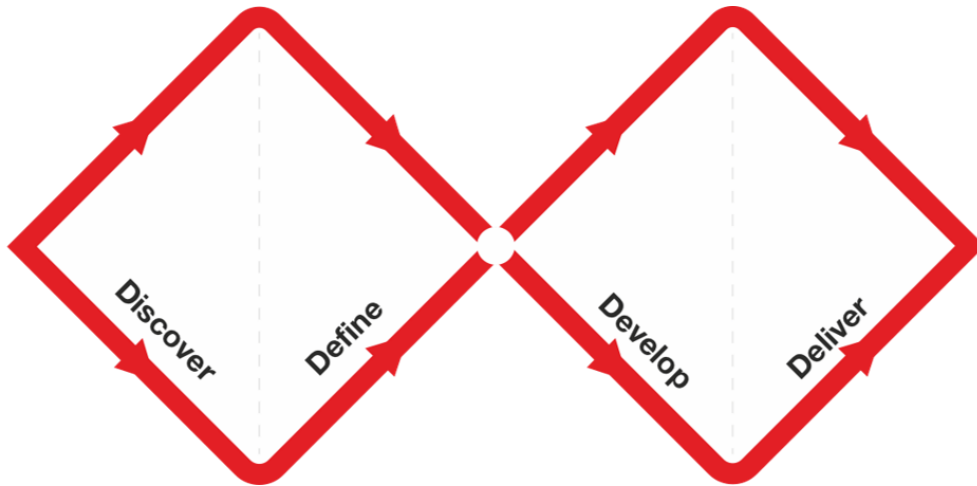


Figure 15: Double Diamond (UK Design Council, n.d.)

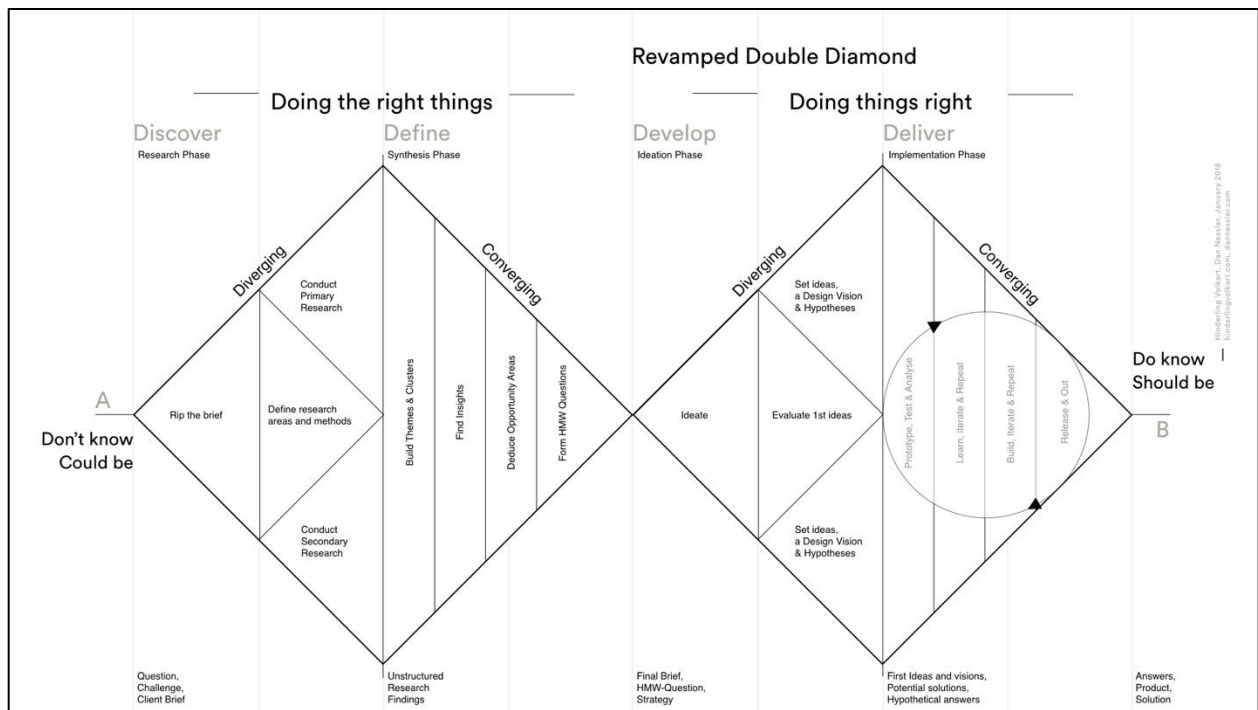


Figure 16: Dan Nessler's Double Diamond (Nessler, 2018)

The Double Diamond is aptly named for the two diamonds appearing in the visual representation of the process. It divides the design process into four sections: Discover, Define, Develop, and Deliver (*Framework for Innovation - Design Council, n.d.*):

- **Discover.** The first diamond helps people understand, rather than simply assume, what the problem is. It involves speaking to and spending time with people who are affected by the issues.
- **Define.** The insight gathered from the discovery phase can help you to define the challenge in a different way.
- **Develop.** The second diamond encourages people to give different answers to the clearly defined problem, seeking inspiration from elsewhere and co-designing with a range of different people.
- **Deliver.** Delivery involves testing out different solutions at small-scale, rejecting those that will not work and improving the ones that will.

Discover and Develop are the divergent phases, where the user expands their knowledge and ideates as many design solutions as they can. The convergent phases are Define and Deliver, in which the user narrows down their ideas to reach decisions. Both the UK Design Council and Dan Nessler informs the reader that The Double Diamond visually looks like a linear process, but there is oftentimes a need to go back and forth between areas, depending on the nature of the project being completed. They also emphasize that this is not the only way to approach design, but rather a visual representation of the design process.

2.4.2 Three Functions of an Artifact

“Three Functions of an Artifact” was developed by Swiss design educator Walter Schaer. In 1958, Schaer graduated from HfG Ulm School, the descendent school of the famous Bauhaus. Schaer was a professor at Auburn University for 32 years, from 1960 to 1992, and brought human-centered, methods-based design to Auburn University. He also studied and wrote about eco-humanistic design extensively during his career. The “Three Functions of an Artifact” ideology still serves as an underpinning to Auburn’s Industrial Design Program. Therefore, it was determined this process would be discussed in the literature review, and aspects will be incorporated into the developed methodology in Chapter 3.

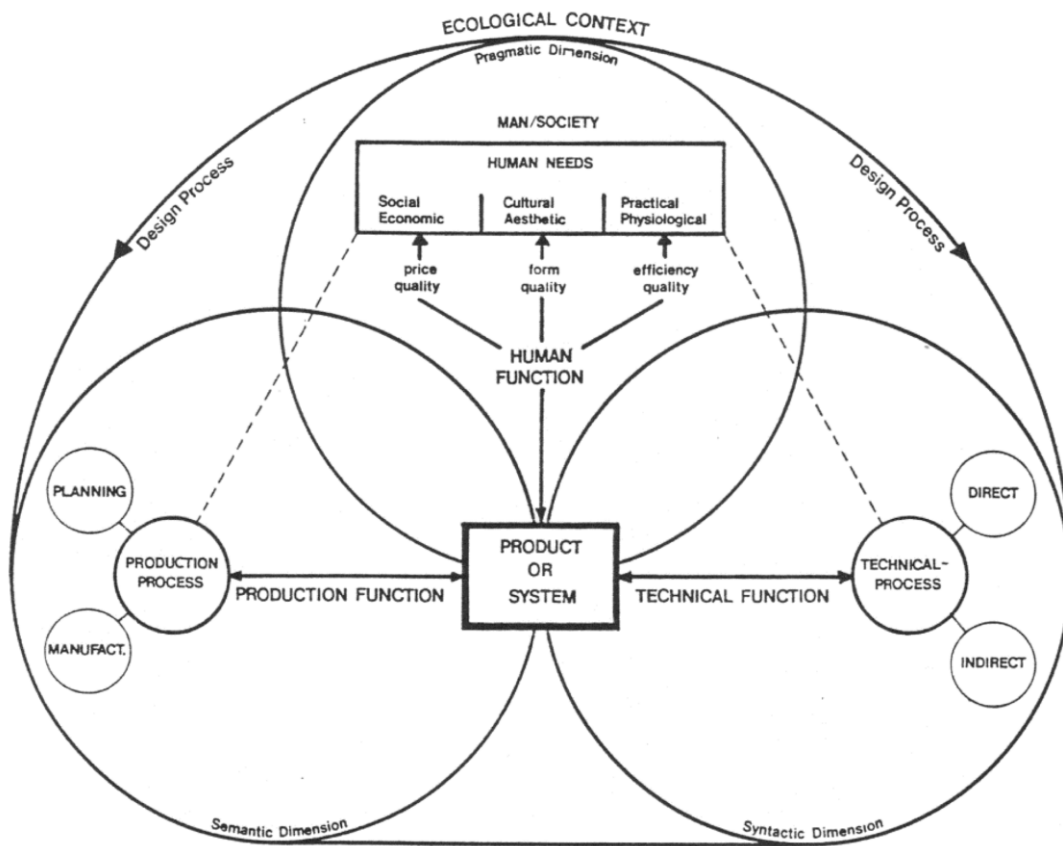


Figure 17: Three Functions of an Artifact (Bartlett, 2020)

In Three Functions of an Artifact, the word “artifact” refers to a product or system that is being developed. The diagram identifies three main functions of an artifact: the human function, the production function, and the technical function. The human function is where industrial designers hold the most influence, whereas the production and technical functions lean a bit more towards engineering.

The human function is concerned with human needs, which is divided into three sections: Economic, Aesthetic, and Practical. The Economic section refers to “the price paid and the social acceptance of the product or system.” The Aesthetic section refers to “the cultural and visual acceptance of a product or system.” The Practical section refers to “the practical and physical efficiency of a product or system.” It could be argued that biomimicry can directly correlate with the “practical function,” as it is concerned with using nature’s function in aiding the development of a design. Furthermore, biomimicry could also be associated with the aesthetic function, as biomimicry also incorporates the visual appearances through geometric solutions for its function. (Bartlett, 2020)

The “Human Function” helps define the technical function. The “Technical Function” deals with factors that affect the design of the product or system. The direct factors “primarily affect the materials used in the design solution, but not limited to materials.” The indirect are “affected by the components in the design solution.” The “Production Process” is associated with manufacturing and planning. Manufacturing is defined as “the production process of the components, parts and assembly.” The planning phase “deals with packaging, distribution, marketing, and sales.” (Bartlett, 2020)

2.5 Artificial Intelligence [AI]

The field of artificial intelligence [AI] is expansive, complex, and still evolving. For the purpose of brevity, this section will be treated as a sort of crash-course on AI, presenting only essential information to understand the use of Generative AI technology in Chapter 3.

AI is an overarching term that is utilized when describing machines that imitate human cognitive functions and human intelligence. To achieve this goal, “AI uses predictions and automation to optimize and solve complex tasks that humans have historically done, such as facial and speech recognition, decision making and translation” (IBM Data Team & IBM AI Team, 2023).

As the abilities of AI have grown and improved, the more often people debate the pros and cons of these technologies. However, debates surrounding ground-breaking tools is not a new concept. When the development of industrial machined furniture began to replace hand-turned furniture in the late 1800’s, there was also a lot of controversy: some people supported the machinery advancement while others vehemently did not. In his 1901 essay *The Art and Craft of the Machine*, American architect Frank Lloyd Wright expressed his opinion on this and stated:

That the Machine has dealt Art in the grand old sense a death-blow, none will deny...

Every age has done its work, produced its art with the best tools or contrivances it knew... We want the man who eagerly seeks and finds, or blames himself if he fails to find, the beauty of this time... (Gorman, 2003, p. 56-59)

This quote can be likened to the pushback against growing AI technologies, specifically generative AI, because it is the current ‘Machine’ that has the capacity to irrevocably change the creative field if designers do not learn how to command it for their benefit.

2.5.1 Machine Learning [ML]

Machine learning [ML] is considered a sub-category of artificial intelligence. IBM describes machine learning as “a subset of artificial intelligence that allows for optimization” (IBM Data Team & IBM AI Team, 2023). ML models optimize “learning” through observing data patterns (*What Is Generative AI?*, 2023). Two main types of ML models are classic ML and deep ML. The two types are differentiated based on a few different factors, one of them being their dependency, or lack thereof, on humans to operate. Classic ML is often dependent on human intervention to operate, whereas deep ML is able to run with little to no human intervention. Another difference between the two is how the algorithms are trained and used (Grieve, 2023):

[Classic] machine learning algorithms solve problems by using explicit programming. Deep learning algorithms solve problems based on the layers of neural networks... [Classic] machine learning algorithms take relatively less time to train, ranging from a few seconds to a few hours. Deep learning algorithms, on the other hand, take a lot of time to train, ranging from a few hours to many weeks.

Mentioned above, neural networks serve as the backbone of deep ML (IBM Data Team & IBM AI Team, 2023). They are a subset of ML that mimics how neurons in the brain send signals to one another, hence the name “neural” (IBM Data Team & IBM AI Team, 2023). Neural networks are made up of nodes that communicate with one another based on specific factors. If there are more than three layers of nodes in a neural network, indicating the “depth” of the network, then the algorithm can be considered a deep ML model. The final difference between classic ML models and deep ML models is the size of the dataset. Classic ML performs well with smaller datasets, perhaps thousands of data points, whereas deep ML is able to interpret

massive amounts of data, think millions of data points, to increase the success of the algorithm's performance and understanding (Grieve, 2023).

2.5.2 Generative Artificial Intelligence [Generative AI]

Generative Artificial Intelligence [Generative AI] is a type of *deep* ML model.

Generative AI models are able to “generate high-quality text, images, and other content based on the data they were trained on” (Martineau, 2023). Arguably the most well-known generative AI software is ChatGPT, which is short for “Chat Generative Pre-trained Transformer” (Gregersen, 2023). ChatGPT is a large-language model [LLM] chatbot which was released in November 2022 by AI research and deployment company, OpenAI (Gregersen, 2023). ChatGPT is an online resource with both free (ChatGPT-3.5) and paid (GPT-4) access options. Users are able to input prompts and questions to ChatGPT, which responds to queries in a conversational manner, with the capability to complete a myriad of writing and other creative tasks. To further explain this topic and illuminate ChatGPT's capabilities, the following prompt, shown as a screenshot, was input into ChatGPT-3.5:

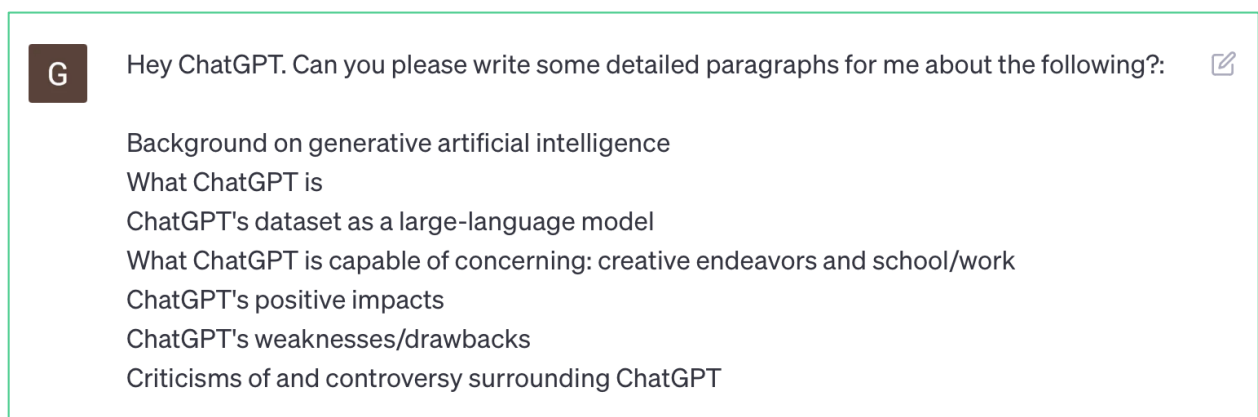


Figure 18: Screenshot of ChatGPT Prompt

ChatGPT-3.5 *quickly* responded with the following information:

Background on Generative Artificial Intelligence:

Generative Artificial Intelligence (AI) is a subset of AI that focuses on creating systems capable of generating new, original content. This content could be in the form of text, images, music, or even videos. These systems are designed to learn patterns from vast amounts of data and then use that knowledge to produce creative outputs. One of the breakthroughs in generative AI is the development of large language models (LLMs) like GPT-3.5, which is trained on diverse datasets to understand and generate human-like text.

What ChatGPT Is:

ChatGPT is a prime example of generative AI. It's a sophisticated language processing AI developed by OpenAI. Based on the GPT-3.5 architecture, ChatGPT can generate coherent and contextually relevant responses to user inputs, making it ideal for various applications, including conversation, content creation, and problem-solving.

ChatGPT's Dataset as a Large-Language Model:

ChatGPT's effectiveness lies in its extensive dataset. It has been trained on a vast corpus of text from books, articles, websites, and other sources. This extensive training enables it to understand context, grammar, and nuances in language, allowing it to generate human-like responses.

What ChatGPT is Capable of Concerning Creative Endeavors and School/Work:

In creative endeavors, ChatGPT can aid writers, artists, and musicians by generating ideas, suggesting improvements, or even creating entire pieces of content. In the context of school and work, ChatGPT can assist with research, answer questions, provide

explanations, and even offer coding assistance. Its versatility makes it a valuable tool for various tasks.

ChatGPT's Positive Impacts:

ChatGPT has several positive impacts. It democratizes information by providing instant access to knowledge. It fosters creativity by offering inspiration and generating novel ideas. It aids in education by providing supplementary explanations and learning materials. Additionally, it enhances productivity by assisting with tasks, thus saving time and effort.

ChatGPT's Weaknesses/Drawbacks:

Despite its capabilities, ChatGPT has limitations. It can generate plausible but incorrect or biased information. It lacks real-world understanding, sometimes providing responses that might sound accurate but are factually wrong. Moreover, it doesn't possess emotions or consciousness, leading to potential misinterpretation of user intent and context.

Criticisms of and Controversy Surrounding ChatGPT:

Critics have raised concerns about ChatGPT's potential to spread misinformation or be used unethically, manipulating public opinion or generating malicious content. There are also worries regarding privacy, as user interactions are logged. The AI's reliance on existing data can perpetuate biases present in the training data, leading to biased or discriminatory responses, which has sparked controversy and calls for improvement in AI ethics and fairness. Additionally, there are concerns about job displacement, as AI like ChatGPT can automate certain tasks, impacting employment in various sectors. OpenAI, in response, continually refines its models and guidelines to mitigate these issues and ensure responsible use of generative AI technologies. (OpenAI, 2023)

This exercise is both informative for the reader on many levels, and illuminates ChatGPT's ability as a software. As mentioned above, one of ChatGPT's drawbacks is its ability to "sometimes [write] plausible-sounding but incorrect or nonsensical answers," which is recognized by OpenAI (*Introducing ChatGPT*, n.d.). Therefore, informational responses from ChatGPT should be fact-checked by the user, as the response was above. However, ChatGPT's ability to aid in research has the potential to be a catalytic tool for biomimicry in industrial design, which will be further expounded upon in Chapter 3.

2.5.3 BIDARA

BIDARA stands for "Bio-Inspired Design and Research Assistant" (*PeTaL | Glenn Research Center | NASA, 2023*). BIDARA is part of NASA's Periodic Table of Life [PeTaL] which is "an open-source software initiative to enable moving from discovery through design using inspiration from natural systems and human achievement" (*PeTaL | Glenn Research Center | NASA, 2023*). BIDARA is a chatbot that runs on ChatGPT and was developed to assist scientists and engineers in comprehending, learning, and mimicking the tactics employed by living organisms to develop sustainable designs and technologies. The online publication states that BIDARA "was instructed to help scientists and engineers understand, learn from, and emulate the strategies used by living things to create sustainable designs and technologies." It also identifies BIDARA's intended audience as "scientists and engineers," and industrial designers are not mentioned. BIDARA's system prompt is based on the Biomimicry Institute's biomimetic ideology and their Biomimicry Design Spiral, helping guide users through the process (*PeTaL | Glenn Research Center | NASA, 2023*). However, this could be considered a limitation of the chatbot as it is only based off of one source which limits the definition of

biomimicry, thus arguably limiting the amount of discoverable biological strategies. While not geared towards industrial designers, the BIDARA system prompt is a great innovation in the biomimicry and generative AI space, as it helps direct ChatGPT and guides users through basic steps of using the Biomimicry Design Spiral.

Chapter 3

Developing a New Biomimetic Approach for Industrial Designers

The following approach places emphasis on the research phase of the design process. One could argue that there is disconnect of the order of operations in current biomimetic practices, often making biomimicry challenging to approach and difficult to integrate within traditional industrial design processes. There is a lack of biomimetic solutions in which inspiration does not precede the brief, showing the gap in implementing biomimicry in industrial design. The goal is to identify an alternative approach to the current biomimicry methodology, so industrial designers can more easily utilize biomimicry in their design practice. By combining traditional industrial design processes, existing biomimicry strategies, and integrating the use of generative artificial intelligence, this goal is achieved.

3.1 Biomimicry Industrial Design Principles

Both the Biomimicry Institute and biomimetic design firm Biomimicry 3.8 have compiled a list of nature's shared characteristics which serve as a basis of their work, coined Nature's Unifying Principles and Life's Principles respectively. These two lists have a lot of overlap. Therefore, I created a streamlined version called Biomimicry Industrial Design Principles combining and re-organizing the two. The principles were named Biomimicry Industrial Design Principles because it emphasizes the design aspect of biomimicry's foundational elements and implies their applicability to industrial design. Furthermore, I incorporated some strategies from the Eco-Design Strategy Wheel in *The Okala Practitioner* (White et.al., 2013) to provide designers a resource to help make the developed Biomimicry Industrial Design Principles more actionable. While Life's Principles includes methods

pertaining to each principle, I decided to instead incorporate sustainable design strategies from the *Okala Practitioner* (White et.al., 2013) because they were created specifically to be applied in industrial design, whereas the former was not. Each strategy category is grouped with the principle it corresponds to best. Some principles have more than one strategy category and some strategy categories are repeated. I then applied sustainable design strategies from these categories that related best to the Biomimicry Industrial Design Principles and the principles corresponding Nature's Strategies. This information is presented in charts for each principle. The Biomimicry Industrial Design Principles are listed below:

1. Nature's form follows function
2. Nature uses energy and materials efficiently.
3. Evolution defines nature.
4. Nature is locally attuned and responsive.
5. Nature uses life-friendly chemistry.
6. Nature provides mutual benefits

3.1.1 Nature’s Form Follows Function.

PRINCIPLE	NATURE’S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature’s form follows function.	Function defines form	Design to mimic biological systems
		Use living organisms in product system
		Rethink how to provide the benefit
		Design flexibility for technological change

Figure 19: “Nature’s Form Follows Function” Chart

The principle in Figure 19 was created by re-wording “Nature uses shape to determine functionality” from the Biomimicry Institute’s list, Nature’s Unifying Patterns. I chose to paraphrase this “unifying pattern” because of the famous 1896 quote from American architect Louis Henry Sullivan: “form ever follows function” (Stinson, 2015). This phrase, though most commonly known as “form follows function,” is very influential in the industrial design community. Since both industrial design and biomimicry are rooted in function, I chose to phrase this principle as “Nature’s Form Follows Function” as a nod to the pervasive phrase “form follows function.” Sustainable design strategies from the strategy category “Innovation” was paired with this principle because biomimicry often results in innovative solutions, and mimicking nature’s processes was one of the listed strategies.

3.1.2 Nature uses energy and materials efficiently.

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature uses energy and materials efficiently.	Up-cycles materials	Use recycled or reclaimed materials
	Utilizes abundant resources and incorporates rare resources sparingly	Avoid materials that deplete natural resources
		Design to encourage low-consumption behavior
	Optimizes energy use	Reduce energy during use
		Minimize energy use in production
		Minimize number of production steps
	Optimizes material use	Reduce material consumption during use
		Minimize manufacturing waste
		Minimize quantity of materials
	Relies on freely available energy	Use renewable resources
		Use carbon-neutral or renewable energy sources

Figure 20: “Nature uses energy and materials efficiently” Chart

This principle and its corresponding Nature’s Strategies were developed by combining the following Nature’s Unifying Patterns from the Biomimicry Institute and Life’s Principles from Biomimicry 3.8 due to their repetitive nature:

<i>Nature's Unifying Patterns</i>	<i>Life's Principles</i>
Nature only uses the energy it needs and relies on freely available energy.	Be resource efficient (material and energy)
Nature recycles all materials.	
Nature tends to optimize rather than maximize.	
Nature builds using abundant resources, incorporating rare resources sparingly.	

Sustainable design strategies are included from the strategy category “Reduced Material Impacts” because this design principle offers ways to optimize the use of materials in a product’s design. In addition, sustainable design strategies from “Reduced Behavior and Use Impacts” and “Manufacturing Innovation” were added to this principle as they provide strategies concerning material and energy use during both the manufacture and use of a product.

3.1.3 Evolution defines nature.

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Evolution defines nature.	Adapts to changing conditions	Design for durability
		Foster emotional connection to product
		Create timeless aesthetic appeal
	Evolves to survive	Design for maintenance and easy repair
		Design for reuse and exchange of products
		Design for a second life with different function
	Integrate development with growth	Design upgradable products
		Design for reuse of components

Figure 21: “Evolution Defines Nature” Chart

I developed the phrase “Evolution defines nature” by combining the following Nature’s Unifying Patterns from the Biomimicry Institute and Life’s Principles from Biomimicry 3.8 in order to encompass multiple ideas that arguably fall under the blanket term of “evolution”:

<i>Life’s Principles</i>	<i>Nature’s Unifying Patterns</i>
Evolve to survive	Nature is resilient to disturbances.
Adapt to changing conditions	
Integrate development with growth	

I chose to apply sustainable design strategies from “System Longevity” and “Transitional Systems” to this principle because evolution, at its core, is about adapting and improving “oneself” (referring to an organism) in order to survive. These sustainable design strategies can be likened to this principle as they pertain to the *survival* of a product, i.e. extending its lifespan. The sustainable design strategies presented in this category offer designers ways to increase the longevity of their products.

3.1.4 Nature is locally attuned and responsive.

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature is locally attuned and responsive.	Hyper-aware of their environments and respond quickly to threats and changes	Reduce product and packaging weight
		Reduce product and packaging volume
		Develop reusable packaging systems
		Use lowest-impact transport system
		Source or use local materials and production

Figure 22: “Nature is Locally Attuned and Responsive” Chart

The principle “Nature is locally attuned and responsive” is on both Life’s Principles from Biomimicry 3.8 and Nature’s Unifying Patterns from the Biomimicry Institute, so I decided to keep the existing verbiage. A “unifying pattern” that I decided to eliminate was “Nature runs on information.” The “information” in this pattern refers to signals within organisms which are responses to their local environments and the other organisms in their ecosystem. I decided to absorb the phrase into this principle because it is arguably redundant and just emphasizes the “information” aspect of being “locally attuned and responsive.”

The sustainable design strategies from the strategy category “Reduced Distribution Impacts” are relevant to this principle because product distribution affects local communities and their environments and can be likened to nature’s awareness and responses to their environment.

3.1.5 Nature uses life-friendly chemistry.

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature uses life-friendly chemistry.	Uses chemicals and materials that are safe for living beings (unless otherwise intended)	Avoid materials that damage human or ecological health
		Avoid materials that deplete natural resources
		Use recycled or reclaimed materials
		Use renewable resources
		Use materials from reliable certifiers
		Use waste byproducts
		Seek to eliminate toxic emissions

Figure 23: “Nature uses life-friendly chemistry” Chart

The principle “Nature uses life-friendly chemistry” combines the Biomimicry Institute’s pattern, “Nature uses chemicals and materials that are safe for living beings,” and Biomimicry 3.8’s principle, “Use life friendly chemistry.” The description for this principle has the phrase “unless otherwise intended” in parentheses because not all of nature’s chemistry is safe to living beings. Many organisms conduct chemistry within themselves, causing them to be poisonous to other organisms as a form of individual protection. Therefore, I deemed this as a necessary note to add in order to maintain accuracy of the principle, as it was not included in Nature’s Unifying

Patterns nor Life’s Principles. The strategy category “Reduced Material Impacts” is applied to this design principle because it offers ways to reduce the negative impacts of products’ materials, as many are unsustainable and cause harm to both ecological and human health.

3.1.6 Nature provides mutual benefits.

PRINCIPLE	NATURE’S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature provides mutual benefits.	Has mutual advantages and dependencies among its various elements and organisms; interconnected relationships within ecosystems	Design for fast manual or automated disassembly
		Design recycling business model
		Use recyclable non-toxic materials
		Provide ability to biodegrade
		Integrate methods for used product collection
		Design for safe disposal

Figure 24: “Nature provides mutual benefits” Chart

This principle was taken from Nature’s Unifying Principles. This principle represents the interconnected quality nature possesses in which oftentimes organisms and other natural elements rely on and support each other within ecosystems. Sustainable design strategies from the strategy category “Optimized End-of-Life” was given to this category because the ultimate hope is that a designed product will benefit both the user and nature, or at the very least have a reduced negative ecological impact. When products are done being used, they can have a negative impact on the environment, whether it be chemical or physical. Therefore, this strategy category is applicable to this principle as it provides designers with tactics to optimize products’ end-of-life, resulting in less waste and negative impacts.

3.2 Biomimetic Industrial Design Approach

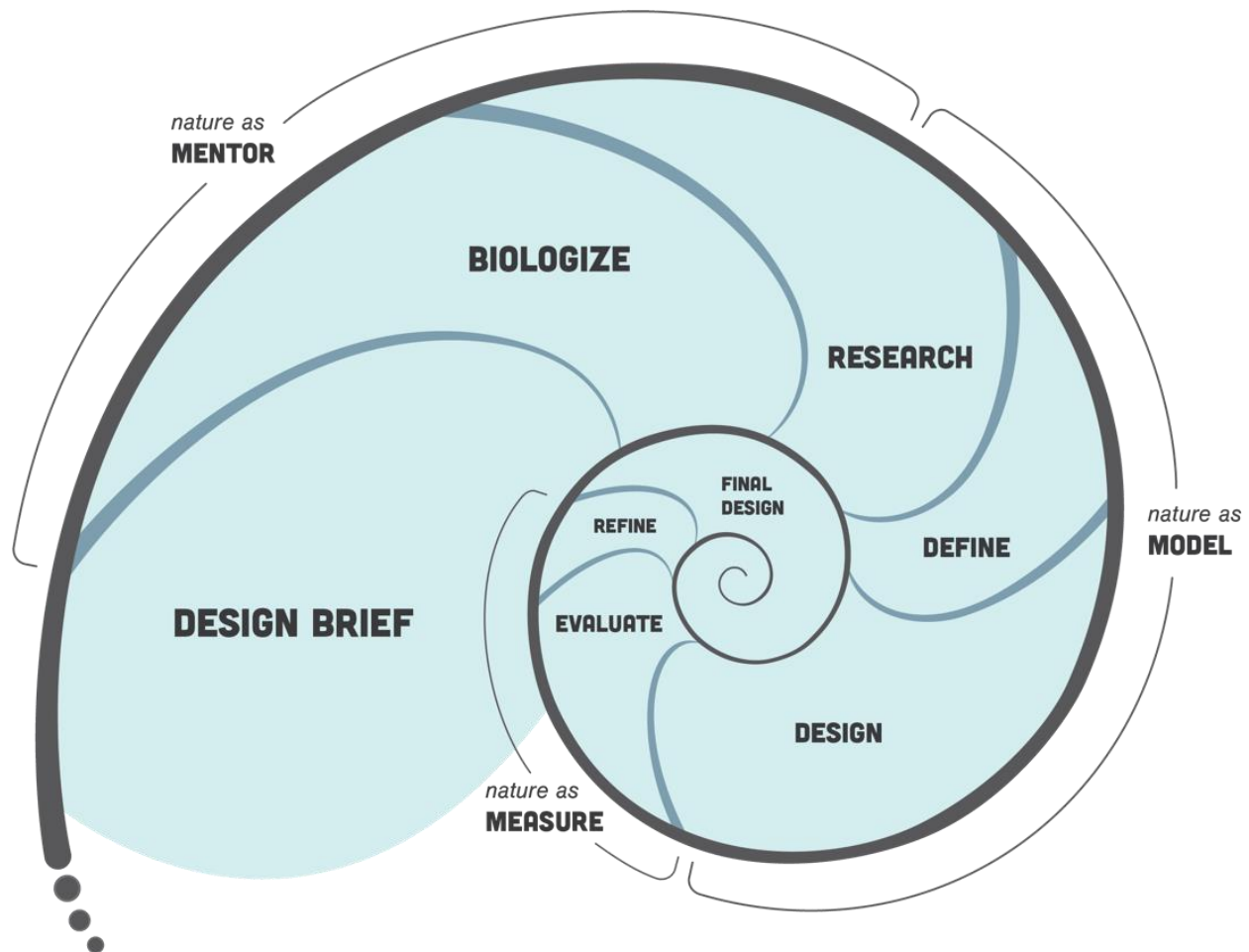


Figure 25: Biomimetic Industrial Design Approach

This diagram is a visual representation of the developed approach. The shape of the graphic mimics the interior architecture of a nautilus shell, an elegant design that is often imitated. Each step of the process is separated by an interior “wall” in order to differentiate between sections. The size of the sections are based on whether they are at converging or diverging stages of the process, taking notes from Nessler’s Double Diamond (2018). The steps of the process follows this order:

1. Design Brief

2. Biologize
3. Research
4. Define Criteria
5. Design
6. Evaluate
7. Refine
8. Final Product

The diagram also feature the major three themes of biomimicry which encompass different steps in the process: nature as mentor, nature as model, and nature as measure. “Nature as mentor” covers the “Biologize” phase and enters “Research” because in these steps the designer’s goal is to *learn from* nature. “Nature as model” covers the “Research, Define, and Design” because in these stages, the designer’s goal is to identify and establish what biological strategies they will be including in their design. “Research” shares “mentor” and “model” because at the beginning, the designer will be looking to nature for solutions and towards the end of the research phase they need to begin identifying what biological strategies they want to mimic. “Nature as measure” encompasses “Evaluate” and “Refine” because in these steps the designer is assessing whether their design fits the Biomimicry Industrial Design Principles, and adjusting that design accordingly.

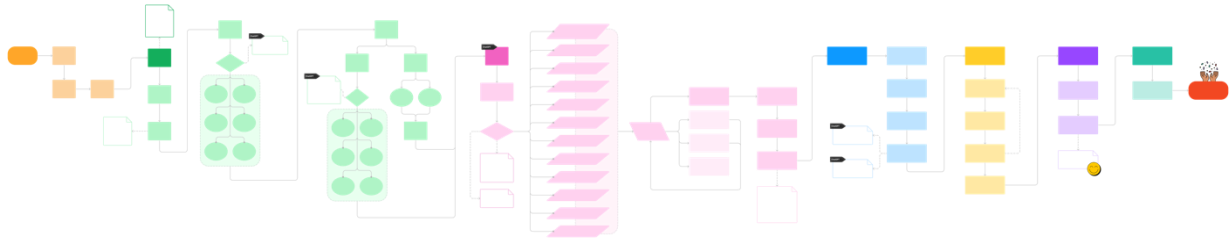


Figure 26: Biomimetic Industrial Design Process Flow Chart

This flow chart was created to help break down and explain each step in the developed approach. In the flow chart, each phase of the approach is represented by a color that corresponds to the color-coded Biomimetic Industrial Design Approach diagram pictured below.

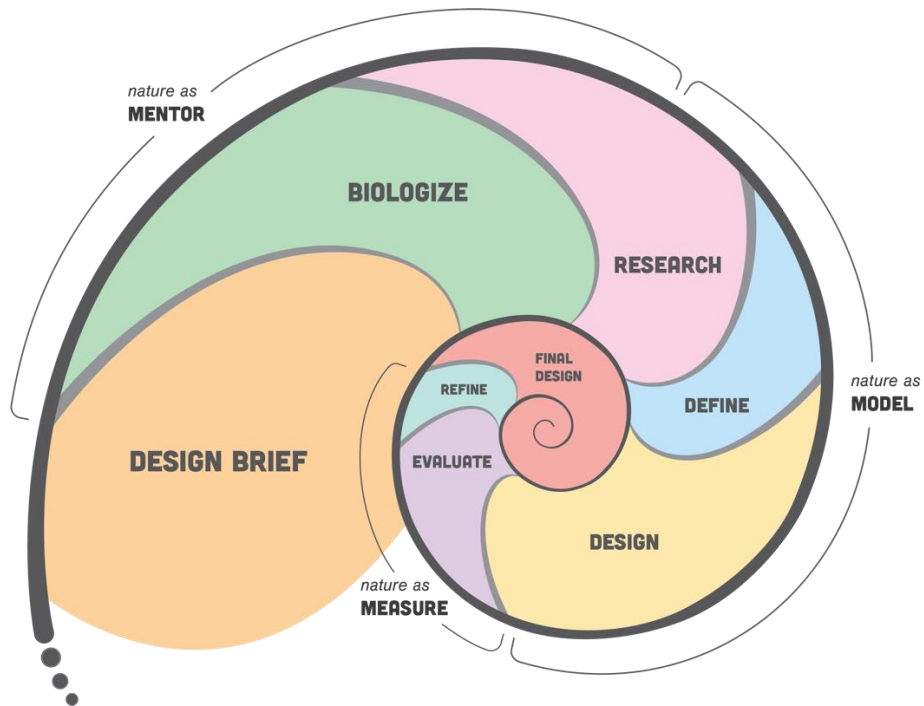


Figure 27: Color-Coded Biomimetic Industrial Design Process

3.2.1 Design Brief

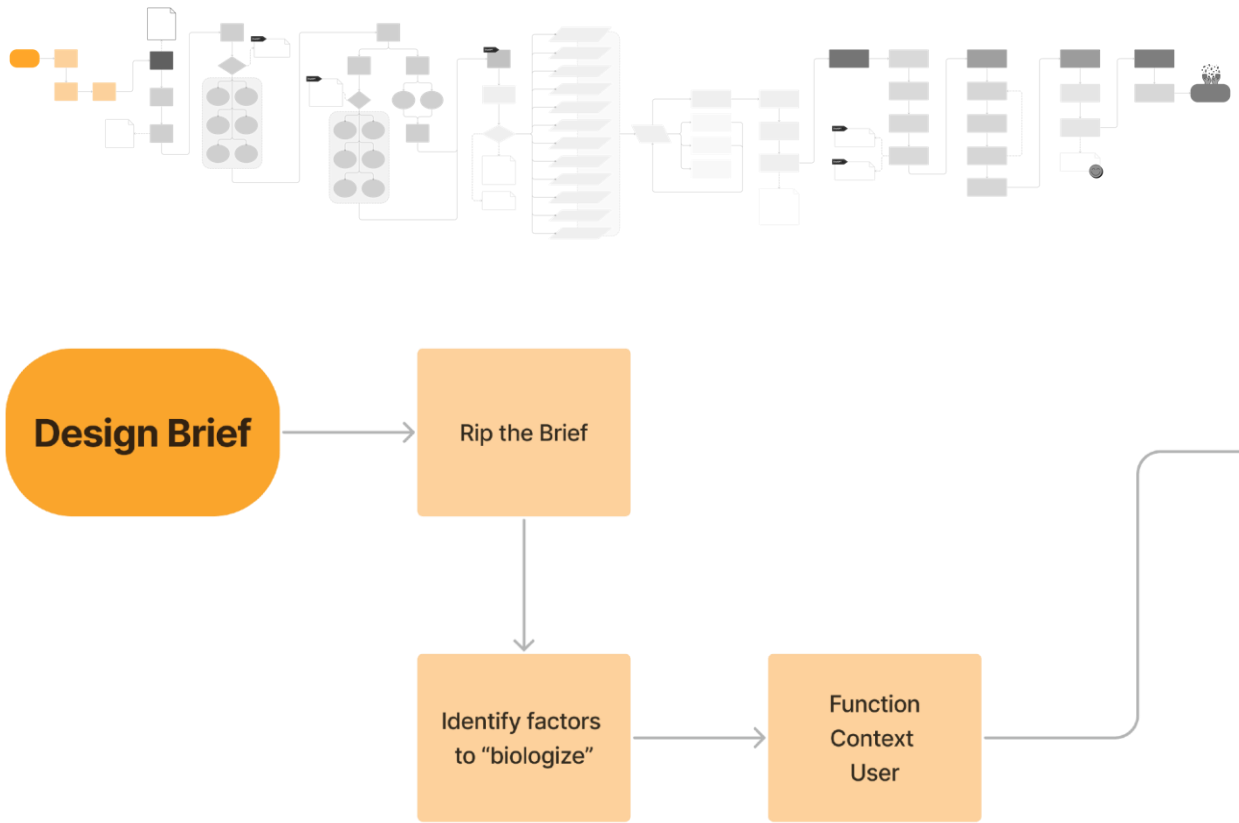


Figure 28: Design Brief Flow Chart

The first step in this methodology is analyzing the design brief. The design brief presents the design challenge, outlining necessary criteria for the deliverable(s) of a design project. This criteria often includes the necessary function(s) of the product, identifies the user(s), and presents the context of where and when the product will be used. In Nessler’s (2018) Revamped Double Diamond Design Process Framework he refers to analyzing the design brief as “[Ripping] the brief,” in which you dissect the design challenge and determine what additional information is required, or what knowledge you want to find in further research. However, in this methodology’s version of “[ripping] the brief,” the designer will identify these factors and also

determine what can be “biologized.” The main factors that can be biologized are function, context of use, and the user.

3.2.2 Biologize

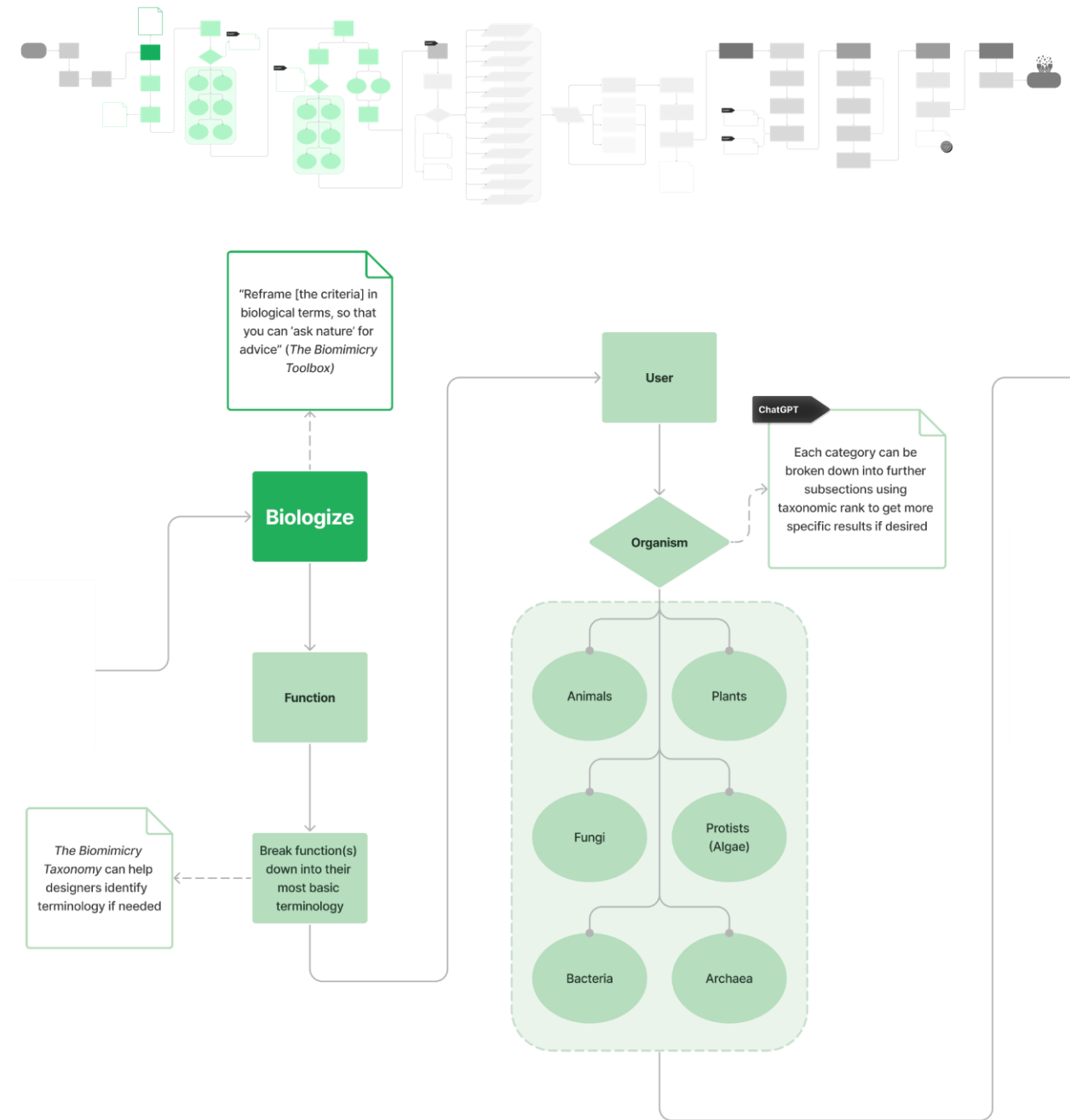


Figure 29: Biologize Flow Chart (*Function, User*)

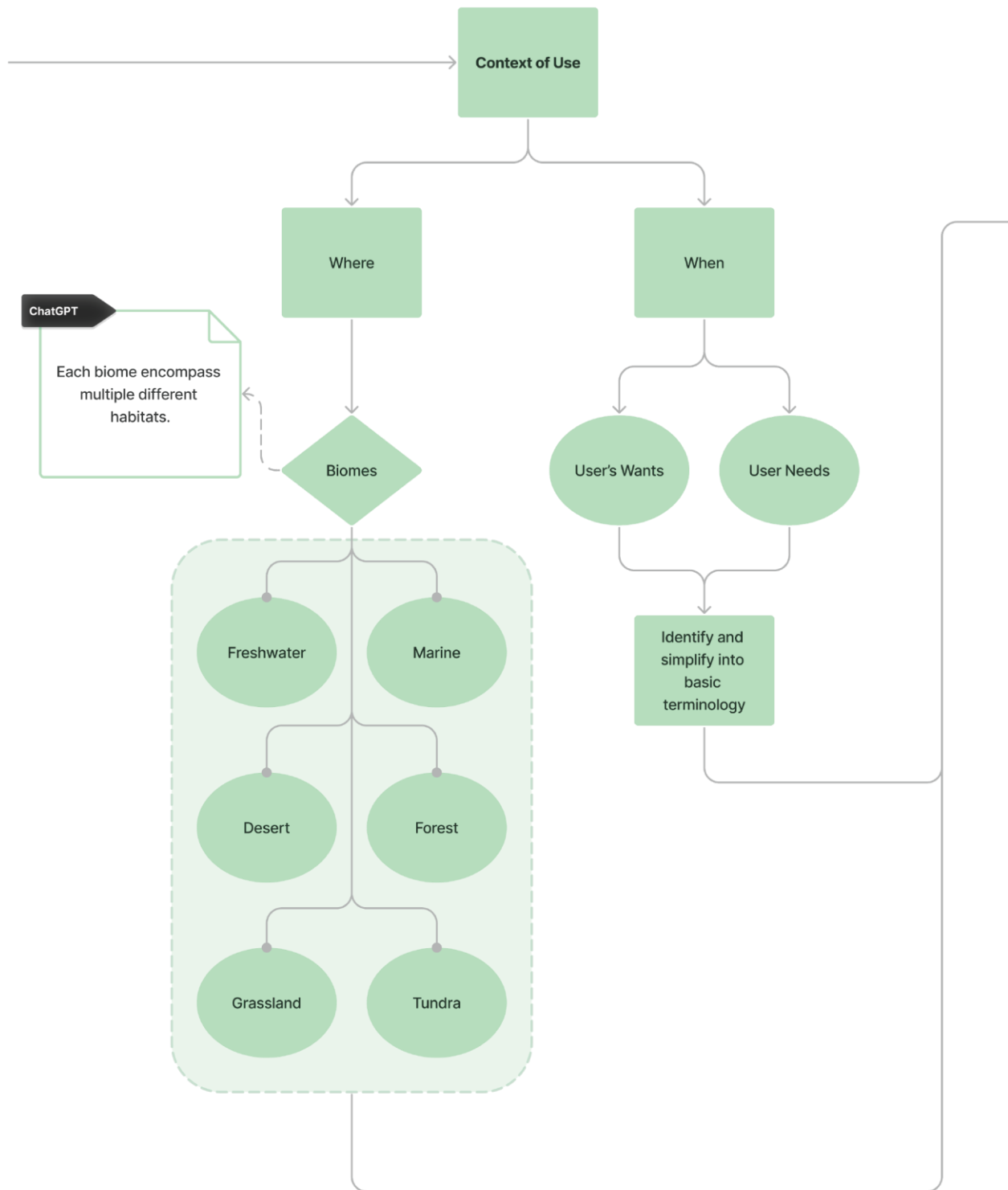


Figure 30: Biologize Flow Chart, (*Context of Use*)

The term “biologize” was created by the Biomimicry Institute to represent the process of identifying “the essential functions and context [the] design solution must address” and then “[reframing these criteria] in biological terms, so that [designers] can ‘ask nature’ for advice” (*Biologize Function & Context*, n.d.). The Biomimicry Toolbox states that both context and function can be biologized, but emphasizes the role of function in biomimicry. Just like industrial design, function is an integral part of biomimicry. However, one factor that is not mentioned in The Biomimicry Toolbox is the product’s user. The user of a product is a pertinent element in industrial design, and also has the capacity to be biologized. Therefore, the main factors from the design brief that are able to be biologized are function, the user, and context of use. In this approach, biologizing is a form of prompt crafting, as the designer is preparing these factors to be entered into ChatGPT in the research phase.

Function should always be the first thing biologized, as almost all of a product’s factors are rooted in function. The same goes in biomimicry, as its essential element is applying the function of the organism or natural system to a design. Based on Schaer’s Three Functions of an Artifact (1958), successful industrial design is rooted in function, and every aspect of a product has a defined function. To biologize function, the designer will break down their product’s functions into its most basic terminology so it can be easily integrated into nature. If desired or necessary, during this step the designer has the option to use The Biomimicry Taxonomy from the Biomimicry Institute in order to help identify verbiage that applies to nature. Since the design’s function(s) have been already been identified in the brief, it makes the taxonomy more effective and approachable.

The next factor to be biologized in the process is the product’s user. The user can most easily be biologized into organisms. An organism is defined as, “a living thing that has an

organized structure, can react to stimuli, reproduce, grow, adapt, and maintain homeostasis... any animal, plant, fungus, protist [algae], bacterium, or archaeon on Earth” (*Organism - Definition and Examples - Biology Online Dictionary*, 2023). When searching for biological strategies, the user can be biologized into one of these organismal categories to aid the search. By narrowing down the term organism into categories, it helps narrow down the search field, providing more specific solutions. It is recommended the designer tries out all six categories, but not required. Furthermore, each organismal category can be broken down into further subsections using taxonomic rank by utilizing ChatGPT to get more specific results. The designer can pick whichever organism they please, allowing for larger exploration of specific topics and possibly providing solutions that may not have been found if just using the broad category of “organism.”

Context of use can also be biologized, but has to be done after biologizing the function(s) and user. It must occur afterwards because a product cannot be used *without* a user, nor without knowing the function(s) of a product. Context of use is separated into *when* and *where* the product is used. *Where* the product is used is biologized into biomes. Biomes are defined as, “...the world's major communities, classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment” (Campbell 1996). There is some debate within the scientific community as to how many biomes there are, but it is generally agreed that these are the main six biomes: freshwater, marine, desert, forest, grassland, and tundra (*The World's Biomes*, n.d.). The designer can choose a biome that is most similar to the environment their product will be used in, or input each biome. Each biome encompasses many different habitats so the designer can use ChatGPT to see what habitats make up each one if they are wanting to explore more specific habitats for biological strategies.

3.2.3 Research

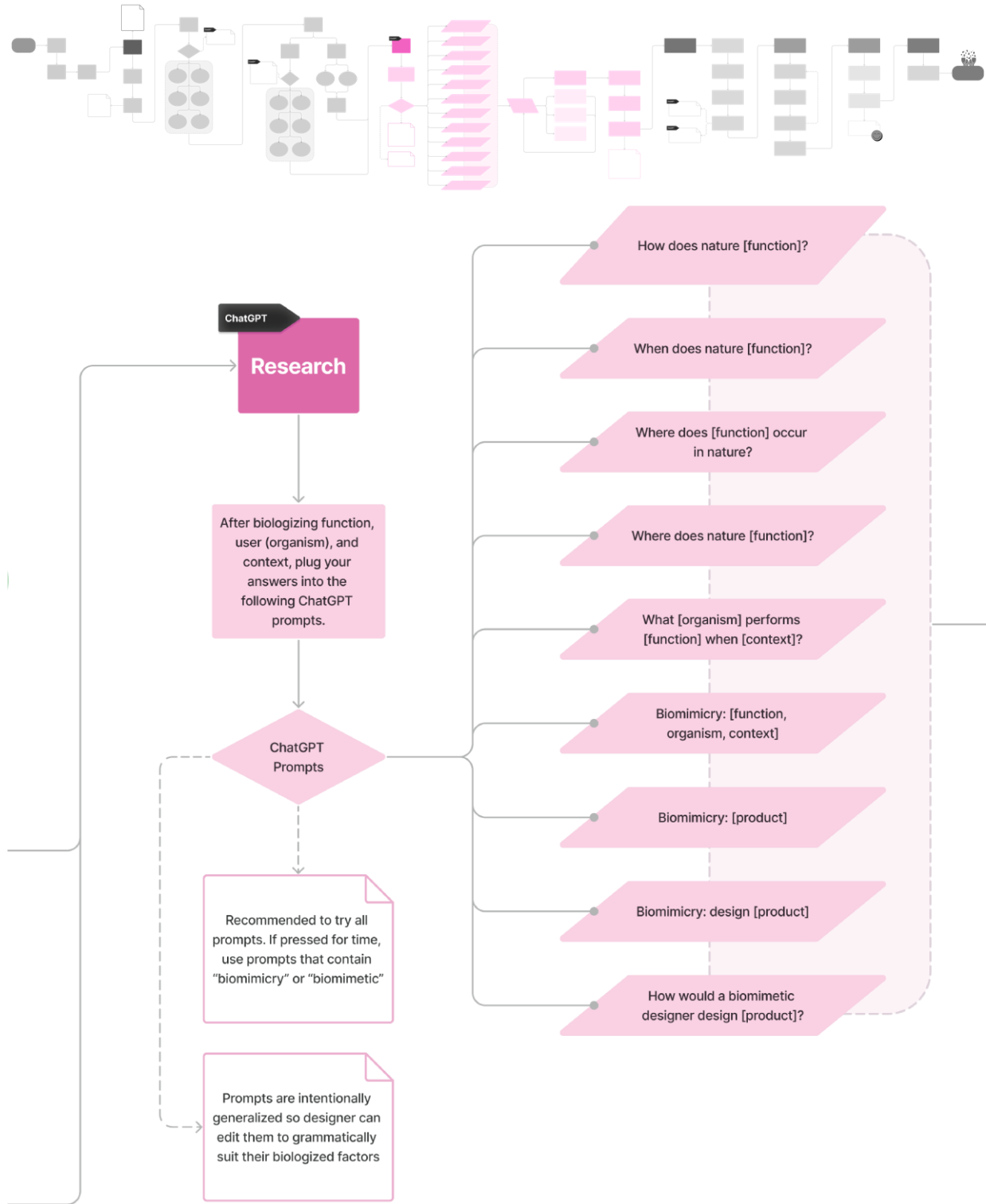


Figure 31: Research Flow Chart (*ChatGPT prompts*)

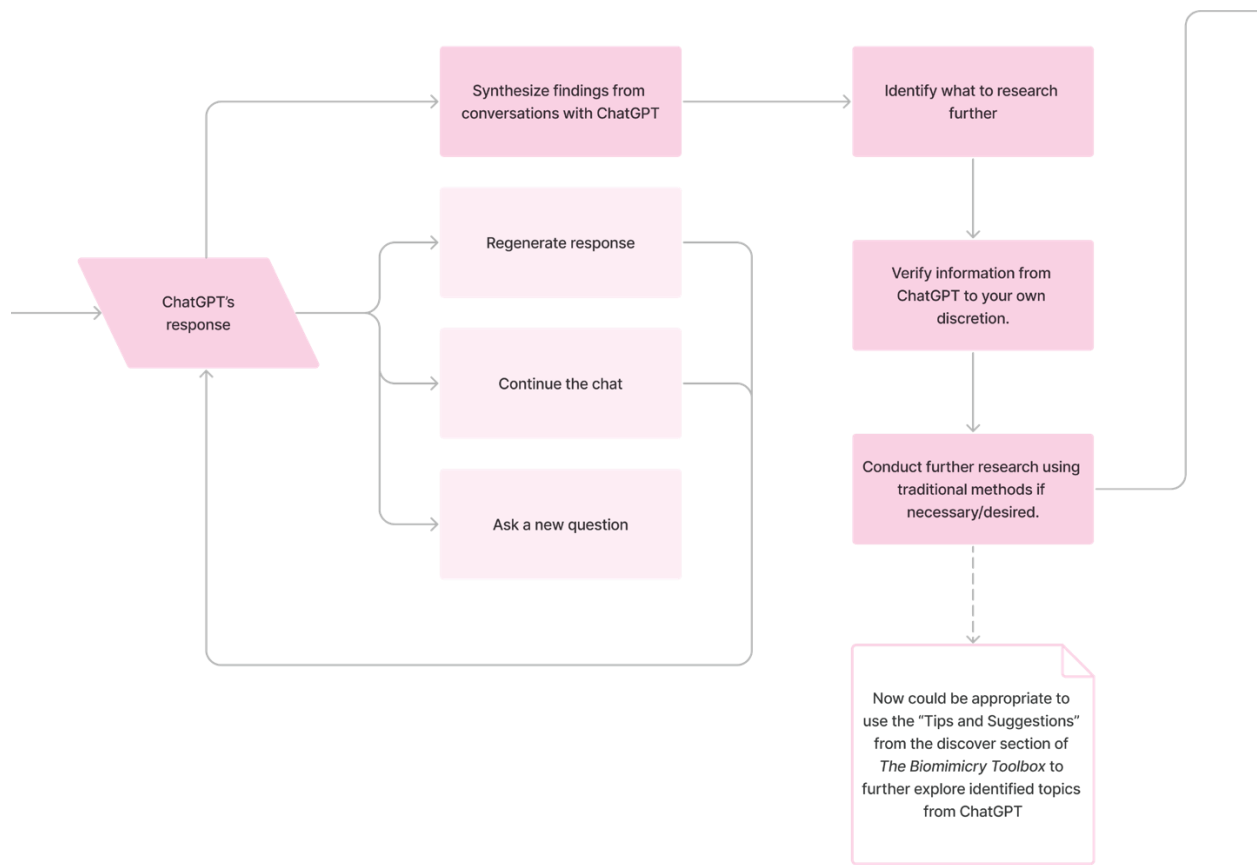


Figure 32: Research Flow Chart (*After Prompting ChatGPT*)

After biologizing the product's function(s), user (organism), and context of use, the designer can move onto the research phase of the Biomimetic Industrial Design Process. As shown through the literature, the main pain point in using biomimicry as an industrial designer is *finding* the biological strategies that can be applied to their design. Incorporating the use generative artificial intelligence [AI] program ChatGPT addresses this common challenge for the designer. ChatGPT serves as a jumping off point for the designer's research process to use biomimicry. Given the massive dataset that ChatGPT has access to, it is able to identify and

present a plethora of potential biomimetic solutions and strategies for the designer to further research and utilize in their design.

I developed a series of prompts for designers to use that I found to be most successful at retrieving applicable biomimetic results. These prompts were designed to be used in ChatGPT's GPT-3.5, not GPT-4, as GPT-3.5 only generates textual responses for designers to respond to or synthesize. However, if desired, these prompts can be input into GPT-4, but may result in image-based responses since DALL-E 3, OpenAI's text-to-image generator, is now integrated into GPT-4 and not a separate entity. Despite this, some demonstrations of the prompts in Chapter 4 use GPT-4, as they were submitted to GPT-4 prior to the integration of DALL-E 3.

The developed prompts are intentionally generalized so the designer can edit them to suit their criteria and make sense grammatically. To avoid confusion, the developed prompts utilize the word "organism" when referring to the user because it is the only option for the user to be biologized as in this approach. In contrast, the product's function(s) and context of use can take various forms, therefore retaining their original terminology. When studying these prompts, I observed that certain verbiage and phrasing affected the types of responses from ChatGPT. Under each prompt, I briefly describe what the prompt is asking for or the type of results designers will most likely see from each to help decide which to use. However, it is recommended to plug biologized factors into every prompt since each one will provide different information. While not necessary, the designer should try putting each prompt into its own chat, as I found ChatGPT's responses were sometimes similar or repetitive if multiple prompts were used in the same chat. However, if the designer is pressed for time and is not able to input all the prompts and synthesize ChatGPT's responses, it is advisable to focus on prompts using the phrase "Biomimicry: [...]" and the prompt "How would a biomimetic designer design [product]"

as they quickly provide applicable biomimetic solutions. However, one drawback of this “fast” approach is that the results may include biological strategies from products that have already been designed, causing the designer to possibly lose the opportunity to find and develop novel biomimetic solutions if they were to use all the prompts and synthesize the results. The ChatGPT prompts and their descriptions are listed below:

1. How does nature [function]?

- a. Original question to “ask nature” from The Biomimicry Toolbox
- b. Focuses on *how* nature may perform [function]
- c. Provides broader results

2. When does nature [function]?

- a. Focuses on *when* nature may perform [function]
- b. Provides broader results

3. Where does nature [function]?

- a. Focuses on *where* nature may perform [function]
- b. Provides broader results

4. What [organism] performs [function] when [context]?

- a. Listing [organism] first places emphasis for ChatGPT to identify “organisms” that perform [function] when [context]
- b. [Context] can be omitted if only looking for “organisms” that perform [function]
- c. [Context] can include “when, where, *or* both”

5. Biomimicry: [function, organism, context]

- a. Listed in order of how factors are biologized, but can be re-ordered

- b. Re-ordering of biologized factors places different emphasis on what ChatGPT will respond with (i.e. if [organism] listed first, ChatGPT will provide designer with users that perform [function] when [context])
 - c. Can also use [function] with only [organism] or [context(s)]
- 6. Biomimicry: [product]**
- a. Open-ended, more general results concerning biomimicry and [product] such as strategies, examples, broad range of concepts, or principles
- 7. Biomimicry: design [product]**
- a. Less exploratory, provides instruction (design) for ChatGPT concerning biomimicry
 - b. Provides more concrete biomimetic strategies to apply in the design specific to [product]
- 8. How would nature design [product]?**
- a. Most creative responses
 - b. Broad range of possible responses because the prompt is pulling from all of nature (in dataset)
 - c. Breaks [product] down into different components and identifies biological strategies that could be applied to each aspect
- 9. How would a biomimetic designer design [product]?**
- a. Emphasizes the designer and gives ChatGPT a “role” to help guide its response
 - b. Outlines general approach a biomimetic designer may take
 - c. Identifies factors a biomimetic designer may consider concerning both biomimicry and the [product]

After submitting a prompt, ChatGPT will respond accordingly. Once the response finishes loading, the designer can take one of the four following actions:

1. Regenerate the response
2. Continue the chat
3. Ask a new question
4. Synthesize findings from conversation(s) with ChatGPT

Once the designer determines they are finished consulting with ChatGPT, they will synthesize their conversations and identify what they want to research further, which is a convergent task. As established from the literature, sometimes ChatGPT provides answers that are incorrect or misleading, even though it's response may have enough intellectual bravado to seem otherwise. Given this, it is recommended that the designer verify information from ChatGPT's responses to their own discretion. If desired, or required, the designer can conduct further research using traditional research methods based on their selected responses from ChatGPT. Now could be an appropriate time to utilize some of the discovery methods found in The Biomimicry Toolbox's "Tips and Suggestions" within their "Biologize" section to continue research since the designer has already identified their biological strategies. After the designer completes the research phase, they need to define their new design criteria.

3.2.4 Define

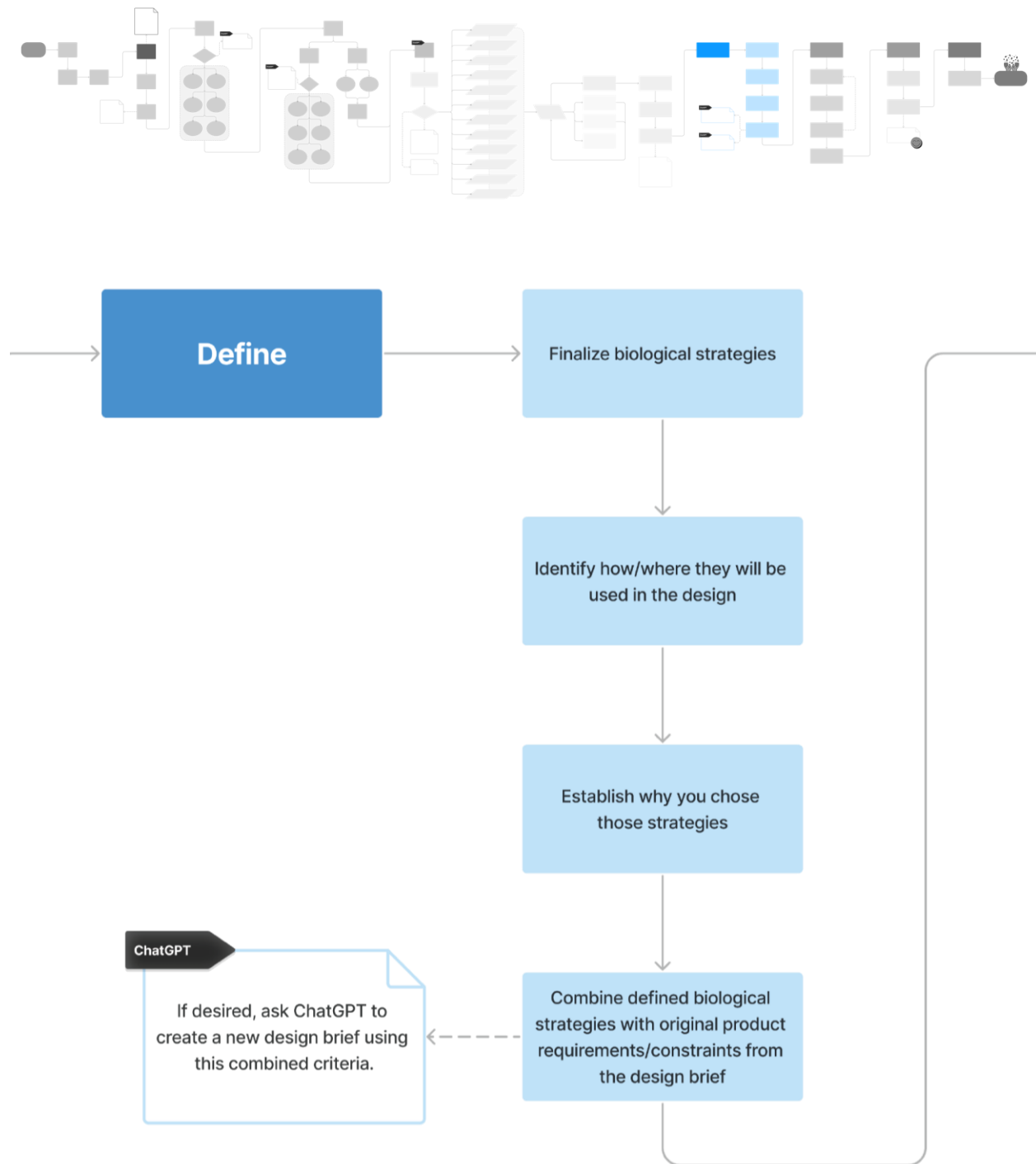


Figure 33: Define Flow Chart

After conducting research the designer has to establish their design criteria, moving into the define phase. In this stage the designer must finalize the biological strategies they will be applying in their design. In order to help them during their design process, they should identify how and where each biological strategy will be used in their design. Furthermore, the designer should also identify *why* each strategy was chosen to help them justify their design decisions.

Once the designer has defined their biomimetic design criteria, they should combine these with the product requirements and constraints from the original design brief. This will help create a sort of checklist for the designer so they can make sure to address everything in their design. It is suggested to prompt ChatGPT to create a new design brief using the defined criteria, but doing so is not required. Since the design criteria has been defined, the designer could also ask ChatGPT to help them establish strategies to evaluate their future concepts relating to the design criteria. Strategies from ChatGPT would be used in tandem with the Biomimetic Industrial Design Principles Checklist developed later in this chapter (Section 3.2.6).

3.2.5 Design

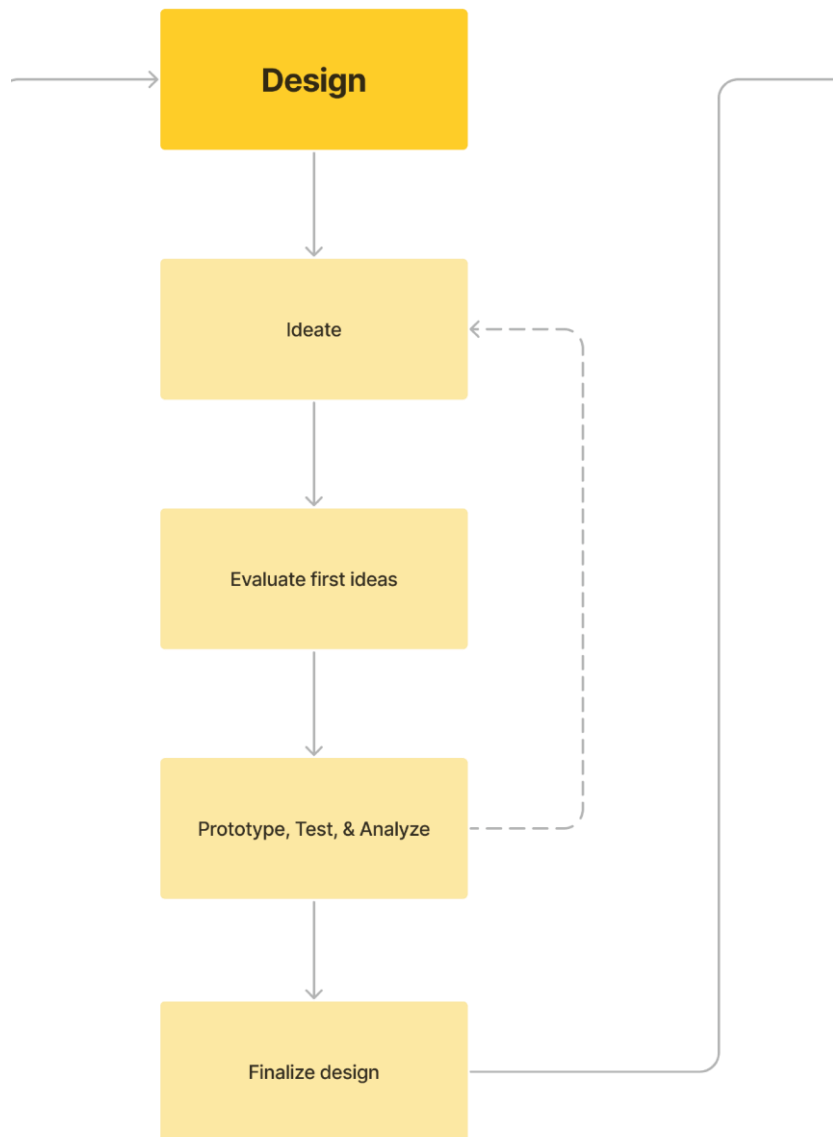
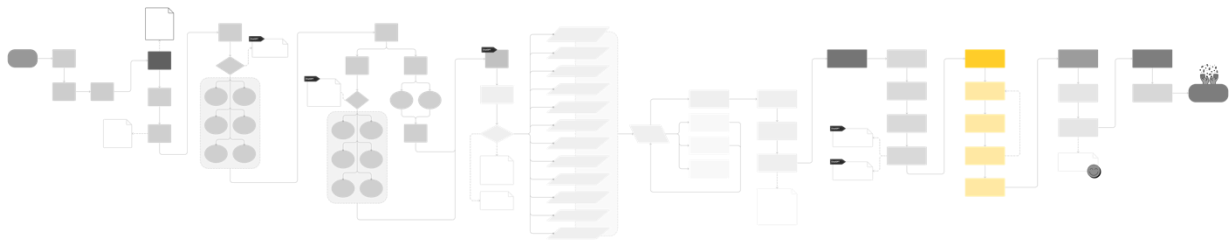


Figure 34: Design Flow Chart

Once the new design criteria have been defined, the designer is able to move into the design process. This section of the process was adapted from the “Design” section of Nessler’s (2018) Revamped Double Diamond Design Process Framework. This stage of the process is both diverging and converging because the designer is exploring design opportunities and also narrowing down to a final concept. This process begins with ideation, developing as many concepts as possible. The designer will then evaluate these initial concepts based on their defined design criteria. Next, they will prototype concepts, put their concepts to the test, and then analyze their results. These steps of ideation through analysis will create a cyclical process until the designer is satisfied and establishes their final concept.

3.2.6 Evaluate

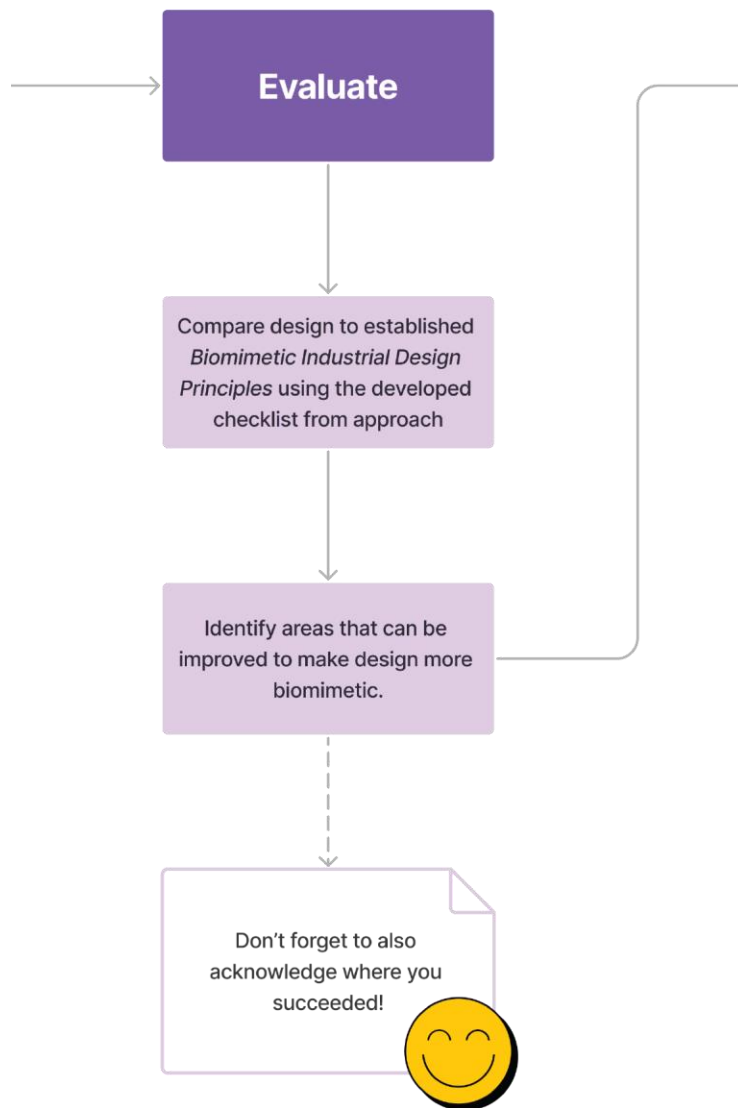
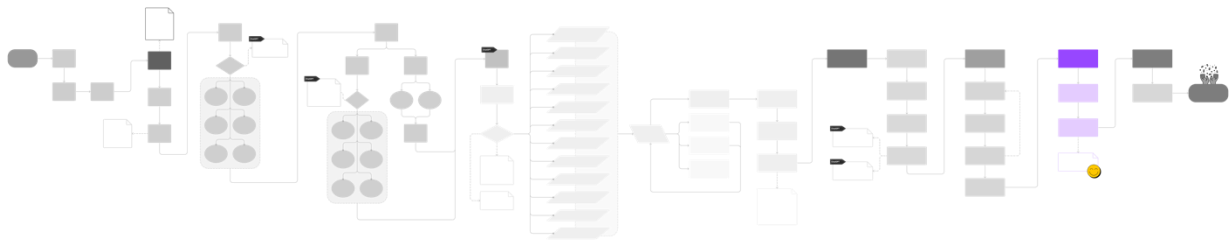


Figure 35: Evaluate Flow Chart

Once the designer finished developing their final concept, they will move into the evaluation phase. The designer will evaluate their concept using the Biomimetic Industrial Design Principles Checklist. This checklist helps the designer compare their design to the Biomimetic Industrial Design Principles, which were developed at the beginning of this chapter. By comparing their design to these principles, the designer will identify areas where their design is not meeting these principles. Identifying these gaps in their design provides the designer with concrete areas to focus on during the refining phase to make their design more biomimetic. The checklist includes check-boxes on both “Nature’s Strategies” and “Sustainable Design Strategies” because the designer could achieve “Nature’s Strategies” by different means than the listed “Sustainable Design Strategies.” The “Sustainable Design Strategies” offer actionable solutions to aid the designer in applying the Biomimetic Industrial Design Principles, but the designer is not limited to these solutions. Furthermore, having one checked box is always better than having none. While it would be ideal if every single principle and strategy were applied to a design, the intention of this checklist is to not check off every box, but rather help guide designers through evaluating their design and help identify areas of improvement in order to make their design more biomimetic. This checklist is provided on the following two pages (Figure 36 & Figure 37).

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature's form follows function	<input type="checkbox"/> Function defines form	<input type="checkbox"/> Design to mimic biological systems <hr/> <input type="checkbox"/> Use living organisms in product system <hr/> <input type="checkbox"/> Rethink how to provide the benefit <hr/> <input type="checkbox"/> Design flexibility for technological change
Nature uses energy and materials efficiently.	<input type="checkbox"/> Up-cycles materials	<input type="checkbox"/> Use recycled or reclaimed materials
	<input type="checkbox"/> Utilizes abundant resources and incorporates rare resources sparingly	<input type="checkbox"/> Avoid materials that deplete natural resources <hr/> <input type="checkbox"/> Design to encourage low-consumption behavior
	<input type="checkbox"/> Optimizes energy use	<input type="checkbox"/> Reduce energy during use <hr/> <input type="checkbox"/> Minimize energy use in production <hr/> <input type="checkbox"/> Minimize number of production steps
	<input type="checkbox"/> Optimizes material use <hr/> <input type="checkbox"/> Relies on freely available energy	<input type="checkbox"/> Reduce material consumption during use <hr/> <input type="checkbox"/> Minimize manufacturing waste <hr/> <input type="checkbox"/> Minimize quantity of materials <hr/> <input type="checkbox"/> Use renewable resources <hr/> <input type="checkbox"/> Use carbon-neutral or renewable energy sources
Evolution defines nature.	<input type="checkbox"/> Adapts to changing conditions	<input type="checkbox"/> Design for durability <hr/> <input type="checkbox"/> Foster emotional connection to product <hr/> <input type="checkbox"/> Create timeless aesthetic appeal
	<input type="checkbox"/> Evolves to survive	<input type="checkbox"/> Design for maintenance and easy repair <hr/> <input type="checkbox"/> Design for reuse and exchange of products <hr/> <input type="checkbox"/> Design for a second life with different function
	<input type="checkbox"/> Integrate development with growth	<input type="checkbox"/> Design upgradable products <hr/> <input type="checkbox"/> Design for reuse of components

Figure 36: Biomimetic Industrial Design Principles Checklist (Page 1)

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature is locally attuned and responsive.	<input type="checkbox"/> Hyper-aware of their environments and respond quickly to threats and changes	<input type="checkbox"/> Reduce product and packaging weight <input type="checkbox"/> Reduce product and packaging volume <input type="checkbox"/> Develop reusable packaging systems <input type="checkbox"/> Use lowest-impact transport system <input type="checkbox"/> Source or use local materials and production
Nature uses life-friendly chemistry.	<input type="checkbox"/> Uses chemicals and materials that are safe for living beings (unless otherwise intended)	<input type="checkbox"/> Avoid materials that damage human or ecological health <input type="checkbox"/> Avoid materials that deplete natural resources <input type="checkbox"/> Use recycled or reclaimed materials <input type="checkbox"/> Use renewable resources <input type="checkbox"/> Use materials from reliable certifiers <input type="checkbox"/> Use waste byproducts <input type="checkbox"/> Seek to eliminate toxic emissions
Nature provides mutual benefits.	<input type="checkbox"/> Has mutual advantages and dependencies among its various elements and organisms; interconnected relationships within ecosystems	<input type="checkbox"/> Design for fast manual or automated disassembly <input type="checkbox"/> Design recycling business model <input type="checkbox"/> Use recyclable non-toxic materials <input type="checkbox"/> Provide ability to biodegrade <input type="checkbox"/> Integrate methods for used product collection <input type="checkbox"/> Design for safe disposal

Figure 37: Biomimetic Industrial Design Principles Checklist (Page 2)

3.2.7 Refine

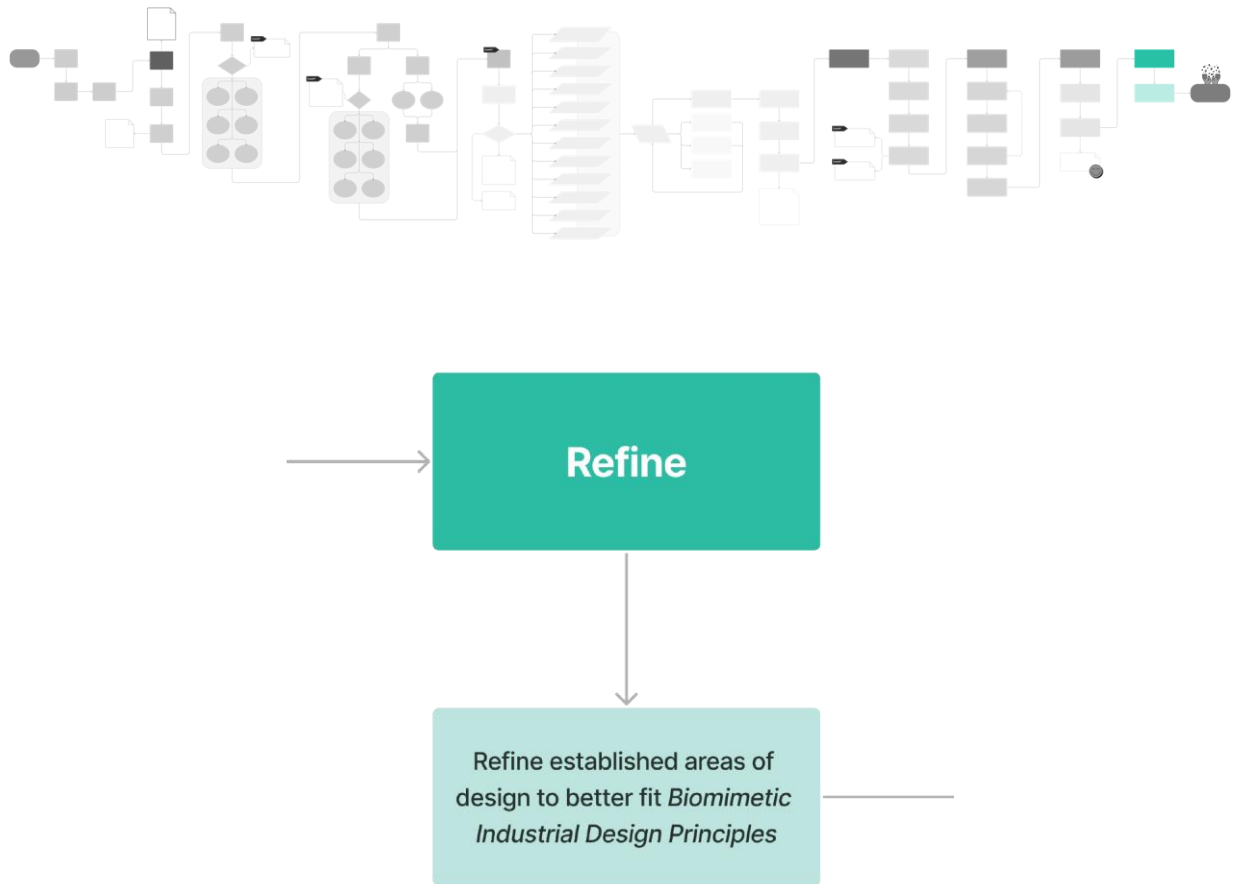


Figure 38: Refine Flow Chart

Once the designer has established which areas they need or want to improve in their design, they can begin to make these changes in the “Refine” phase. Based on the Biomimicry Industrial Design Principles, the designer can make changes to address the identified areas needing improvement. By using these principles as a basis for refinement, it allows the designer to not only improve their design, but creatively address their design’s challenges. This systematic approach ensures the designer will work purposefully to enhance their design, leading to a more successful final product while aligning with their overarching design goals and objectives.

3.2.8 Final Design

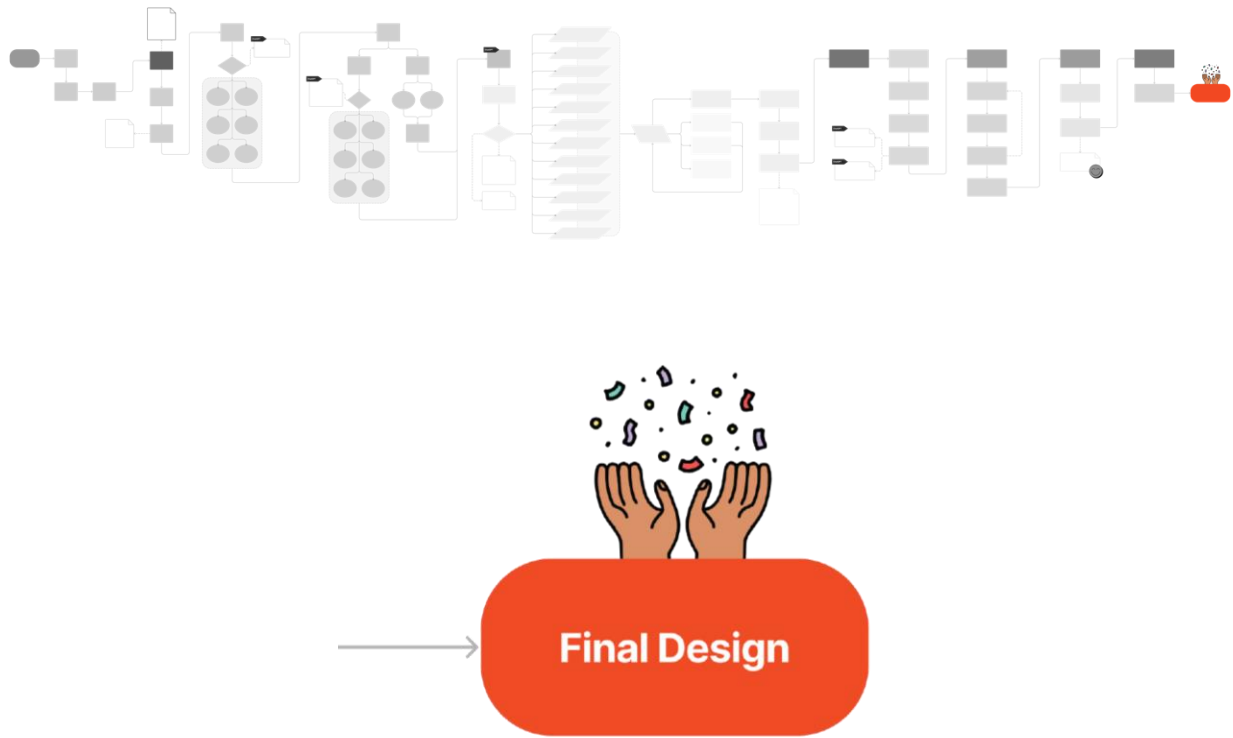


Figure 39: Final Design Flow Chart

Once the designer has gone through all the steps of this approach, it will be assumed they have created a successful biomimetic solution for their design challenge.

Chapter 4

Demonstrating the Developed Biomimetic Approach for Industrial Designers

This chapter applies and demonstrates the Biomimetic Industrial Design Approach developed in Chapter 3. The goal of this approach is to integrate biomimicry into industrial design by incorporating the use of generative artificial intelligence program ChatGPT. This approach places emphasis on the research phase of the design process, as that is where the main point of integrating biomimicry is located. This approach is demonstrated through a design project of a travel backpack. The approach is pictured below.

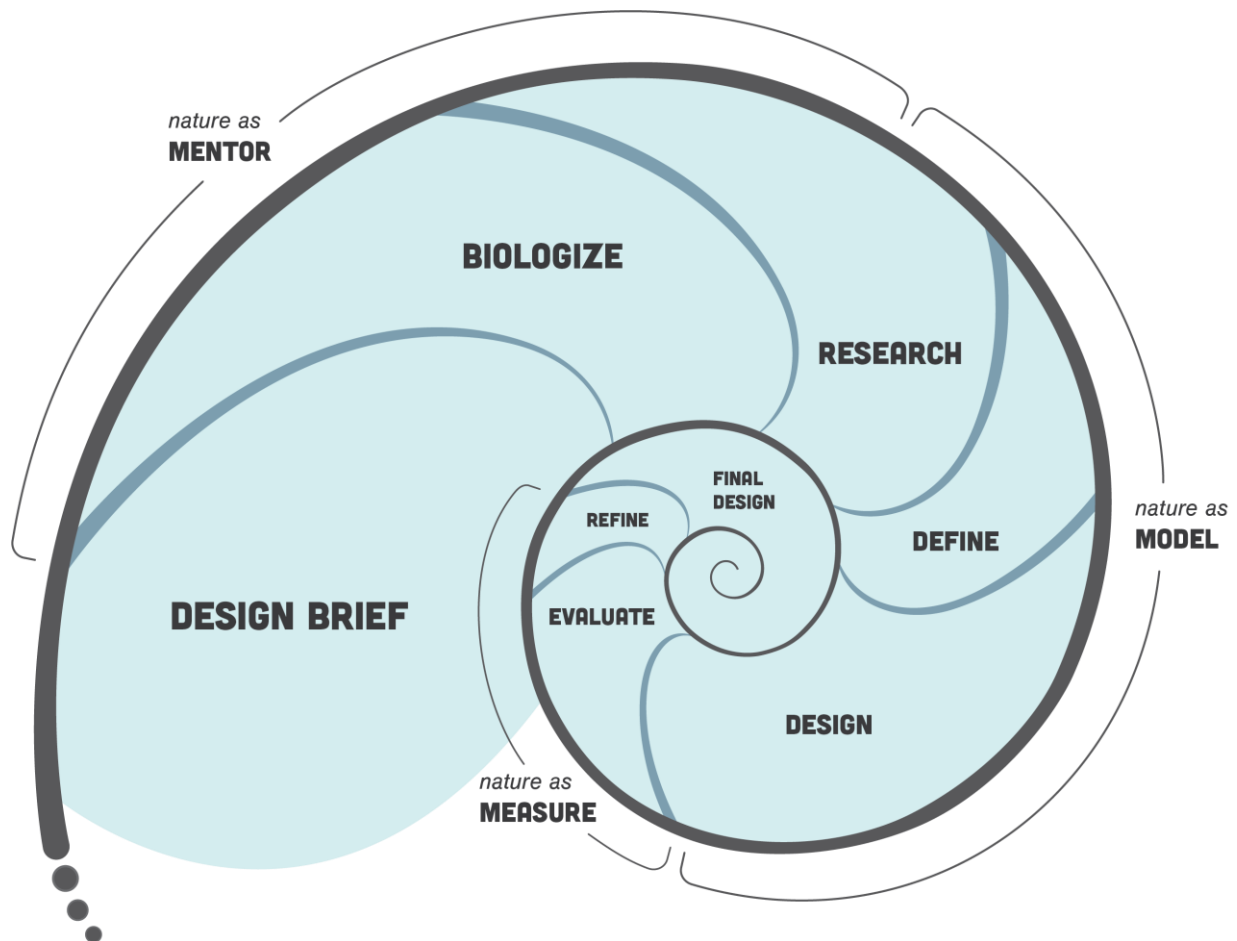


Figure 40: Biomimetic Industrial Design Process

4.1 Design Brief

The first step of integrating biomimicry into industrial design is analyzing the design brief. The design brief presents the design challenge, outlining criteria for the deliverable(s) of a design project. This criteria often includes the necessary function(s) of the product, identifies the user(s), and presents the context of where and when the product will be used. In this stage, the designer will identify factors from the brief that can be “biologized” which are the product’s desired function(s), the user, and its context of use. I created the following design brief to base the design project on:

The product you will be designing is a travel backpack for the young world explorer. The target user for this product is an 18-30 year old individual. The backpack should be gender-neutral and have modern aesthetics that appeal to the user age group. The target user will be using their backpack on a wide variety of trips in various climates as their personal item. Therefore, the backpack must fit in within the TSA personal item size constraints of 18 x 14 x 8 inches. Since it will be used in a variety of conditions, the backpack should be comfortable, durable, and waterproof. Ideally, the backpack will be made from sustainable materials. The backpack should be functional and promote organization, considering the role of technology in modern travel.

After reading through and “ripping” the brief, I have identified the design criteria that are able to be biologized. The words in the parentheses denote which component of the backpack the listed function is referring to:

- **Function:** transporting personal items over large distances (backpack), durable (materials), waterproof (bag’s outer shell, materials), comfortable (straps),
- **User:** young world explorer, age 18-30

- **Context of Use:** user needs to carry their belongings when they want/need to travel long distances (when), various climates and conditions (where)

The other design constraints I identified from the brief, that are not biologized, are listed below:

- Size constraint: 18 x 14 x 8 inches
- Gender-neutral
- Modern aesthetics
- Age 18-30

4.2 Biologize

The second step of this approach is to “biologize” the factors identified in the brief. The term “biologize” was created by the Biomimicry Institute to represent the process of identifying “the essential functions and context [the] design solution must address” and then “[reframing these criteria] in biological terms, so that [designers] can ‘ask nature’ for advice” (*Biologize Function & Context*, n.d.). The factors I identified to be biologized are listed below:

- **Function:** transporting personal items over large distances (backpack), durable (materials), waterproof (bag’s outer shell, materials), comfortable (straps),
- **User:** young world explorer, age 18-30
- **Context of Use:** user needs to carry their belongings when they want/need to travel long distances (when), various climates and conditions (where)

The approach calls for the factors to be biologized in the following order: function, user, context.

To biologize function, I broke down the backpack’s main function into its most basic terminology so it can be easily integrated into nature. Therefore, I simplified the backpack’s function from “transporting personal items over large distances” to “transporting items.” The

next factor I biologized is the backpack's user: a young world explorer. The user is biologized into organism(s). As stated in Chapter 3, there are six main types of organisms: animals, plants, fungi, protists (algae), bacteria, and archaea. I chose to biologize my user into "animals" because they are one of the more dynamic organismal categories. Context of use is separated into *when* and *where* the product is used. *Where* the product is used is biologized into biomes. As defined in Chapter 3, biomes are overarching categories that encompass multiple different habitats. The six main biomes: freshwater, marine, desert, forest, grassland, and tundra (*The World's Biomes*, n.d.). Given that the backpack will be used in various climates and conditions (context of use: where), I chose "forest" as my biome because it is the biome with the most variation, as there are many different types of forests all over the world that ChatGPT could possibly pull biological strategies from. The final factor that can be biologized is context of *when* the product is used. When a product is used is typically triggered by user's wants and needs. To biologize when a product is used, the designer should simplify the user wants and needs into its most basic terminology. Therefore, I simplified *when* from "transporting personal items over large distances" to "traveling."

4.3 Research


Once the factors have been biologized, the next step is research using the ChatGPT prompts provided in Chapter 3. These prompts were designed to be used in ChatGPT's GPT-3.5, not GPT-4, as it only responds with textual answers for the designer to respond to or synthesize. Therefore, this demonstration uses the GPT-3.5 version of ChatGPT. During this phase, I plugged my biologized factors into each prompt provided in Chapter 3 and then submitted them to individual chats in ChatGPT. After submitting the prompt, ChatGPT will provide a response


with which the designer can take one of the following actions: regenerate the response, continue the chat, ask a new question, or synthesize findings from conversation(s) with ChatGPT. For the sake of length, I will demonstrate each prompt using my biologized factors and show each of the following actions once, not for every prompt. These will be demonstrated through screenshots of my conversations with ChatGPT. A link to the screenshotted conversation is below each prompt. Once finished interacting with ChatGPT and after all conversations have been synthesized, the next steps are to identify what to research further, verify information to one's own discretion, and conduct further research if necessary or desired. These steps will also be demonstrated in this section. The ChatGPT prompts are listed below:

1. How does nature [function]?
2. When does nature [function]?
3. Where does nature [function]?
4. What [user] performs [function] when [context]?
5. Biomimicry: [function, user, context]
6. Biomimicry: [product]
7. Biomimicry: design [product]
8. How would nature design [product]?
9. How would a biomimetic designer design [product]?

Prompt 1: How does nature [function]?

<https://chat.openai.com/share/71103826-0208-4f69-a7c4-45048bf723bd>

 **You**
how does nature transport items?

 **ChatGPT**
Nature employs various mechanisms to transport items, such as nutrients, water, and pollen, within and between organisms. These mechanisms have evolved over millions of years to ensure the survival and reproduction of different species. Here are some examples of how nature transports items:

1. **Capillary action:** In plants, capillary action allows water to be transported from the roots to the leaves through tiny tubes called xylem. This phenomenon relies on the cohesive and adhesive properties of water molecules, which enable them to move upward against gravity.
2. **Circulatory systems:** Animals, including humans, have circulatory systems that transport nutrients, oxygen, and waste products throughout the body. The heart pumps blood through a network of blood vessels, ensuring that essential substances reach cells and tissues.
3. **Phloem transport:** In plants, the phloem is responsible for transporting nutrients, primarily sugars produced during photosynthesis, from the leaves to other parts of the plant, such as roots, fruits, and flowers. This process is called translocation and relies on pressure gradients.
4. **Wind dispersal:** Many plants have evolved adaptations to disperse their seeds via the wind. They produce lightweight seeds or structures like parachutes, wings, or hairs that catch the wind and carry the seeds to new locations.
5. **Animal dispersal:** Some plants rely on animals to transport their seeds. Fruits often develop appealing colors and flavors to attract animals. When animals eat the fruits, they ingest the seeds, which are later excreted at different locations, aiding in seed dispersal.
6. **Pollination:** Pollen, the male reproductive cells of plants, is transported from one flower to another by various agents, including wind, insects, birds, and bats. This enables the fertilization of plants and the production of seeds.
7. **Mycorrhizal networks:** Mycorrhizal fungi form symbiotic relationships with many plants. These fungi extend their networks into the soil and assist in the transport of nutrients, such as phosphorus and nitrogen, from the soil to the plant roots in exchange for sugars produced by the plant.
8. **Ocean currents:** In aquatic ecosystems, ocean currents can transport items like nutrients, plankton, and marine organisms over long distances. These currents play a crucial role in marine ecosystems and can affect the distribution of marine life.
9. **Geophysical processes:** Natural processes such as erosion, sedimentation, and tectonic movements can transport materials like rocks, minerals, and sediments over large distances, shaping landscapes and ecosystems.

These examples demonstrate the diverse and intricate ways in which nature has evolved to transport items, ensuring the survival, growth, and reproduction of organisms and contributing to the complexity and interconnectedness of ecosystems.


   

Figure 41: ChatGPT Response- When does nature [function]?

Prompt 2: When does nature [function]?

<https://chat.openai.com/share/55adfb0-9320-4b07-9eb2-927a25aa7967>

 **You**
When does nature transport items?

 **ChatGPT**
Nature transports items through various mechanisms and processes, depending on the context and the items in question. Here are a few examples:

1. **Seed Dispersal:** Many plants have evolved mechanisms for transporting their seeds to new locations. This can be done through the wind (e.g., dandelion seeds carried by the wind), by animals that eat the fruits and then excrete the seeds in a different location, or by attachment to animals' fur or feathers.
2. **Water Transport:** Water plays a significant role in transporting items in nature. Rivers, streams, and ocean currents can carry debris, nutrients, and organisms over long distances. For example, driftwood can be transported by water from one location to another.
3. **Pollination:** In the case of flowering plants, nature uses pollinators such as bees, butterflies, and birds to transport pollen from one flower to another, facilitating the reproduction of plants.
4. **Animal Dispersal:** Animals also play a role in transporting items in nature. For instance, squirrels bury nuts and seeds in the ground, which can lead to the dispersal and germination of new plants. Some animals, like beavers, transport logs and branches for use in building dams and lodges.
5. **Erosion:** Natural processes like erosion can transport soil, rocks, and minerals over time. Wind, water, and ice can erode landscapes and carry sediments from one place to another.
6. **Ocean Drift:** In the marine environment, ocean currents can transport a wide range of items, including marine organisms, debris, and nutrients. This can have a significant impact on the distribution of marine life and the movement of materials in the oceans.
7. **Volcanic Activity:** Volcanic eruptions can transport volcanic ash, rocks, and other materials over long distances. The eruption of Mount St. Helens in 1980, for example, resulted in the transport of ash across several states.

These are just a few examples of how nature transports items through various natural processes and mechanisms. The specific mechanisms and processes involved can vary widely depending on the item in question and the environmental conditions.



Figure 42: ChatGPT Response- When does nature [function]?

Prompt 3: Where does nature [function]?

<https://chat.openai.com/share/7aa2422e-2e8d-4d27-87cf-6aa3b4e61233>



You

Where does nature transport items?



ChatGPT

Nature transports items through various mechanisms and processes depending on the context and the items in question. Here are some common ways in which nature transports items:

1. **Wind:** Wind is a powerful natural force that can transport items such as seeds, pollen, and dust particles over long distances. Plants have evolved various mechanisms to release seeds that are carried by the wind to new locations for dispersal and germination.
2. **Water:** Water plays a significant role in transporting items in nature. Rivers, streams, and ocean currents can carry debris, sediment, and various organisms to different locations. Some aquatic plants and animals also use water currents for dispersal.
3. **Animals:** Many animals, including birds, mammals, and insects, are involved in the transportation of items in nature. For example, birds can carry seeds in their beaks or on their feathers, aiding in the dispersal of plants. Bees and other pollinators transport pollen between flowers as they collect nectar.
4. **Gravity:** The force of gravity can cause items to move downhill or be transported by erosion. Rocks, soil, and sediment can be carried by gravity, leading to geological processes like erosion and sedimentation.
5. **Ocean currents:** Ocean currents are responsible for transporting marine life, including plankton, fish larvae, and other organisms, across vast distances in the ocean. This movement can impact the distribution of species and ecosystems.
6. **Volcanic eruptions:** Volcanic eruptions can transport items like ash, gases, and volcanic rocks into the atmosphere and deposit them over large areas. These events can have significant ecological and geological consequences.
7. **Atmospheric processes:** The atmosphere plays a role in transporting items such as airborne dust, spores, and pollutants over long distances. This can affect air quality, weather patterns, and the distribution of particles in the atmosphere.
8. **Ice and glaciers:** Glaciers can transport rocks, sediment, and other materials as they flow downhill. When glaciers melt, they release the transported materials, which can have a lasting impact on the landscape.
9. **Tides:** Tidal movements in coastal areas can transport water, sediment, and marine organisms, influencing the ecology of tidal zones.

These are just a few examples of how nature transports items through various natural processes and mechanisms. Each of these processes plays a crucial role in shaping ecosystems, distributing species, and influencing geological and environmental changes on Earth.



Figure 43: ChatGPT Response- Where does nature [function]?

Prompt 4: What [user] performs [function] when [context]?

<https://chat.openai.com/share/71321725-6014-4fcc-84fc-538b71c1adde>

As stated in Chapter Three, this prompt can be divided into four separate prompts, which I demonstrated below. I asked the first question following the order of the original prompt: “What [animals] [transport items] when [traveling] in a [forest]?” The original prompt includes both types of context of use, but they can also be used by themselves instead of in unison which I demonstrated with the prompts: “What [animals] [transport items] when [traveling]?” and “What [animals] [transport items] in a [forest]?” Furthermore, *both* contexts of use can also be omitted, so I also demonstrated the prompt: “What [animals] [transport items]?”



You

what animals transport items when traveling in a forest?



ChatGPT

Many animals in a forest may transport items when traveling, often unintentionally. These animals play important roles in seed dispersal and ecosystem dynamics. Some examples include:

1. Squirrels: Squirrels are known for their habit of burying nuts and seeds in the ground. They often forget some of their caches, which can lead to the growth of new plants.
2. Birds: Many bird species eat fruits and then disperse the seeds by excreting them in different locations. Examples include thrushes, pigeons, and jays.
3. Rodents: Various rodents, like mice and chipmunks, can transport seeds in their cheek pouches. They may carry seeds to their burrows or caching sites, inadvertently aiding in plant propagation.
4. Ants: Ants are important seed dispersers in some forest ecosystems. They often collect seeds and carry them back to their nests, where they may be stored or discarded, helping to spread the seeds.
5. Wind: While not animals, wind can also transport seeds and other plant materials over long distances in a forest.
6. Larger mammals: Some larger mammals, like deer and wild boars, can transport seeds on their fur or hooves as they move through the forest.

These activities are essential for the regeneration and diversity of plant species within a forest ecosystem. They help plants spread to new areas, increasing their chances of survival and adaptation.

Figure 44: ChatGPT Response- what animals transport items when traveling in a forest?



You

what animals transport items when traveling?



ChatGPT

Various animals transport items when traveling for various reasons, such as foraging, building nests, or relocating their young. Here are some examples:

1. **Bees:** Bees collect pollen and nectar from flowers and transport them back to their hives to make honey. In the process, they inadvertently pollinate the flowers, aiding in plant reproduction.
2. **Ants:** Ants are known for transporting food to their nests. They work together in organized groups to carry food items like dead insects or seeds back to their colonies.
3. **Crows and ravens:** These birds are known for their intelligence and use tools, including sticks and leaves, to obtain food. They may transport these tools to different locations to aid in their foraging.
4. **Dolphins:** Dolphins are known to carry items such as sponges on their rostrums (beaks) while foraging on the ocean floor. They use these tools to protect their snouts from sharp rocks and to uncover prey hiding in the sand.
5. **Some primates:** Certain species of primates, like capuchin monkeys, use tools like sticks to extract insects from tree crevices or to open nuts. They often transport these tools from place to place while foraging.
6. **Birds building nests:** Birds that build nests, such as sparrows and crows, transport materials like twigs, leaves, and grass to construct their nests.
7. **Migratory birds:** Many bird species transport themselves long distances during migration, carrying nothing but their own bodies. However, they play a crucial role in dispersing seeds and plant material when they eat and excrete seeds from various locations.
8. **Hermit crabs:** Hermit crabs transport and use empty shells as protective armor for their soft abdomens. They are known to switch shells as they grow or find larger, more suitable ones.
9. **Kangaroos:** Female kangaroos carry and transport their young, known as joeys, in their pouches as they move about.
10. **Squirrels:** Squirrels transport items like nuts and seeds to different locations, often burying them for later consumption. This behavior helps in seed dispersal and can contribute to forest regeneration.

These are just a few examples of how animals transport items when traveling. Their actions serve various purposes, including obtaining food, shelter, and resources for survival and reproduction.



Figure 45: ChatGPT Response- what animals transport items when traveling?



You

what animals transport items in a forest?



ChatGPT

Animals in a forest often transport items as part of their natural behaviors and ecological roles. These items can include food, nesting materials, and seeds. Here are some examples of animals that transport items in a forest:

1. **Squirrels:** Squirrels are well-known for transporting and caching nuts and seeds. They bury these items in various locations within the forest, helping with seed dispersal and potentially aiding in the growth of new plants.
2. **Birds:** Many bird species in the forest transport items such as twigs, leaves, moss, and feathers for building nests. They collect these materials from the forest floor and trees.
3. **Ants:** Ants are responsible for the transport of food items like dead insects, seeds, and other organic matter to their nests. This behavior contributes to nutrient cycling within the forest ecosystem.
4. **Bees:** Bees collect nectar and pollen from forest flowers and transport them back to their hives. In the process, they pollinate the flowers, aiding in plant reproduction.
5. **Rodents:** Various rodent species, including mice and chipmunks, transport seeds in their cheek pouches. They may carry seeds to their burrows or caching sites, contributing to seed dispersal.
6. **Deer:** Deer can inadvertently transport seeds on their fur or hooves as they move through the forest. This can help spread seeds to new locations.
7. **Wild boars:** Like deer, wild boars may carry seeds on their fur and hooves as they forage through the forest, assisting in seed dispersal.
8. **Foxes:** Foxes are known to carry food items such as small mammals, birds, and insects in their mouths to their dens or hiding spots within the forest.
9. **Penguins (in forests near the coast):** In some coastal forests where penguins nest, these birds transport pebbles and stones to their nesting sites, using them to build and maintain their nests.
10. **Bats:** Bats transport food items, such as insects, fruits, and nectar, to their roosting sites within the forest. They may also inadvertently disperse seeds when they consume fruits and then fly to new locations.

These animals play important roles in the ecology of forests by aiding in seed dispersal, nutrient cycling, and habitat maintenance, among other functions. Their activities contribute to the diversity and health of forest ecosystems.



Figure 46: ChatGPT Response- what animals transport items in a forest?

G You
What animals transport items?

ChatGPT

Many animals transport items as part of their daily activities or for specific purposes. Here are some examples of animals that transport items:

1. **Ants:** Ants are well-known for transporting food and building materials to and from their nests. They work together in organized colonies to carry items like leaves, dead insects, and seeds.
2. **Bees:** Bees collect pollen and nectar from flowers and transport them back to their hives to make honey. In the process, they inadvertently pollinate the flowers, aiding in plant reproduction.
3. **Birds:** Various bird species transport materials for building nests. They collect twigs, leaves, grass, feathers, and other items to construct their nests for raising their young.
4. **Hermit crabs:** Hermit crabs transport and use empty shells as protective armor for their soft abdomens. They frequently change shells as they grow or find more suitable ones.
5. **Dolphins:** Dolphins have been observed using tools like sponges to protect their rostrums (beaks) while foraging on the ocean floor. They transport these tools to aid in their hunting activities.
6. **Primates:** Some primate species, such as capuchin monkeys, use tools like sticks to extract insects from tree crevices or to open nuts. They may transport these tools from place to place while foraging.
7. **Squirrels:** Squirrels are known for transporting items like nuts and seeds to different locations, often burying them for later consumption. This behavior helps in seed dispersal and can contribute to forest regeneration.
8. **Penguins:** Penguins transport pebbles and stones to their nesting sites, where they use them to build and maintain their nests.
9. **Migratory birds:** Many bird species transport themselves over long distances during migration, carrying nothing but their own bodies. However, their activities during migration can have important ecological impacts, including seed dispersal and nutrient cycling.
10. **Kangaroos:** Female kangaroos carry and transport their young, known as joeys, in their pouches as they move about.

These examples demonstrate the various ways in which animals transport items as part of their behaviors and adaptations for survival, reproduction, and maintaining their habitats.



Figure 47: ChatGPT Response- what animals transport items?

Prompt 5: Biomimicry: [function, user, context]

<https://chat.openai.com/share/cdb1e730-ae76-4877-b790-b6cedc062ce1>

 **You**

Biomimicry: transport items, travel, forest, animals

 **ChatGPT**

Biomimicry in the context of transport items and travel, especially inspired by forest ecosystems and animals, opens up a realm of unique design solutions. Here's how forests and its inhabitants can guide innovations:

- 1. Tree Nut Dispersal:**
 - **Inspiration:** Nuts like acorns have a hard shell and can roll, which aids in their dispersal across the forest floor.
 - **Application:** Packaging designs for transport can be inspired by the robustness and simplicity of these natural containers.
- 2. Spider Webs:**
 - **Inspiration:** Spider webs are strong, lightweight, and efficiently capture prey.
 - **Application:** Lightweight and strong netting for securing cargo, especially in aerial or aquatic transport contexts.
- 3. Monkeys and Brachiation:**
 - **Inspiration:** Many forest monkeys use brachiation – swinging from branch to branch using their arms – for locomotion.
 - **Application:** Design of efficient and flexible urban transportation systems, like cable cars or suspended monorails.
- 4. Flying Squirrels:**
 - **Inspiration:** Flying squirrels glide from tree to tree using a membrane called the patagium.
 - **Application:** Design of lightweight gliders or drones for transporting small items over short distances.
- 5. Forest Canopy Layers:**
 - **Inspiration:** Forests are vertically stratified into layers (understory, canopy, emergent layer), each with its own microenvironment and inhabitants.
 - **Application:** Multi-layered transportation systems in urban settings, with different levels optimized for different transport methods (e.g., underground trains, surface vehicles, aerial drones).

Figure 48: ChatGPT Response- Biomimicry: transport items, travel, forest, animals (Part 1)

6. **Elephants as Path Makers:**
 - **Inspiration:** Elephants in forests create paths by trampling vegetation, which are then used by other animals.
 - **Application:** Autonomous vehicles could be programmed to recognize and follow trails blazed by leading vehicles, optimizing routes over time.
7. **Snakes and Locomotion:**
 - **Inspiration:** Forest snakes like the anaconda move using lateral undulation or concertina motion.
 - **Application:** Design of flexible robots or vehicles that can navigate challenging terrains in forests or other dense environments.
8. **Bird Migration:**
 - **Inspiration:** Many birds use the Earth's magnetic field and stars for long-distance navigation.
 - **Application:** Incorporating bio-inspired navigation systems that use a combination of natural and technological cues.
9. **Fungi Mycelium Networks:**
 - **Inspiration:** Fungi form vast underground networks that transport nutrients and communicate with plants.
 - **Application:** Development of underground transport or delivery systems, or communication networks to relay traffic or route information.
10. **Bats and Echolocation:**
 - **Inspiration:** Bats emit sound waves and listen to the echoes to navigate and locate prey.
 - **Application:** Advanced sonar and radar systems for vehicles, especially in low-visibility environments like foggy or dense forests.

By diving deep into the mechanics and behaviors of forest ecosystems and their inhabitants, we can derive strategies and designs to improve how we transport and travel in our human-made environments.



Figure 49: ChatGPT Response- Biomimicry: transport items, travel, forest, animals (Part 2)

Prompt 6: Biomimicry: [product]

<https://chat.openai.com/share/887951fd-e4d1-4cd7-8c57-436bb15913e2>

You
Biomimicry: travel backpack

ChatGPT

Biomimicry, the practice of emulating nature's designs and processes to solve human problems and challenges, has inspired numerous innovations in various fields, including product design. When it comes to creating a travel backpack with biomimetic features, you can draw inspiration from various aspects of nature. Here are some ideas:

1. **Spider Silk Strength:** Spider silk is known for its incredible strength-to-weight ratio. You can incorporate biomimetic materials inspired by spider silk into the backpack's construction to make it lightweight yet incredibly durable.
2. **Leaf-Inspired Ventilation:** Leaves have tiny pores called stomata that open and close to regulate moisture and airflow. Incorporate a ventilation system in the backpack that mimics this concept, allowing for improved airflow and moisture management to keep the user comfortable during travel.
3. **Gecko-inspired Attachment Mechanisms:** Geckos can cling to surfaces using tiny hair-like structures on their feet. Design innovative attachment mechanisms, such as straps or fasteners, inspired by gecko feet to secure items to the backpack or allow it to cling to surfaces.
4. **Bird Wing Folding Mechanism:** Many birds have intricate wing folding mechanisms that allow them to tuck their wings neatly when not in use. Apply similar principles to create a backpack with a compact, foldable design for easy storage and transportation.
5. **Whale Shark Filtering:** Whale sharks are filter feeders that use their gills to sieve plankton from the water. Develop a water filtration system within the backpack, inspired by this natural process, to help users purify water while traveling.
6. **Owl Silent Flight:** Owls are known for their silent flight, thanks to specialized wing structures that reduce turbulence. Incorporate noise-reducing materials or designs inspired by owl wings to make the backpack quieter when in motion.
7. **Cheetah Speed and Agility:** The cheetah is the fastest land animal, known for its speed and agility. Design the backpack with a streamlined and ergonomic shape inspired by the cheetah's body to enhance mobility and reduce drag during travel.
8. **Termite Mound Climate Control:** Termite mounds have a remarkable ability to maintain a consistent internal temperature. Develop a climate control system within the backpack, inspired by termite mound design, to keep perishable items at an optimal temperature.
9. **Camouflage and Color Adaptation:** Some animals, like chameleons, can change their skin color to blend into their surroundings. Create a backpack with color-changing or camouflage capabilities, allowing it to adapt to different environments and user preferences.
10. **Lotus Effect Water Repellency:** The lotus leaf has a unique surface structure that repels water and keeps it clean. Apply similar surface treatments to the backpack's fabric to make it water-repellent and easy to clean.

By integrating these biomimetic principles into the design and functionality of a travel backpack, you can create a product that not only serves its primary purpose effectively but also offers innovative features inspired by nature's wisdom.



Figure 50: ChatGPT Response- Biomimicry: travel backpack

Prompt 7: Biomimicry: design [product]

<https://chat.openai.com/share/f9530f97-393e-4d53-8ebd-4f79f94ae55d>

You
Biomimicry: design travel backpack

ChatGPT
Designing a travel backpack inspired by biomimicry involves drawing inspiration from nature's solutions to various challenges and applying those principles to create a functional and sustainable backpack. Here are some ideas and considerations for designing a biomimetic travel backpack:

1. Efficiency and Weight Distribution:
 - Inspired by the way birds distribute their weight for flight, design a backpack with an ergonomic shape that evenly distributes the weight of the contents across the wearer's body. This could reduce strain and discomfort during long travels.
2. Ventilation and Cooling:
 - Emulate the cooling mechanisms of animals like elephants or rabbits by incorporating natural airflow and cooling features. This could include breathable materials, strategically placed vents, or a design that minimizes contact with the wearer's back to reduce sweating.
3. Durability and Adaptability:
 - Look to the resilience of natural materials like tree bark or animal hides for inspiration. Incorporate durable and weather-resistant materials that can adapt to different climates and conditions.
4. Camouflage and Aesthetics:
 - Take cues from animals that use camouflage for protection. Design a backpack that can blend into different environments or adapt its appearance to suit the traveler's preferences.
5. Self-Repairing Features:
 - Draw inspiration from self-healing properties found in some organisms. Integrate materials or mechanisms that can self-repair minor damage to the backpack, extending its lifespan and reducing the need for replacements.
6. Lightweight and Strong Materials:
 - Learn from natural structures like spider silk or bird feathers, which are both lightweight and strong. Utilize advanced materials, such as lightweight composites or high-strength fibers, to create a backpack that's both durable and lightweight.

Figure 51: ChatGPT Response- Biomimicry: design travel backpack? (Part 1)

7. Smart and Adaptive Features:
 - Biomimicry can also extend to the design of smart features. Look to animal behaviors for inspiration in creating adaptive features like expandable storage, adjustable compartments, or even intelligent weight distribution systems.
8. Sustainable and Eco-friendly:
 - Incorporate sustainable materials and manufacturing processes inspired by nature's resource-efficient systems. Use recycled or biodegradable materials, and minimize waste in production.
9. Energy Harvesting:
 - Take inspiration from photosynthetic processes in plants or energy-efficient animals. Consider integrating energy-harvesting technologies, such as solar panels or kinetic energy generators, to power devices while on the go.
10. Bio-Inspired Fasteners and Closures:
 - Look at the natural world for innovative fastening and closure mechanisms, like the grip of gecko feet or the snapping motion of Venus flytrap leaves. These could inspire more efficient and reliable closures for your backpack.

Remember that biomimicry isn't about directly copying nature but rather understanding its principles and adapting them to human-made designs. When designing a biomimetic travel backpack, consider the functionality, sustainability, and aesthetics that align with the principles found in the natural world. Additionally, user comfort and practicality should always be at the forefront of your design process.



Figure 52: ChatGPT Response- Biomimicry: design travel backpack? (Part 2)

Prompt 8: How would nature design [product]?

<https://chat.openai.com/share/74d6c426-19b5-4fae-bb11-8152c43e998d>



You

How would nature design a travel backpack ?



ChatGPT

Nature is a master of efficiency, adaptability, and resilience. When designing things, nature always aims for solutions that meet the requirements of an organism's environment, survival, and reproduction. If nature were to design a travel backpack, it would likely draw inspiration from animals, plants, and other natural phenomena to create a pack that's adaptable, durable, ergonomic, and environmentally-friendly.

Here's a speculative description of how nature might design a travel backpack:

1. **Materials:**

- The bag would be made of sustainable and biodegradable materials, like natural fibers or even fungi-based leather alternatives.
- Waterproofing could be inspired by the water-repellent nature of lotus leaves or the way ducks' feathers repel water.
- It might incorporate a flexible, yet rigid frame, similar to exoskeletons in certain insects. This frame would distribute weight efficiently, reducing the strain on the wearer.

2. **Compartments:**

- Mimicking nature's compartmentalization, as seen in cells or even fruits like oranges, the backpack would have multiple pockets and sections tailored for different items.
- There might be a self-cleaning or antimicrobial section, inspired by the antimicrobial properties of certain plants or animals, designed for storing food or dirty clothes.

3. **Comfort and Ergonomics:**

- The design would distribute weight across the body in the most effective manner, possibly resembling the way certain animals distribute weight, like a camel's hump.
- Ventilation would be inspired by the breathing systems of insects or the way certain plants promote air circulation.
- The shoulder straps and back panel might take inspiration from padded paws, hooves, or other natural cushioning systems.

Figure 53: ChatGPT Response- How would nature design a travel backpack? (Part 1)

4. Adaptability:

- Just as animals adapt to different environments, the backpack would be modular, allowing users to add or remove sections as needed.
- Inspired by camouflage patterns in nature, it could change color or pattern based on the environment or user preference.

5. Durability:

- The backpack would be designed for longevity, borrowing ideas from the tough skins, shells, and exoskeletons found in nature.
- Self-healing materials, inspired by the regenerative abilities of some animals and plants, could be incorporated to mend minor damages.

6. Safety and Security:

- Reflecting patterns, similar to those seen on nocturnal or deep-sea creatures, could be incorporated to make the backpack visible in low light.
- The backpack could also have natural deterrents, like materials with structures or scents that repel insects or unwanted creatures.

7. Environmental Impact:

- As nature always aims for balance, the backpack would be designed to have minimal environmental impact, both in its production and its end of life. It would be fully recyclable or compostable.
- It might also incorporate plant seeds or other natural elements that benefit the environment when the backpack decomposes.

While this is a speculative and imaginative approach, it's worth noting that many modern innovations are already inspired by biomimicry, which is the design and production of materials, structures, and systems modeled on biological entities and processes. So, nature's principles can indeed guide us in creating more sustainable and efficient products.



Figure 54: ChatGPT Response- How would nature design a travel backpack? (Part 2)

Prompt 9: How would a biomimetic designer design [product]?

<https://chat.openai.com/share/87350b28-2ee7-4bfd-b9e2-f6a5a8b256af>

G You

How would a biomimetic designer design a travel backpack ?

ChatGPT

A biomimetic designer, inspired by nature and its solutions to problems, would approach the design of a travel backpack by studying the natural world and drawing parallels. Here's a step-by-step process on how a biomimetic designer might design a travel backpack:

1. Research and Inspiration:

- **Study Animal Carrying Systems:** Look at how animals carry things. For example, kangaroos have pouches that safely store their joeys. Some ants can carry items many times their own body weight. What features or structures make these carrying mechanisms effective and efficient?
- **Explore Natural Protection Mechanisms:** How do creatures protect themselves or their carried items from the elements? For instance, how does a turtle's shell keep it safe, or how do cacti store water without it evaporating?

2. Initial Design Ideas:

- **Adaptive Capacity:** Just as animals adjust their storage and protection based on need (like a pelican's pouch or a chipmunk's cheeks), the backpack might have adjustable compartments or expandable sections.
- **Natural Materials:** Use materials that are sustainable, possibly drawing inspiration from strong spider silk, tough beetle shells, or water-resistant lotus leaves.
- **Ergonomics Inspired by Nature:** Mimic the ways animals distribute weight or how they maintain balance with loads. The backpack's straps and back panel might emulate structures in animals that are built to carry weight efficiently.

3. Functional Features:

- **Waterproofing:** Inspired by the water-shedding properties of lotus leaves or duck feathers, the backpack material or coating might repel water in a similar manner.
- **Temperature Regulation:** Mimicking the insulating properties of animal fur or feathers, certain compartments of the backpack could help maintain temperature, keeping items cool or warm as needed.

Figure 55: ChatGPT Response- How would biomimetic designer design a travel backpack? (Part 1)

- **Anti-Theft:** Drawing from animals that have evolved camouflage or deceptive appearances to deter predators, the backpack could have hidden compartments or designs that deter theft.
- **Weight Distribution:** Emulating the biomechanics of animals that carry heavy loads can guide the design of straps and the backpack's overall shape, ensuring even weight distribution and reduced strain on the user's back.

4. **Aesthetics:**

- **Texture and Pattern:** Integrate natural patterns, such as the hexagonal structures of honeycombs or the fractal patterns seen in ferns, for both visual appeal and potential functional benefits.
- **Colors:** Use colors inspired by nature, which can be both aesthetically pleasing and functional (e.g., reflective colors for safety or camouflaging colors for discretion).

5. **Testing and Iteration:**

- Like evolution in nature, a biomimetic design would require testing and iteration. Gather feedback, observe how the backpack performs in real-world scenarios, and continuously refine the design to optimize its function and sustainability.

6. **Sustainability:**

- Embrace a closed-loop system similar to nature, where waste is minimal, and materials can be recycled or composted.
- Consider the backpack's full lifecycle, ensuring that at the end of its life, it doesn't harm the environment.

By incorporating these principles, the biomimetic designer would not only create a functional and aesthetic backpack but also one that's in harmony with nature and sustainable for the long term.



Figure 56: ChatGPT Response- How would biomimetic designer design a travel backpack? (Part 2)

After submitting each prompt, I interacted with ChatGPT's response(s). There are four different actions the designer can take: regenerate the response, continue the chat, ask a new question, or synthesize findings from conversation(s) with ChatGPT. For the sake of length, I will demonstrate each prompt using my biologized factors and show each of these actions once, *not* for every prompt. I decided to use the prompt: "How would nature design a travel backpack?" to demonstrate these actions because it breaks the product down into different

components while identifying biological strategies that could be applied. These demonstrations utilize GPT 4 because the question was initially asked in GPT-4 prior to the integration of DALL-E. The link listed above contains the following screenshots except for the regenerated response. Note: I was not able to create a new link for this without destroying the first one.

Regenerate response:

 **You**

How would nature design a travel backpack ?

 **ChatGPT**

If nature were to design a travel backpack, it would likely follow principles of biomimicry, where human engineering mimics the solutions found in nature. Here's how nature might approach the design:

1. **Material Selection:**

- **Durability and Adaptability:** The backpack might be made of materials similar to spider silk, which is known for its incredible strength and flexibility. Alternatively, it could mimic the waterproof and resilient properties of lotus leaves or the tough, yet lightweight, structure of bird feathers.
- **Sustainability:** Materials would be biodegradable or easily recyclable to minimize environmental impact, much like how plants and animals biodegrade and contribute to the ecosystem after their life cycle ends.

2. **Structure:**

- **Ergonomic Design:** The design would be inspired by the way animals are built to carry loads efficiently, such as the shell structure of a tortoise for protection and load distribution or the muscular structure of apes for mobility and strength.
- **Expandability:** Mimicking the way some animals can expand their bodies (like pufferfish or certain fruits that can open to release seeds), the backpack could have an expandable structure to increase storage space when needed.

3. **Compartmentalization:**

- **Organic Compartments:** Just as plants use cells and animals use organs to compartmentalize functions, the backpack would have specialized compartments for different items, possibly using adjustable or removable partitions for customization.
- **Accessibility:** The backpack would take inspiration from how animals like kangaroos use pouches for easy access, ensuring that the most frequently needed items are the easiest to reach.

Figure 57: Regenerate response (Part 1)

4. **Security:**

- **Camouflage and Protection:** The backpack might feature materials and patterns that blend with a variety of environments, similar to the camouflage of a chameleon or octopus. It could also have tough, protective areas inspired by armadillo armor or the hard shells of nuts to protect valuables.
- **Anti-theft:** Mimicking defensive mechanisms found in nature, such as the sharp spines of a porcupine or the sting of a bee, the backpack could incorporate deterrents for thieves.

5. **Comfort:**

- **Weight Distribution:** The straps and back panel would distribute weight as seen in the anatomy of pack animals, ensuring comfort and reducing strain.
- **Breathability:** Inspired by the skin of animals or the surface of leaves, the backpack would have excellent ventilation to prevent sweat and increase comfort.

6. **Adaptability:**

- **All-Weather Resistance:** The backpack would be designed to adapt to various climates, much like how animals have different fur or feathers for different seasons. It could feature a layered approach or adjustable insulation.

7. **Sensory Integration:**

- **Feedback Systems:** Taking cues from the way animals have sensory organs to respond to their environment, the backpack might include features that change color or emit a signal based on specific conditions, like a change in temperature or an attempted theft.

8. **Maintenance:**

- **Self-Healing:** Inspired by the self-healing capabilities of certain animals and plants, the backpack could feature materials that mend themselves when punctured or torn.

9. **Aesthetics:**

- **Natural Aesthetics:** The design would likely be pleasing to the eye, with patterns and shapes that are commonly found appealing in nature, such as the Fibonacci sequence seen in shells and flowers, or fractal patterns seen in snowflakes and leaves.

By integrating these natural design elements, a nature-designed travel backpack would not only be functional and sustainable but also harmonious with the environment, adapting to the needs of the traveler much like animals and plants adapt to their surroundings.

Figure 58: Regenerate response (Part 2)

Respond to ChatGPT's response:

6 You

Can you elaborate on nature's compartmentalization in relation to a travel backpack's organization system?

ChatGPT

Certainly! Nature's approach to compartmentalization can offer intriguing insights into optimizing the organization system of a travel backpack. In nature, compartmentalization serves various purposes, from protecting vital organs to efficiently storing resources. This concept can be translated into the design of a backpack to enhance functionality, accessibility, and protection of contents.

1. **Cellular Structure Inspiration:**

- Just as cells in living organisms have specialized compartments for different functions, a backpack could feature various pockets and compartments designed for specific items. For instance, a padded compartment for electronics, a waterproof pocket for liquids, and a breathable section for clothes.

2. **Modularity and Flexibility:**

- In nature, certain organisms can adapt their structure based on needs (like how some plants grow towards light). Similarly, a backpack could have adjustable compartments that expand or compress depending on the contents. Modular pouches or sections could be added or removed as needed, much like how some organisms add or shed layers.

3. **Protective Structures:**

- Many natural compartments, like nutshells or eggshells, are designed to protect delicate contents. This principle could be applied to a backpack by using hard-shell compartments for fragile items like sunglasses or cameras.

4. **Efficient Packing and Accessibility:**

- Nature often uses spiral or layered structures for efficient packing (like the Fibonacci sequence seen in sunflowers or pinecones). A backpack might feature a spiral zipper system or layered pockets that maximize space and allow easy access to items at different levels.

5. **Integrated Support System:**

- In nature, support structures are often built into the design, like the way a tree's trunk supports its branches. A backpack could integrate its support structure (like the frame) into the overall design, using it to define and separate compartments while providing strength and stability.

6. **Adaptive Barriers:**

- Some natural compartments can change in response to external stimuli (like cells that can change permeability). Similarly, parts of the backpack could be designed to respond to external factors, like compartments that expand in response to increased contents or external compression straps that adjust to maintain a compact form.

7. **Eco-Friendly and Sustainable:**

- Reflecting nature's cycle of growth and decay, the materials used in the backpack would be sustainable, biodegradable, or recyclable. Compartments might be lined or constructed with natural fibers that are durable yet environmentally friendly.

By integrating these principles of natural compartmentalization, a travel backpack could become more than just a storage solution—it could be an adaptable, efficient, and protective system that caters to the diverse and dynamic needs of travelers, much like how nature designs for the varied and changing needs of organisms.



Figure 59: Continue the chat

Ask a new question:



You

What are some organisms that can adapt their structure based on needs?



ChatGPT

Several organisms in nature exhibit remarkable abilities to adapt their structures based on environmental needs or challenges. This adaptability is often a key factor in their survival and efficiency. Here are a few examples:

1. **Octopuses and Other Cephalopods:** Octopuses, along with their cephalopod cousins like squids and cuttlefish, are famous for their ability to change their skin color and texture. They do this not only for camouflage but also for communication and temperature regulation. Their skin contains specialized cells called chromatophores that expand and contract to change color, and papillae that can change the texture of their skin.
2. **Plants (Tropism):** Many plants exhibit tropism, which is a growth response towards or away from stimuli. For example, phototropism is a plant's ability to grow towards light, while gravitropism (or geotropism) refers to a plant's growth in response to gravity. Roots often exhibit positive gravitropism (growing downwards) while stems show negative gravitropism (growing upwards).
3. **Mimosa Pudica (Sensitive Plant):** This plant is known for its rapid leaf folding in response to touch, a defense mechanism to deter predators or conserve water. The leaves reopen after a few minutes, showing an example of reversible structural adaptation.
4. **Pufferfish:** When threatened, pufferfish can inflate their bodies by rapidly ingesting water or air. This adaptation makes them appear larger and less palatable to predators. Their spines, which are normally not very visible, become more pronounced when they are inflated.
5. **Chameleons:** Chameleons are renowned for their ability to change color for camouflage, temperature regulation, and communication. This change is facilitated by specialized cells in their skin called chromatophores, similar to those in octopuses.
6. **Arctic Fox:** The Arctic fox provides an example of seasonal structural adaptation. It changes the color of its fur from white in winter to brown or gray in summer for better camouflage against the changing landscapes.
7. **Venus Flytrap:** This carnivorous plant has leaves that adaptively snap shut when tiny hairs on their inner surfaces are triggered, usually by an insect. This is a structural adaptation for feeding, unusual among plants.
8. **Slime Molds:** These unique organisms can alter their structure and behavior in response to their environment. When food is abundant, they live as individual cells, but when food is scarce, they can aggregate to form a larger, multicellular organism.

These examples show the incredible variety and ingenuity of structural adaptations in the natural world, many of which have inspired technological innovations and designs in various fields.



Figure 60: Ask a new question

Synthesize findings from conversations with ChatGPT:

After I completed my conversations with ChatGPT, which are not all pictured for the sake of brevity, I began to synthesize all of ChatGPT's responses and identify what to research further. To synthesize my conversations with ChatGPT, I read through all my responses and jotted down repeated words and phrases that I thought deserved a closer look into:

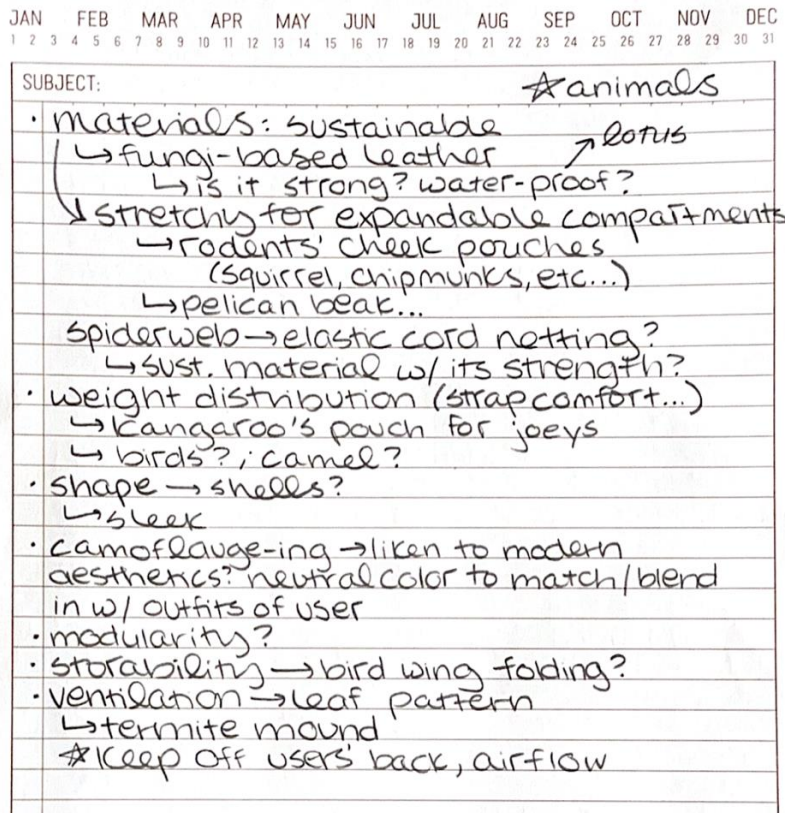


Figure 61: Notes of Synthesized Findings from ChatGPT

Once I had my biological strategies identified, I conducted further research using traditional research methods and verified any information from ChatGPT that I deemed necessary. I did not document this part of the process because the use of ChatGPT to aid the discovery and application of biomimetic solutions is the focus, not traditional research methodology.

4.4 Define

The next step in the approach is defining the design criteria. After researching the biological strategies I found using ChatGPT, I finalized which strategies I wanted to use in my travel backpack design. I identified where and how I plan to use them in the design, and also established *why* I selected the chosen strategies to use. After defining my biomimetic criteria, I combined them with the original product constraints from the design brief. To help with this step, I used ChatGPT to help me write a design brief using my new set of criteria. While helpful, this step is not required. In this phase of the process the designer can also prompt ChatGPT to help establish strategies to use to evaluate future concepts. However, I did not demonstrate this step as I will evaluate my concept later in this chapter using the Biomimetic Industrial Design Principles checklist I developed in Chapter 3.

Finalized Biological Strategies:

- Chipmunk cheek pouches
 - *Where:* side pockets
 - *How:* panels of tight weave recycled polyester mesh to allow for stretch
 - *Why:* allows pockets to fit a variety of bottle sizes



Figure 62: Chipmunk cheek pouches, (Sobus, 2022)

- Termite mound ventilation
 - *Where*: padded back panel
 - *How*: mimic termite mound's shape and vent pathways using 3D spacer mesh padding made from recycled polyester to mimic the mound's porous dirt walls
 - *Why*: to increase airflow on user's back in hot conditions, provide back support, increase user comfort

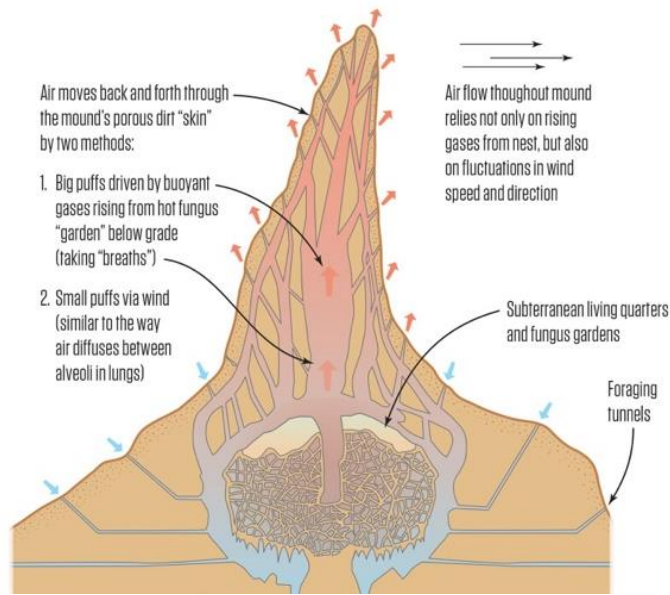


Figure 63: Termite mound ventilation (Healy, 2020)

- Kangaroo pouch
 - *Where*: side pockets and main pocket
 - *How*: mimics kangaroo's muscle anatomy of pouch opening using adjustable bungee drawstring
 - *Why*: adjustable, secures belongings of varying sizes

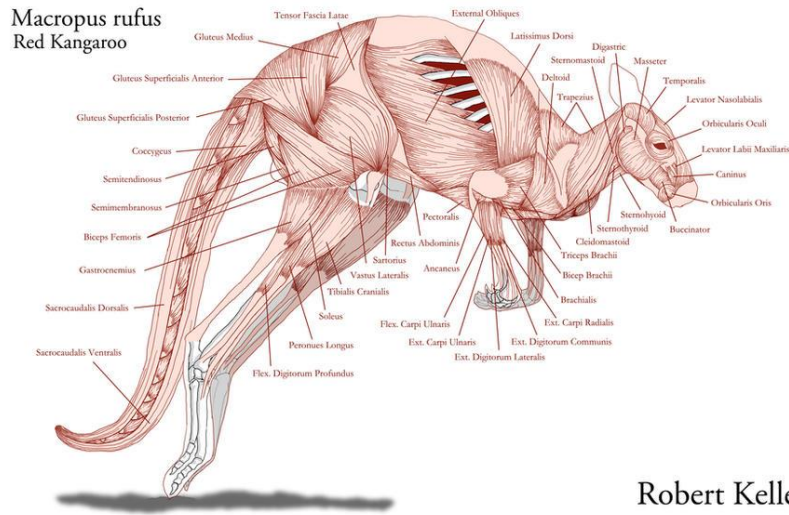


Figure 64: Kangaroo muscle anatomy (Kelley, 2011)

Original Constraints:

- Size: 18 x 14 x 8 inches
- Gender-neutral
- Modern aesthetics
- Age 18-30

New Design Brief:

After integrating my new biomimetic criteria with the initial product limitations outlined in the design brief, I employed ChatGPT to assist me in formulating a design brief based on my updated criteria. This new design brief from ChatGPT is pictured on the following page.



ChatGPT

Design Brief: Biomimicry-Inspired Travel Backpack

Project Overview:


We are seeking an industrial designer to create a travel backpack that seamlessly integrates biomimicry-inspired elements for enhanced functionality, comfort, and aesthetics. The goal is to develop a versatile, gender-neutral backpack tailored to the needs and preferences of users aged 18-30. The key biomimicry inspirations include chipmunk cheek pouches, kangaroo muscle anatomy, and termite mound ventilation.

Project Constraints:

1. Chipmunk Cheek Pouch-Inspired Mesh Panels:

- Incorporate mesh panels on the side pockets of the backpack, mimicking the efficiency and expandability of chipmunk cheek pouches.
- Ensure the mesh panels are durable, breathable, and capable of stretching to accommodate various items securely.

2. Kangaroo Muscle Anatomy-Inspired Pockets:

- Design side pockets and the main pocket to mimic the muscle anatomy of a kangaroo's pouch opening.
- Implement an adjustable bungee drawstr  mechanism for easy and secure access to the pockets.
- The drawstrings should be intuitive to use and sturdy, allowing users to customize the opening size.

3. Termite Mound-Inspired Ventilated Back Panel:

- Create a ventilated padded back panel that mimics the shape of a termite mound.
- Integrate vent pathways using mesh padding to replicate the porous dirt walls of the mound, allowing for efficient airflow.
- Ensure that the ventilation system enhances comfort and minimizes back sweating during extended use.

4. Dimensions and Size:

- The backpack dimensions should be 18 × 14 × 8 inches (H x W x D), providing sufficient capacity for travel essentials while remaining compact and portable.

5. Gender-Neutral Design:

- Develop a design that appeals to users of all genders, focusing on modern aesthetics and minimalistic details.

6. Target User Age:

- The backpack's design should cater to the needs, preferences, and style preferences of users aged 18-30, with a contemporary and versatile look.

Fig 65: New Design Brief

4.5 Design

This section of the approach will not demonstrate the entire design process presented in Chapter 3. Given the emphasis of the approach is incorporating biomimicry in the research phase, I decided to keep the demonstration of the design stage in sketching. The hero shot sketch of my final concept is below and supplemental views are on the following page.

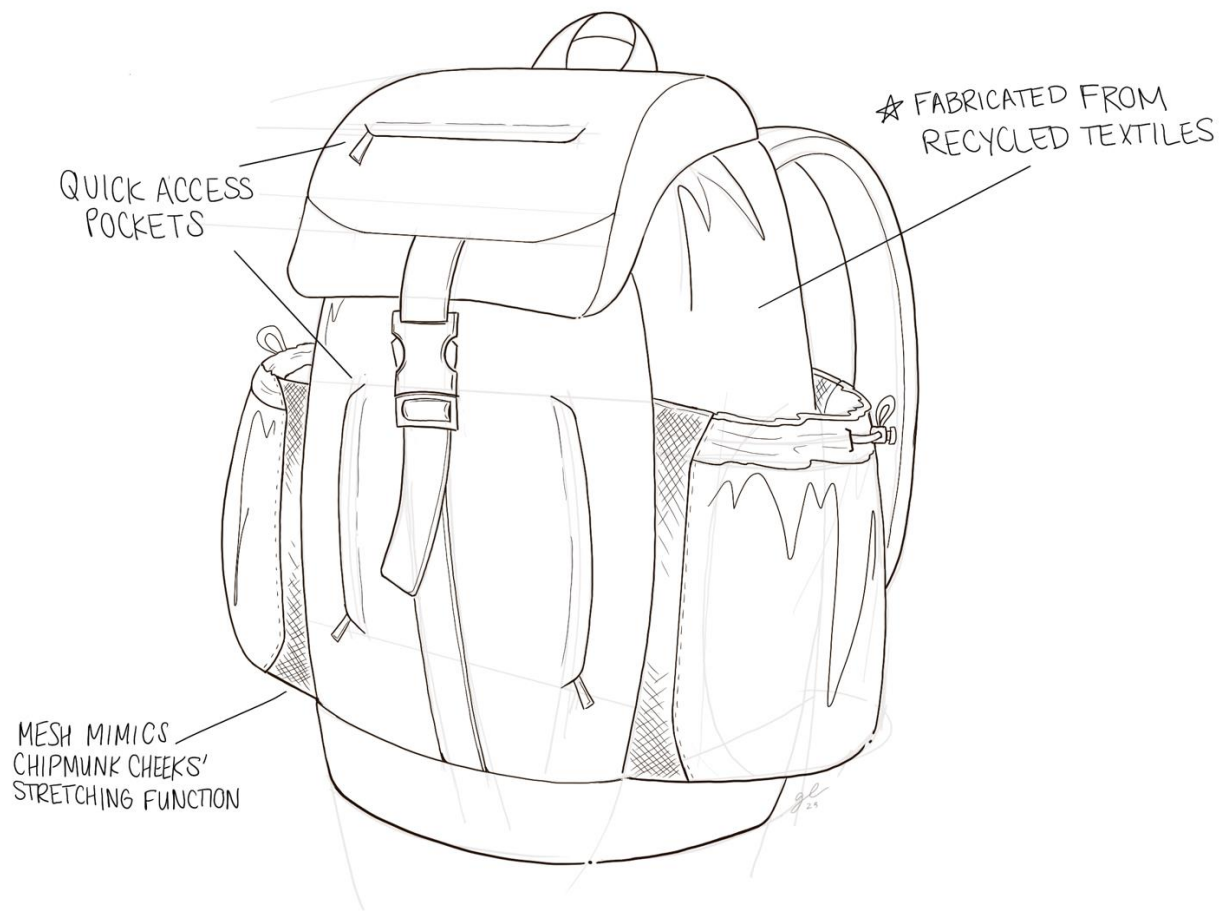


Figure 66: Final Concept Sketch, Hero Shot

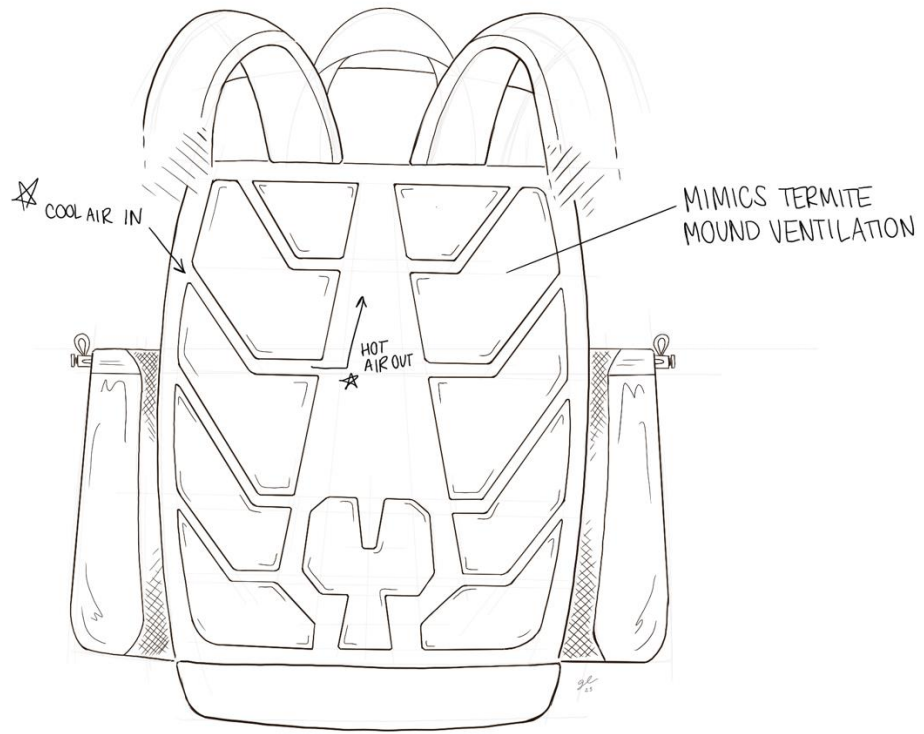


Figure 67: Final Concept Sketches, Back and Detail Shot

4.6 Evaluate

After finalizing my travel backpack design, I evaluated it by using the Biomimetic Industrial Design Principles checklist developed in Chapter 3. This process allowed me to identify areas where my design was not meeting these principles. Identifying any gaps in my design provided me with concrete areas to focus on during the refining phase. As discussed in Chapter 3, having one checked box is always better than having none. Therefore, the intention of this checklist is to not check off every box, but rather help guide designers through evaluating their design and help identify areas of improvement in order to make their design more biomimetic. My filled out checklist is on the following pages, along with explanations.

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature's form follows function	<input checked="" type="checkbox"/> Function defines form	<input checked="" type="checkbox"/> Design to mimic biological systems <input type="checkbox"/> Use living organisms in product system <input checked="" type="checkbox"/> Rethink how to provide the benefit <input type="checkbox"/> Design flexibility for technological change
Nature uses energy and materials efficiently.	<input checked="" type="checkbox"/> Up-cycles materials	<input checked="" type="checkbox"/> Use recycled or reclaimed materials
	<input checked="" type="checkbox"/> Utilizes abundant resources and incorporates rare resources sparingly	<input checked="" type="checkbox"/> Avoid materials that deplete natural resources <input type="checkbox"/> Design to encourage low-consumption behavior
	<input checked="" type="checkbox"/> Optimizes energy use	<input type="checkbox"/> Reduce energy during use <input type="checkbox"/> Minimize energy use in production <input checked="" type="checkbox"/> Minimize number of production steps
	<input checked="" type="checkbox"/> Optimizes material use	<input type="checkbox"/> Reduce material consumption during use <input checked="" type="checkbox"/> Minimize manufacturing waste <input checked="" type="checkbox"/> Minimize quantity of materials
	<input type="checkbox"/> Relies on freely available energy	<input type="checkbox"/> Use renewable resources <input type="checkbox"/> Use carbon-neutral or renewable energy sources
Evolution defines nature.	<input checked="" type="checkbox"/> Adapts to changing conditions	<input checked="" type="checkbox"/> Design for durability <input type="checkbox"/> Foster emotional connection to product <input checked="" type="checkbox"/> Create timeless aesthetic appeal
	<input type="checkbox"/> Evolves to survive	<input type="checkbox"/> Design for maintenance and easy repair <input type="checkbox"/> Design for reuse and exchange of products <input type="checkbox"/> Design for a second life with different function
	<input checked="" type="checkbox"/> Integrate development with growth	<input type="checkbox"/> Design upgradable products <input type="checkbox"/> Design for reuse of components

Figure 68: Completed Biomimetic Industrial Design Principles Checklist (Page 1)

PRINCIPLE	NATURE'S STRATEGIES	SUSTAINABLE DESIGN STRATEGIES
Nature is locally attuned and responsive.	<input type="checkbox"/> Hyper-aware of their environments and respond quickly to threats and changes	<input type="checkbox"/> Reduce product and packaging weight <input type="checkbox"/> Reduce product and packaging volume <input type="checkbox"/> Develop reusable packaging systems <input type="checkbox"/> Use lowest-impact transport system <input type="checkbox"/> Source or use local materials and production
Nature uses life-friendly chemistry.	<input checked="" type="checkbox"/> Uses chemicals and materials that are safe for living beings (unless otherwise intended)	<input checked="" type="checkbox"/> Avoid materials that damage human or ecological health <input type="checkbox"/> Avoid materials that deplete natural resources <input checked="" type="checkbox"/> Use recycled or reclaimed materials <input type="checkbox"/> Use renewable resources <input type="checkbox"/> Use materials from reliable certifiers <input type="checkbox"/> Use waste byproducts <input type="checkbox"/> Seek to eliminate toxic emissions
Nature provides mutual benefits.	<input type="checkbox"/> Has mutual advantages and dependencies among its various elements and organisms; interconnected relationships within ecosystems	<input type="checkbox"/> Design for fast manual or automated disassembly <input type="checkbox"/> Design recycling business model <input type="checkbox"/> Use recyclable non-toxic materials <input type="checkbox"/> Provide ability to biodegrade <input type="checkbox"/> Integrate methods for used product collection <input type="checkbox"/> Design for safe disposal

Figure 69: Completed Biomimetic Industrial Design Principles Checklist (Part 2)

1. *Nature's form follows function.*

- a. This principle applies as I successfully incorporated the defined biological strategies in my design, making the form of my bag to be dictated by the functions of each biological strategy I chose.

2. *Nature uses energy and materials efficiently.*

- a. "Up-cycles materials" applies because the bag is made out of recycled polyester
- b. "Utilizes abundant resources and incorporates rare resources sparingly" applies as the design uses recycled textiles and includes minimal virgin materials, such as zippers or other hardware.
- c. "Optimizes energy use" applies because if I were to create a paper pattern for this backpack, the majority of cuts will be straight, allowing pieces to be nested together, therefore minimizing number of production steps
- d. "Optimizes material use" applies because by nesting pattern pieces together, it maximizes fabric use and minimizes waste.
- e. "Relies on freely available energy" **does not apply** because if this design were to be manufactured, the factory it will be produced in would most likely not rely on freely available energy, such as solar power. Therefore, I will not revisit this in the refine phase.

3. *Evolution defines nature.*

- a. "Adapts to changing conditions" applies because the backpack's back padding mimics a termite mound's ventilation system and increases airflow on the user's back in hot conditions. In addition, the overall design of the backpack follows a more traditional shape and the material the bag made of is durable.

- b. “Evolves to survive” **does not apply** because I did not consider this during the design phase, so I will consult the sustainable design strategies in the refine phase.
 - c. “Integrate development with growth” applies because the biomimetic components increase the backpack’s usability and functionality.
4. *Nature is locally attuned and responsive.*
- a. This principle **does not apply** because I did not consider it during the design phase, so I will consult the sustainable design strategies in the refine phase.
5. *Nature uses life friendly chemistry.*
- a. This principle applies because it uses recycled polyester textiles which are better for the environment than virgin polyester or other unsustainable fabrics.
6. *Nature provides mutual benefits.*
- a. This principle **does not apply** because I did not consider the product’s end-of-life during the design phase, so I will consult the corresponding strategy category in the refine phase.

4.7 Refine

After evaluating my design, the principles I established that I needed to revisit are “evolves to survive (evolution defines nature), nature is locally attuned and responsive, and nature provides mutual benefit.”

Evolves to survive. (Evolution defines nature)

Evolution defines nature.	<input checked="" type="checkbox"/> Adapts to changing conditions	<input checked="" type="checkbox"/> Design for durability
		<input type="checkbox"/> Foster emotional connection to product
		<input checked="" type="checkbox"/> Create timeless aesthetic appeal
	<input type="checkbox"/> Evolves to survive	<input type="checkbox"/> Design for maintenance and easy repair
		<input type="checkbox"/> Design for reuse and exchange of products
		<input type="checkbox"/> Design for a second life with different function
	<input checked="" type="checkbox"/> Integrate development with growth	<input type="checkbox"/> Transitional Systems
		<input type="checkbox"/> Design upgradable products
		<input type="checkbox"/> Design for reuse of components

Figure 70: “Evolution defines nature” Checklist Section

After identifying this as an area I need to address in my design, I consulted the corresponding sustainable design strategies. I decided to apply the strategy “Design for maintenance and easy repair” to better address the principle’s “evolution” aspect. If this bag were to be manufactured and sold, the company would offer free bag repairs to customers in order to prolong the backpack’s use.

Nature is locally attuned and responsive.

Nature is locally attuned and responsive.	<input type="checkbox"/> Hyper-aware of their environments and respond quickly to threats and changes	<input type="checkbox"/> Reduce product and packaging weight
		<input type="checkbox"/> Reduce product and packaging volume
		<input type="checkbox"/> Develop reusable packaging systems
		<input type="checkbox"/> Use lowest-impact transport system
		<input type="checkbox"/> Source or use local materials and production

Figure 71: “Nature is locally attuned and responsive” Checklist Section

After identifying this as a principle I needed to address in my design, I referred to its corresponding sustainable design strategies. After reviewing the chart, I decided to apply “source or use local materials and production” to my design. I chose to include this because fabricating and repairing the backpack locally in the US could help stimulate the economy, support local communities, and reduce the negative impacts of shipping overseas.

Nature provides mutual benefits

Nature provides mutual benefits.	<input type="checkbox"/> Has mutual advantages and dependencies among its various elements and organisms; interconnected relationships within ecosystems	<input type="checkbox"/> Design for fast manual or automated disassembly
		<input type="checkbox"/> Design recycling business model
		<input type="checkbox"/> Use recyclable non-toxic materials
		<input type="checkbox"/> Provide ability to biodegrade
		<input type="checkbox"/> Integrate methods for used product collection
		<input type="checkbox"/> Design for safe disposal

Figure 72: “Nature provides mutual benefits” Checklist Section

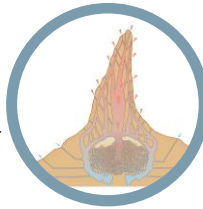
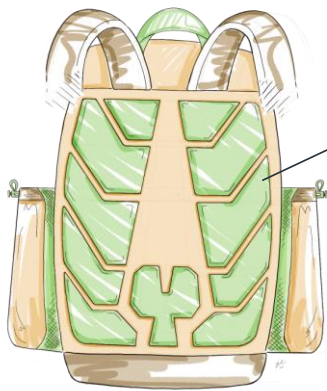
After I identified this as a principle I need to address in my design, I consulted the corresponding sustainable strategies. The underlying goal of this principle is that the designed product will benefit both the user and nature, or at the very least have a reduced negative ecological impact. In order to address this, I decided to include “design a recycling business model.” The company that produces this backpack will have a take-back program for their bags and will recycle the backpack’s textiles into small soft-goods to complement the backpack.

4.8 Final Design

The poster pictured on the following page (Figure 73) highlights the biological strategies included in the final design of the biomimetic travel backpack. This design incorporates biological strategies from chipmunk cheek pouches, termite mound ventilation, and the muscular structure of the opening of a kangaroo’s pouch. The design meets the original brief criteria and was refined to better meet the Biomimetic Industrial Design Principles.

Biomimetic TRAVEL BACKPACK

Drawstring pocket openings mimic a kangaroo pouch's muscular structure in order accommodate the user's belongings of varying sizes



Padded back paneling mimics a termite mound's ventilation capabilities to increase airflow on the user's back in hot conditions and increase comfort

Panels of tight weave mesh on side pockets mimic the function of chipmunk cheeks to fit water bottles or other items of varying sizes



DESIGN PROJECT DEMONSTRATING An Approach to Incorporate Generative Artificial Intelligence as a Means to Include Biomimicry within Industrial Design by Gabby Lascari (2023)

Figure 73: Final Design Poster

Chapter 5

Conclusion

The goal of this thesis was to develop a systematic approach to integrate biomimicry into industrial design by incorporating the use of generative artificial intelligence. This thesis was developed because biomimicry has the potential to make industrial design more sustainable and innovative, but had yet to be fully realized within industrial design. Based on the literature, the current challenge to using biomimicry was identified to be in the research phase. Industrial designers traditionally begin with a design brief, move onto the research phase, and then ideate and test design solutions from there. On the other hand, in numerous biomimetic design solutions, the inspiration comes before identifying the design criteria or is happened upon by chance, implying the possible challenge of looking to nature for solutions post-design brief. By combining aspects of existing biomimetic methods, industrial design methodology, and generative artificial intelligence software, I developed a new, streamlined approach to biomimetic design that incorporates the use of ChatGPT to strategically include biomimicry in industrial design.

The developed approach hones in on the research phase of the design process, as that is largely where the challenge for industrial the designer using biomimicry lies. This thesis does not aim to change an industrial designer's process, but rather integrate the use of biomimicry in the current design processes. Therefore, the approach emphasizes the use of generative artificial intelligence technology in the research phase. This thesis focused solely on the use of ChatGPT, specifically its text-to-text generation capabilities, because it is widely considered a frontrunner in the field of generative artificial intelligence. If someone were to advance this study further, they could consider examining other forms of generative artificial intelligence and how it could

be incorporated to support the use of biomimicry throughout the entire design process, not just aiding the discovery of biological strategies. However, by concentrating the use of ChatGPT in the research phase, it promises the potential to connect its dataset of nature's biological strategies to industrial designers, allowing them to incorporate biomimicry post-design brief.

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