Design of a visually enhanced searchable database for exploration and application of biomimicry in interior design

Meredith Chambers
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/etd
Part of the Art and Design Commons

Recommended Citation
Chambers, Meredith, "Design of a visually enhanced searchable database for exploration and application of biomimicry in interior design" (2011). Graduate Theses and Dissertations. 11958.
https://lib.dr.iastate.edu/etd/11958

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Graduate Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
Design of a visually enhanced searchable database for exploration and application of biomimicry in interior design

by

Meredith Anne Chambers

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF ART

Major: Art and Design (Interior Design)

Program of Study Committee:
Frederic Malven, Major Professor
Jihyun Song
Bruce Bassler

Iowa State University
Ames, Iowa
2011

Copyright © Meredith Anne Chambers, 2011. All rights reserved.
Table of Contents

Chapter 1: Introduction .......................................................................................................................... 1
  History of Biomimicry ........................................................................................................................ 1
  Current Trends in Biomimicry ........................................................................................................... 2
  Scholarship and Biomimetics .......................................................................................................... 3
  Mass Production and Biomimetics ................................................................................................. 5
  Green Design and Biomimicry ........................................................................................................... 7
  Importance of Biomimicry to Interior Design and the Built Environment ................................. 15

Chapter 2: Review of Literature ........................................................................................................... 19
  Processes and Approaches to Biomimetic Design ......................................................................... 20
    Approaches to Design Challenges .............................................................................................. 20
    Problem Driven vs. Solution Driven Design ............................................................................... 23
    General Trends in Biomimetic Application and Solution Generation ........................................ 30
  Comparative Analysis of Biomimetic and Interior Design Methodology ...................................... 31
  Identification and Application of Biological Sources of Inspiration ............................................. 34
  Methods of Biological Transfer ....................................................................................................... 36
    Analogical Transfer and Biologically Inspired Design ............................................................. 39
  Common Errors in Applying Biomimicry ......................................................................................... 44
  Guidelines for Successful Application of Biomimicry ................................................................. 46
  Overview of Strategies in Nature ..................................................................................................... 46
  Information Seeking Methods, Behavior and Procedures ............................................................. 55
    Software Options and General Tool Design ............................................................................... 56
    Spreadsheet and Software Capabilities ...................................................................................... 57
    Search Strategies ......................................................................................................................... 58
    The Current Biomimetic Database, Search Engines and Other Resources .............................. 59

Chapter 3: Methods and Procedures ................................................................................................. 68
Chapter 1: Introduction

As noted in many ecological and design focused texts in nature, the concept of waste does not exist – there are no landfills, no superfluous parts, and no hazardous materials to dispose of. Instead, by-products serve not as something to dispose of but rather as ingredients in other processes and systems. Everything – from bacteria to biomes – plays an integral role in something beyond itself. By looking to nature and natural processes for inspiration through a design approach called biomimicry, designers can create products, processes and spaces that seamlessly and harmoniously integrate themselves within the larger environment. While there are two main approaches to biomimetic design, the basic process involves the identification and application of natural strategies, methods or principles to solve functional design challenges. Biomimetic design can be applied to virtually any design challenge on virtually any scale - from nano, such as self-cleaning surfaces, to macro, such as the spatial layout of a city.

History of Biomimicry

While the term “biomimicry” (Gust & Moore, 1985, p. 173) was coined fairly recently, the concept of gaining inspiration from nature is anything but new. Almost 500 years ago, Leonardo Da Vinci (1505) studied birds in flight to try to create a machine that would allow man to soar among the clouds, a study that would be undertaken again hundreds of years later, by the Wright brothers (Johnson-Laird, 2005) and, even more recently, by a group of Canadian engineers who successfully flew a human powered ornithopter (The University of Toronto Human Powered Ornithopter Team, 2010). Biological design is not restricted to just large scale projects however; a little over 50 years ago a dog’s romp through some burrs led

---

1 (McDonough & Braungart, 1998), (McDonough & Braungart, 2002), (Hawken, Lovins, & Lovins, 1999), (Benyus, 1998), (Korhonen, 2001)
George de Mestral to invent the precursor to Velcro, which is used in numerous everyday objects. Plants served as a source of inspiration as well for Joseph Paxton, the architect of the Crystal Palace, who was inspired by the support structure of the giant lotus. Although these high profile applications of biomimicry within design may suggest a high level of overall adoption, throughout the course of history, the degree of popularity and application of biomimetic design has waxed and waned.

The late 1800’s and early 1900’s was one such period of increased interest in biology and biologically inspired design, fueled in part by a nationwide movement toward preservation of natural areas and resources. It was during this time that national parks were first established in the United States and general interest in nature and outdoor activities was high. Although this interest in nature did not focus solely on biomimetic design, the range of developments that grew from it, such as Henry Ford’s explorations into soy plastic, would inspire biologically related industries which are currently on the cutting edge of design today (Finlay, 2003). These include biobased material development, many facets of green and sustainable design and, of course, biomimetics. Inevitably, this fascination with nature that marked the turn of the 20th century, fell into decline due to a myriad of social, political and economic factors, however, the seeds of inspiration it planted are now blossoming through the advancements made at the turn of the 21st century.

**Current Trends in Biomimicry**

Now a century later there has been a resurgence in interest in biomimetics and biologically inspired design. Two ways in which this renewed interest is visible is through scholarship, which reflects academic and theoretical applications, and through the level of interest shown by the industrial and commercial sectors, which can be seen by examining the organizations and corporations applying biomimetics to the design and production of goods and services.
Scholarship and Biomimetics

Reflecting this growing interest in biomimetics are the results from a quick survey of patents (Google Patents) and scholarly research (Google Scholar). While not necessarily indicative of real world, mass-consumer applications, patents and research can illustrate the potential that biomimetics hold for future development. Figure 1 shows the results of a cursory search for patents and Figure 2 the results of a search of scholarly research over the last ten years with the key words “biomimetic”, “biomimicry” or “biologically inspired”.

The general upward trends of these charts reflects both a growing interest in and awareness of biologically inspired design, a course that further supports the integration of biomimetics within interior design and the built environment in general.

Further supporting this correlation between increases in interest and potential application are the findings of a study by Richard Bonser (2006) examining academic research and the increase in number of biologically inspired patents. In his research, Bonser cites the work of a few different authors (Anderson, 1999) (Hayashi, 2004) (Utterback, 1993) in support of the theory that an increase in patenting is indicative of increasing levels of innovation within the relevant sectors. The main findings of Bosner’s research show that not only has the
number of biomimetic related patents increased over the 20 year period from 1985 to 2005, but also that they have increased proportionately faster than non-biomimetically based patents (Bonser, 2006, p. 40). Finally, the author also notes that there may be even greater numbers of biomimetically-inspired patents than those found in his Boolean driven search, since biological inspiration may not be mentioned within the patent, as exemplified by De Mestral’s patent for the precursor to Velcro, which made no notation of natural inspiration (De Mestral, 1964).

Another trend that is indicative of the increasing interest in biomimetics across the design, manufacturing and industrial sectors is the growing amount of exploration and application of biomimicry by major corporations and organizations. One example of this trend is found in the work of the Biomimicry Guild (The Innovation Consultancy for Bio-Inspired Design, 2008), which provides biomimetic consultation and educational services to both corporate clients and the general public.

Illustrating the breadth of companies and industries that have shown interest in biomimetics is the list found in Table 1 showing some of the well-known companies that have explored biomimicry through consultation with the Biomimicry Guild (Client List, 2008).
TABLE 1

Selected Clients of the Biomimicry Guild Consultation Services

| American Institute of Architects | Johnson & Johnson |
| American Interior Design Association | Kohler |
| American Society of Interior Designers | Levi’s |
| Arizona State University | NASA |
| Ball State University | National Council for Interior Design Qualification |
| Boeing | Nike |
| Brookfield Zoo | Oberlin College |
| California Academy of Sciences | Patagonia |
| City of Seattle | President’s Council on Sustainable Development |
| Coca-Cola Company | Procter & Gamble |
| Cooper Hewitt | Rocky Mountain Institute |
| Dial Corporation | S.C. Johnson |
| DuPont | Seventh Generation |
| Environmental Protection Agency | Shell |
| General Electric | Sierra Club |
| General Mills | Stanford University |
| Gensler Architects | State of Montana |
| Georgia Tech | Steelcase |
| Hallmark | The Land Institute |
| Herman Miller | The Natural Step |
| Hewlett-Packard | United States Fish and Wildlife Service |
| HOK Architects | United States Forest Service |
| Interface | United States Green Building Council |
| International Interior Designers Association | University of Iowa |

Mass Production and Biomimetics

In addition to being found within the context of abstract, hypothetical ideas about ways to design a product or process by individuals and entities alike, biomimetic design ideas are more and more frequently finding their way into mass production—a step that is indicative of a growing degree of adoption and acceptance among designers and engineers. Furthermore, estimates indicate that the revenue generated by the 100 largest biomimetic products between 2005 and 2008 was approximately $1.5 billion (Bhushan, 2009, p. 1447).
A search for real world examples of biomimicry yields an abundance of interesting results spanning a wide range of industry sectors and applications. While some of these will be examined in more detail later, one of the most noteworthy general results of this search is the relatively high percentage of examples that are currently in production and available to the public, as opposed to existing solely as prototypes. Examples of biomimetic products and applications can be found across a highly diverse range of markets, a trend that indicates an increasing level of biomimetic adoption since biomimetically-inspired products are not just relegated to one or two niche markets within a couple of industry sectors. Table 2 illustrates both the range of currently available biomimetic products as well as the wide range of industries they represent.

**Table 2**

*Selection of Current Biomimetic Application Areas*

<table>
<thead>
<tr>
<th>Product type</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesives</td>
<td>Healthcare, Packaging, Office Supply,</td>
</tr>
<tr>
<td>Vehicle body design</td>
<td>Transportation, Automotive</td>
</tr>
<tr>
<td>Building design</td>
<td>Architecture</td>
</tr>
<tr>
<td>Carpet</td>
<td>Interiors</td>
</tr>
<tr>
<td>Wind turbine design</td>
<td>Energy Generation</td>
</tr>
<tr>
<td>Self-Cleaning Coatings</td>
<td>Architecture, Healthcare,</td>
</tr>
<tr>
<td>Insulating Glass</td>
<td>Architecture</td>
</tr>
<tr>
<td>Agricultural Systems</td>
<td>Farming</td>
</tr>
<tr>
<td>Solar Cells</td>
<td>Energy Generation</td>
</tr>
<tr>
<td>Water Filtration</td>
<td>Water Treatment</td>
</tr>
<tr>
<td>Wave Power Systems</td>
<td>Energy Generation</td>
</tr>
<tr>
<td>Anti-Microbial Coating</td>
<td>Interiors, Healthcare</td>
</tr>
<tr>
<td>Refrigeration free storage</td>
<td>Healthcare</td>
</tr>
<tr>
<td>Biopolymers</td>
<td>Water Treatment</td>
</tr>
<tr>
<td>Cement Production</td>
<td>Building and Architecture</td>
</tr>
<tr>
<td>Software and Network Design</td>
<td>Information Technology</td>
</tr>
<tr>
<td>Self-Healing &amp; Responsive Fibers and Fabric</td>
<td>Apparel, Interiors</td>
</tr>
<tr>
<td>Color Shifting Paints and Fabrics</td>
<td>Apparel, Automotive, Interiors</td>
</tr>
<tr>
<td>Radiant Heat System</td>
<td>Interiors</td>
</tr>
</tbody>
</table>
This small sampling only begins to illustrate the breadth of biologically inspired development throughout a wide range of industries. However, while there has been some biomimetic development focused on interior elements and spaces, the adoption and application of biomimicry within interior design does not seem to have progressed at the same rapid pace as other closely related areas and industries, such as construction and architecture. By providing designers with a tool to assist with the exploration, identification of biological sources of inspiration and application of biomimetics to design challenges this research hopes to advance the application of biomimicry within the built environment, particularly within the design and furnishing of interior spaces.

**Green Design and Biomimicry**

Looking to nature for solutions to design problems through biologically inspired design offers more than just a different approach to design challenges. It offers the potential to reduce the environmental impacts associated with many methods of product design, development and manufacturing as well as the impacts created by the use of these products within interior spaces and the overall built environment. These impacts can be far reaching, affecting areas such as water, soil and air quality, resource availability and habitat depletion in addition to worker health and safety. (The American Institute of Architects, 1999) In light of these potential issues as well as more global concerns regarding water and oil resources and availability, there is a great need for products and processes that have fewer environmental impacts. Natural organisms and processes rely solely on biological practices, which typically occur in an ideal, life friendly range of conditions and are generally composed of a very narrow range of multifunctional components (Benyus, 1998). Consequently, the emulation of these elements and processes can result in decreased environmental impacts, including reduced resource and energy usage.
In an ideal scenario, greener product selections and specifications would be the norm, however there can be a myriad of different concerns, constraints and other requirements, such as health, safety and welfare issues, budgetary constraints or building codes, that dictate the specific type or characteristics of the elements being used in these spaces. Consequently, as highlighted by the aforementioned research, the resulting selections may not always be the most environmentally responsible options. Research and surveys conducted by numerous researchers, including Moussatche, King and Rogers (2002) and Guerin & Geithner (1999; 2000) all highlight the strong influences of these non-environmental issues and constraints on the product selection processes.

There is some evidence of an emerging shift in priorities though as the growing trends of green and sustainable design, exemplified by programs and certifications like Leadership in Energy and Environmental Design (LEED), GreenSeal and Energy Star, are bringing some environmental issues to the forefront. Even with this shift however, the environmental impacts of products are still not generally primary areas of concern in the product design, specification and selection processes. When material and product selection criteria do include environmental issues, the focus is commonly on end-product attributes such as recycled content, volatile organic compound (VOC) emittance or the use of certified wood.

Although not necessarily focusing on product level selections and specific attributes, trends in LEED credit achievement can be illustrative of these general trends in green product selection. These selections may include more traditional green technologies such as recycled content, and well as less commonplace attributes such as renewably resource based components. While no credit achievements are specifically linked to biomimetically inspired products yet biologically inspired products could potentially gain a greater presence in design through the adoption of an LCA focused LEED credit in a future version of the
rating system, currently an LCA focused credit is available within the LEED pilot credit library (U.S. Green Building Council, 2010).

Research conducted by Silva and Ruwanpura (2009) comparing LEED credit achievements between the US and Canada reflects this. In their analysis of the achievements of material and resource related credits in the projects examined, Silva and Ruwanpura’s findings pertaining to green product usage highlights a few common tendencies. In both the Canada and the US, lower levels of achievement were found as the environmental requirements for the respective credits became more stringent, such as in MR 4.2, which calls for 10 - 15% recycled content (Silva & Ruwanpura, 2009). Achievement of credits pertaining to rapidly renewable products and certified wood were rarely achieved by either Canada or the US, a trend that was particularly evident in the lower certification levels. Silva and Ruwanpura’s finding are illustrated in Figure 3.
While the credit achievements shown in Figure 3 are not directly linked to the application of biomimetics, they are indicative of a shift toward more environmentally conscientious product and material selections within the design process, a shift that may create a greater market for and interest in biomimetically inspired products.

Life cycle analysis (LCA) is another facet of sustainable design that, while not directly linked to biomimicry, is nevertheless representative of a potentially beneficial development for biomimetics within the context of the emerging green design movement. A life cycle analysis can look at either one portion of the production, use or disposal of a product or it may look at the entire lifespan of a product from cradle to grave. In the case of the latter, it looks at
everything from the initial raw material acquisition stages to production to distribution to use and disposal.

A thorough LCA of virtually any product can uncover a potential multitude of environmental issues ranging from soil and water damage, to decreases in indoor and outdoor air quality, to resource depletion as well as human health and safety concerns. While some attention may be given to the production and manufacturing locations of materials being used, particularly for LEED projects, life cycle considerations are not typically determinant criteria for product and material selection. Due to a lack of consumer demand in addition to the high labor and costs associated with conducting a thorough LCA, there has traditionally been a general lack of life cycle assessment and life cycle inventory usage and data availability within industry (Smith Cooper & Fava, 2008). This absence of life cycle information is potentially detrimental to the advancement of biomimetic design, for it is within the broad boundaries of life cycle assessment that biologically inspired products can make significant contributions.

Due in part to the recent interest in green products and production, particularly among consumers and stockholders, some sectors of industry are, however, beginning to incorporate life cycle issues into the design and end use of their products. Recent examples of this include initiatives undertaken by Levi Strauss & Co. (2009) and InterfaceFlor, LLC (Environmental Product Declaration).

After an LCA revealed that nearly 60% of the climate impacts from a pair of jeans were generated during the end use phase and that nearly 80% of these impacts resulted from energy intensive drying methods, Levi Strauss & Co. sponsored the “Care to Air Design Challenge” (Levi Strauss & Co., 2009) to promote air-drying of their products by consumers.
One example more directly related to interior design can be found in one of the many environmental initiatives undertaken by Interface, Inc. In order to better educate customers and facilitate improved environmental comparisons between products, InterfaceFlor now includes *Environmental Product Declarations* (InterfaceFlor, LLC) within their product literature that outline the environmental impacts associated with each product. Although these are not examples of biomimetic inspiration derived from a particular organism, they are illustrative of some of the broader concepts inherent to biomimetic design, such as the principle of reduced resource consumption.

Further examining biomimetics in a broader sense is research by Reap, Baumeister and Bras (2005). Frequently biomimetic approaches are reductionist in nature, focusing only on one specific technology on a specific scale. The authors assert that this tendency can actually limit biomimicry’s role in sustainable design and that a preferable approach applies biomimicry in more holistic manner (Reap, Baumeister, & Bras, 2005, p. 8). Modeled off of the Biomimicry Institute’s *Life’s Principles*, which are outlined in Chapter 2, *Overview of Strategies in Nature*, Reap, Baumeister and Bras have identified seven different principles in nature which can be applied to design (2005, p. 5).

1. Life builds from the bottom up
2. Life fits form to function
3. Life depends on water
4. Life is cyclic and recycles
5. Life is locally attuned and resourceful
6. Life adapts and evolves
7. Life coexists within a cooperative framework
These characteristics, the authors find, can be applied to many different aspects of the production process. To support the application of these principles, Reap, Baumeister and Bras have mapped these natural principles onto a general life cycle chart, shown in Figure 4, to illustrate the areas in which biomimetics could be applied.

**Figure 4**

*Potential applications of biomimetics to a generic product life cycle*

There are numerous potential benefits outlined by the Reap, Baumeister and Bras in this modified life cycle.

- Waste reduction and more function specific materials can be generated through bottom-up fabrication in the extraction and manufacturing stages. (Reap, Baumeister, & Bras, 2005, p. 6)

- Water-based formulations can reduce the need for organic solvents (p. 6)

- Cyclical flows within the manufacturing process can allow the utilizations of previously discarded waste materials (p. 6)
• Locally focused raw material selection and acquisition would promote the use of regionally abundant materials and avoid the use of locally scarce resources (p. 6)

• Adaptive and evolving manufacturing can lead to greater flexibility in the types of products manufactured and also reduce the demand for retooling of the system when product modifications occur. (p. 6)

• Looking a manufacturing in a broader sense, cooperative frameworks can yield greater interactions between recycled material suppliers as well as the utilization of waste products generated in other manufacturing processes. (p. 7)

Although the tool designed based upon the research presented in this thesis does not currently focus directly on life cycles and the production process, a general understanding of LCA’s and the role biomimetics can play on a broader scale is beneficial to designers since this increased understanding can lead to more environmentally conscientious product design and selection.

In addition to areas like LEED and LCA’s there are currently a few other design philosophies and systems that incorporate and promote biomimetic design within industry. One of the more well-known being Natural Capitalism (Hawken, Lovins, & Lovins, 1999), a system that extols a few potential benefits of biomimicry including the reduction of waste in the manufacturing process, cradle to cradle material reuse cycles and decreased levels of toxicity. Another well known design approach that promotes biomimetic thinking is Cradle to Cradle (McDonough & Braungart, 2002), which looks at product design as a closed loop, waste free, system. Additionally, it emphasizes the adoption of a more holistic approach to design.
Importance of Biomimicry to Interior Design and the Built Environment

Each year millions of square feet of property are built or renovated in the United States. Since these projects typically require some interior furnishings and finishes, even small steps toward lessened environmental impacts can quickly yield large scale reductions in environmental damages if applied across a large percentage of these properties.

Two examples of this can be found within the Marriott International, Inc. (2009) chains of hotels. By switching to key cards with 50 percent recycled material, Marriott was able to divert 66 tons of plastic from US landfills. A second example, from the Marriott hotel properties in Texas, stemmed from energy audits by TXU Energy that found switching to CFL bulbs and upgrading control systems in just 40 properties would result in a two million kilowatt-hour reduction in electricity consumption and save over $250 thousand annually (TXU Energy, 2009). Although neither of these examples necessarily incorporate biomimetic principles, they are illustrative of the power relatively small improvements can have if incorporated on a larger scale and, as with the earlier examples illustrating LCAs, do reflect some of the broader concepts found in design in nature.

Although few quantifiably successful examples exist within the specific context of interior design to illustrate the benefits of biomimicry, examples can be found on smaller, less quantifiable, scales that are more directly focused on interior spaces.

Examples can be found in furniture and lighting design, where natural elements like bird’s nests, leaves (Enea Studio) and spider webs (Junio Design) have influenced the aesthetic characteristics of seating designs and lighting fixtures. Looking to more functional applications, other advancements pertaining to the interior environment can be found in the biomimetic exploration of surface and material properties including self-cleaning, self-
healing and moisture resistance. Examples of self-cleaning surfaces can be found in research examining the superhydrophobicity of the lotus and other aquatic and semi-aquatic plants. Recently there have been quite a few studies, such as the research done by Barthlott & Neinhuis (1997) and Ma & Hill (2006), conducted on the various methods by which this water repellency is achieved and many of these findings can potentially be applied to interior surfaces and finishes.

Looking at successful applications of biomimicry within the context of material and component construction, there are a few interesting examples that demonstrate both economic and environmental benefits. One of these is Columbia Forest Products PureBond® adhesive, which is not only bio-inspired, but also biobased and formaldehyde free. The source of inspiration was the natural adhesive used by the blue mussel and the resulting glue meets the California Air Resources Board Phase 2 formaldehyde emission limit, which is an 85% reduction from ANSI standards (Piland, 2005).

Another well-publicized example of biomimicry as applied to finish materials is found in the Entropy and i2 lines of carpet tiles as well as the TacTiles installation system that are both produced by InterfaceFLOR, LLC (2008). The carpet tiles were inspired by the random pattern of leaves on the forest floor and the resulting tile designs feature a non-directional pattern. This innovation provides easy installation and replacement as well as reduction in waste due to over-ordering to ensure pattern matching when laying the tiles. The TacTile installation system, which looks to nature through inspiration from various methods of glueless adhesion, eliminates the need for glue when the carpet tiles are installed on hard surfaces. These innovations have proven successful for Interface and, as of 2008, 82 products in their collections were biomimetically inspired and sales of these products made
up over 40% of all carpet tile sales with the Entropy line accounting for approximately one third of it $1 billion in annual revenue (Atlanta Business Chronicle, 2008).

Biomimetics is also being applied to the design of plumbing fixtures as well as exemplified by Moen Incorporated’s Inspire line of showerheads. Inspired by the ratio of Phi, which is found in many spiral patterns in nature, the nozzle pattern in the showerhead is designed around a Fibonacci-inspired spiral (Flinn, n.d.).

Looking beyond interior spaces to the architecture surrounding them, various examples can be found of biomimetic applications as well. Perhaps one of the best known examples of biomimetics in architecture is the Eastgate building in Harare, Zimbabwe. By looking at the design of termite mounds, which are able to maintain a constant interior temperature, the Eastgate building uses only 10% of the energy used by a traditionally designed building of a similar size. This reduction in energy use has resulted in obvious economic benefits as well, in its first five years of operation the energy savings was $3.5 million dollars (Zolli, 2004).

Viewing environment in terms of the surrounding spatial construct, biomimicry has also been proposed as potential tool to combat crime, thereby improving the safety and well-being of inhabitants. This idea was proposed by D. E. Santos-Reyes (2008) in research identifying four main steps in applying biomimetics to crime prevention.

1. Identify, as the author terms it, the similitude between biological systems and crime. In this case, this is found by looking at crime from the perspective of victim/offender and at the biological issue of prey/predator (2008, p. 46).

2. Develop an analogy between victim/offender and prey/predator interactions. Key points for Santos-Reyes in this step focus predominately on survival mechanisms and strategies (2008, p. 46).
3. Formulate and map, through isomorphism, design principles that can be transferred between biology and crime (2008, p. 47).

4. Adapt those principles that have been identified relating to prey/predator behavior and patterns. Some of these principles, which are listed by the author within the text, include aposematism, coevolution, mimicry and shield protection (2008, p. 46).

While the author does not examine any specific product level applications of these principles, this area of exploration is noted by Santos-Reyes as a direction for future work on the subject.

As shown by the aforementioned examples, biomimicry, both in interiors and in general, can have applications outside the range of product and material design and production. This intrinsic versatility gives designers the ability to not only to address the specific challenge at hand but also to create solutions that address environmental and social challenges on a broader scale.
Chapter 2: Review of Literature

As noted in the introductory chapter, an increasing amount of research has been conducted in recent years on the use of biomimicry in concept generation and product development spanning a wide range of industries and fields. Because this recent research is spread across a diverse array of disciplines and sectors, differences in terminology and design processes exist that can impede the utilization of biomimicry as a design tool. To negate some of these potential obstacles, the research presented here aims to create a tool to assist designers with the successful incorporation of biomimetics into the design approach by facilitating the exploration and identification of biological sources of inspiration and the productive application of biomimetics to design challenges.

In order to arrive at a tool which most effectively combines the approaches, tools and methods best suited to support the integration of biomimetics within interior design, a number of biologically-inspired design and interior design processes and methodologies were reviewed, along with research concerning various methods of information collection and retrieval. This literature will be addressed in terms of several main categories:

- Approaches to Design
- Comparative Analysis of Biomimetic and Interior Design Methodology
- Methods of Biological Transfer
- Identification and Application of Biological Sources of Inspiration
- Guidelines for Successful Application of Biomimicry
- Information Seeking Methods, Behavior and Procedures
- Search Strategies
- The Current Biomimetic Database, Search Engines and Other Resources
Processes and Approaches to Biomimetic Design

While the basic concept of biomimicry - finding inspiration in nature, may initially seem straightforward, the process of actually applying it to a design problem can be challenging. When initially considering the utilization of biomimicry many questions may be raised, particularly by those new to biomimetics including:

- Where does one begin?
- How does one find inspiring organisms?
- Once a source of inspiration has been found, how does one actually apply nature’s solution to the problem at hand?

Examined within this chapter are a few studies looking at various aspects of biologically inspired design including initial methods of approach, the search for natural sources of inspiration and the application of biomimicry to challenges. Each step in the design process, from the choice of approach method to the selection of inspirational organisms to the design of the final solution can have noteworthy impacts on the overall success of the final product. By better understanding the methods, approaches and processes that typically yield the most favorable outcomes, these can be integrated into the design of a tool that promotes and supports the best biomimetic practices among interior designers.

Approaches to Design Challenges

The type of approach used to address a design challenge, either biomimetic or non-biomimetic, can have notable impacts on the quantity, quality and overall creativity demonstrated in the proposed solutions. Various research, examined in more detail below,
identifies a range of different approaches to design challenges, each with differing strengths and weaknesses.

Focusing on these different strategies within the context of practicing industrial designers is a 2006 study by Kruger and Cross. In their study, designers are presented with a typical small-scale industrial design assignment. Kruger and Cross subsequently evaluate the processes followed and the solutions generated to ascertain the different strategies that were employed. Finally, they assess the overall quality of the solutions generated by each strategy.

One of the early steps of their research was to generate a model of the tasks that designers worked through to arrive at their final solution. The main steps Kruger and Cross identify through this process are:

1. Gather data (Kruger & Cross, 2006, p. 531)
2. Assess value and validity of data (p. 531)
3. Identify constraints and requirements (p. 531)
4. Model behavior and environment (p. 532)
5. Define problems and possibilities (p. 532)
6. Generate partial solutions (p. 532)
7. Evaluate solutions (p. 532)
8. Assemble a coherent solution (p. 532)

While some of these steps may differ slightly from those followed by interior designers, there are quite a few similarities, particularly in the areas of the identification of requirements and constraints, problem definition and solution generation and evaluation. Based upon their evaluations of these steps and the relative time spent on each stage, Kruger and Cross
identified four main strategies that each yielded differing results in regard to the quantity of solutions generated, the level of creativity demonstrated and the overall success of these solutions. These strategies were:

- **Problem Driven**
  - Relies only on the information and knowledge that is necessary to solve the problem. Problem definition is emphasized and the solution tends to be generated as soon as possible. This approach yields numerous solutions, scores high for creativity and overall receives a high total score. (Kruger & Cross, 2006, pp. 536-537)

- **Solution Driven**
  - Focuses primarily on the generation of solutions with information gathering dictated by which information will assist with solution identification. Initially problem definition receives minimal time, though the definition may be re-examined or re-addressed as solutions emerge. This approach results in numerous solutions in addition to receiving a high score in creativity; however, the overall quality of the solutions is low. (pp. 537-538)

- **Information Driven**
  - Emphasizes external information collection, which serves as the basis for solution generation. Few solutions are generated with this approach, which also receives a low score for creativity; the overall score however, was high. (p. 538)

- **Knowledge Driven**
  - Emphasizes personal and prior knowledge as basis for solution generation. Little external information is collected. Of the four strategies identified, this
approach yields the most average results overall, resulting in few solutions and mid-range scores for both creativity and total overall score. (pp. 538-539)

Another finding of Kruger and Cross’ research is the relatively high percentage of designers that utilize either problem or solution driven design, with 33% of designers using problem driven, 33% using solution driven, 22% relying on knowledge driven and only 11% utilizing an information driven approach (Kruger & Cross, 2006, p. 542).

**Problem Driven vs. Solution Driven Design**

Given the prevalence of problem and solution driven strategy usage shown by Kruger and Cross’ research as well as the relatively successful results obtained through these strategies, one or both of these strategies seem optimal for integration into the design of the tool proposed here. Consequently, further research is necessary to determine the usage rate and usefulness of these strategies within biomimetic applications. Within the context of biologically inspired design quite a bit of research has been conducted by the team of Helms, Vattam, Goel on the different stages and processes in biomimetic design.

One noteworthy study by Helms, Vattam and Goel, in collaboration with Yen and Weissburg (2008), focuses on cognitive related observations within the application of biologically inspired design and their findings offer some interesting insights that can be utilized to assist with the development of more effective solutions to design challenges. Looking at both problem and solution driven processes, Helms, et al. (2008) identify the general steps involved in each respective approach and the main steps in each process are outlined in Table 3 and subsequently examined in greater detail. While both processes are outlined in a linear arrangement, the actual processes tend to be more circular, with later findings leading to a re-evaluation of earlier steps.
TABLE 3

Comparison of Problem and Solution Driven approaches

<table>
<thead>
<tr>
<th>Problem Driven</th>
<th>Solution Driven</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(Helms, Vattam, Goel, Yen, &amp; Weissburg, 2008, p. 3)</em></td>
<td><em>(Helms, Vattam, Goel, Yen, &amp; Weissburg, 2008, pp. 6-7)</em></td>
</tr>
<tr>
<td>Step 1: Define the Problem</td>
<td>Step 1: Identify Biological Solution</td>
</tr>
<tr>
<td>Step 2: Redefine the Problem</td>
<td>Step 2: Define Biological Solution</td>
</tr>
<tr>
<td>Step 3: Search for Biological Solution</td>
<td>Step 3: Extract Main Principles</td>
</tr>
<tr>
<td>Step 4: Define Biological Solution</td>
<td>Step 4: Redefine the Solution</td>
</tr>
<tr>
<td>Step 5: Extract Main Principles</td>
<td>Step 5: Identify Problems</td>
</tr>
<tr>
<td>Step 6: Apply Principles</td>
<td>Step 6: Define the Problem</td>
</tr>
<tr>
<td></td>
<td>Step 7: Apply Principles</td>
</tr>
</tbody>
</table>

**Problem Driven**

As found by Helms, et.al. (2008) Step 1 in this approach has two main components. The initial portion of this step involves the identification of a problem or challenge to address while the latter portion focuses on the subsequent translation of this problem into functional terms with further refinement of the requisite functions typically occurring as the process progresses. Two different methods are suggested to participants to assist with the functional translation. The first is functional decomposition, which breaks a complex function down into its sub-functions. The second technique is functional optimization, which identifies functions based upon optimization criteria – abstraction which, Helms, et.al. note, can facilitate simpler transitions of functional requirements between different disciplines. The second main step in problem driven design is to redefine the problem in biological terms. Generally, this takes the form of a question similar to: What methods do biological solutions use to successfully achieve the identified function? Step 3 is comprised of the search for biological solutions and in the study by Helms, et.al. the subjects are provided with four different search
strategies. (2008, p. 4) These strategies are outlined in Table 4. While not the focus of their study, the identification, understanding and incorporation of these different search strategies into the design tool created in this thesis will assist designers with more effective identification of biological solutions.

**Table 4**

*Biological Solution Search Strategies*

<table>
<thead>
<tr>
<th>Search Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjust Constraints</td>
<td>Broaden problem definition to widen search area</td>
</tr>
<tr>
<td>Identify Champions</td>
<td>Locate organisms which survive in the most extreme examples of the problem being investigated</td>
</tr>
<tr>
<td>Find Variations</td>
<td>Look at different methods utilized by different “families” or sub-species of organisms</td>
</tr>
<tr>
<td>Multi-functional</td>
<td>Identify single solutions that successfully resolve multiple challenges</td>
</tr>
</tbody>
</table>

After the biological solution is identified in Step 3, the next step is to develop a deeper understanding of how it works. Helms, et.al. note that the utilization of the functional decomposition strategies outlined in the Step 1 may assist with this process. After an increased level of comprehension has been obtained and main principles have been subsequently extracted in a solution-neutral form, the final step, Step 5, in this approach involves applying the main principles to the desired domain, such as industrial design, engineering or interior design. This may, in turn, create new problems or highlight additional constraints or opportunities and consequently may result in additional opportunities for biologically inspired solutions.

**Solution Driven**

While the problem driven approach was the method introduced to the study participants, Helms, et al. (2008) note that nearly half of the designers utilized a second approach,
solution driven. This approach includes some of the same steps found in problem driven design, however the order of the steps does change. The initial step, Step 1, is to identify a particular biological solution that could be applied to challenges in different domains. Step 2 is to define the solution in functional terms with the Step 3 being to extract the main principles. Once these principles have been identified, the Step 4 is to reframe these principles within the context of the perceived usefulness of the function or functions being achieved. Step 5 seeks to identify potential challenges where these principles could be applied with Step 6 further refining and defining this problem. Finally, the last step, Step 7, is to brainstorm possible applications to which these principles could be applied.

**Biomimicry Guild’s Design Spirals**

A similar approach to applying biomimicry to design is the method developed by Carl Hastrich, in conjunction with Janine Benyus and Dayna Baumeister. (2009) Visually depicted as spirals, this method offers designers guidance in a step-by-step approach – with each step providing refinement of both the formal and functional goals. Much like the solution and process driven methods outlined above, these methods offer the designer two different approaches to the design process as well: Biology to Design and Challenge to Biology (Hastrich, Benyus, & Baumeister, 2009). These approaches are similar to the problem driven and solution driven methods reviewed above with the primary identification of a biological source of inspiration (solution driven) represented by the Biology to Design spiral and the primary identification of the challenge (problem driven) represented by the Challenge to Biology spiral.
**Figure 5:**

*Design Spirals*

<table>
<thead>
<tr>
<th>Biology to Design</th>
<th>Challenge to Biology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Discover</td>
<td>1. Identify</td>
</tr>
<tr>
<td>2. Abstract</td>
<td>2. Interpret</td>
</tr>
<tr>
<td>3. Brainstorm</td>
<td>3. Discover</td>
</tr>
<tr>
<td>4. Emulate</td>
<td>4. Abstract</td>
</tr>
<tr>
<td>5. Evaluate</td>
<td>5. Emulate</td>
</tr>
<tr>
<td></td>
<td>6. Evaluate</td>
</tr>
</tbody>
</table>

**Biology to Design**
(Hastrich, Benyus, & Baumeister, 2009)

The first spiral outlined above in Figure 5, “Biology to Design”, begins with Step 1: Discover, which consists of the discovery of an inspirational organism and the various strategies that the organism uses to solve the challenges it faces within its respective environment. To determine the different strategies utilized, the authors recommend asking questions pertaining to how the inspirational selection addresses and deals with challenges within its environment. The next step, Step 2: Abstraction, focuses on the identification of potential inspirational strategies through the comparison of the similarities and differences that run through these selected strategies to extract the most successful methods of achievement.
Once a list is created of the strategies that seem to offer the greatest potential for further development, potential applications and industries that could benefit from these strategies can then be brainstormed in Step 3: Brainstorm, with focus directed toward those areas that face similar challenges. Step 4: Emulate, looks at ways in which these natural methods and strategies can be applied to design on a variety of levels. Finally, Step 5: Evaluate, compares these potential methods of emulation to *Life’s Principles* (Benyus, 1998) to measure and analyze the breadth and depth of biomimetic integration with the idea.

**Challenge to Biology**
(Hastrich, Benyus, & Baumeister, 2009)

The second method outlined by the Design Spirals closely resembles the problem driven approach outlined above, with the identification of the root problem or challenge being the initial action. While the order of these steps varies between the different spirals, the general aim of many of these steps remains the same. Consequently the following overview will provide on a general description of each step in light of the more thorough explanation provided in the Biology to Design description outlined above.

The first step in the Challenge to Biology process, Step 1: Identify, serves to isolate the basic function or functions required by the design. Rather than focusing on what specifically is being designed such as a chair or a light fixture, the focus instead should be on what the design aims to accomplish. First, ask “What do you want your design to do?” not “What do you want to design?”. Next, pose the question “Why do you want the design to do that?” (Hastrich, Benyus, & Baumeister, 2009). By asking these questions, the designer will be able to arrive at the basic function the design needs to achieve.
Once the desired function is identified, the next step, Step 2: Interpret, is to convert these into functions found in nature. To determine this, one must inquire “How does nature perform this function?” (Hastrich, Benyus, & Baumeister, 2009). Another facet of this step is to determine those natural conditions or habitats that most closely represent the parameters defining the design challenge. After these are ascertained, the next phase in this process, Step 3: Discover, is to find out what in nature may provide the best solution to this challenge. Given the virtually infinite number of potentially inspiring natural elements, this can seem a daunting undertaking; however, Hastrich, et al, offer some suggestions on how best to approach this. Asking “whose survival depends upon this?” may prove beneficial, as well as seeking out those organisms which are “most challenged by the problem you are trying to solve, but are unfazed by it” (Hastrich, Benyus, & Baumeister, 2009). Along with these suggestions, the authors also recommend considering the problem from both literal and metaphorical perspectives in addition to looking to the extremes of the habitat that was determined in the Step 2. (2009) Charting the techniques and strategies used by nature can also help to reveal those that have the highest rate of success within those conditions most similar to the constraints shaping the design challenge at hand. The next step, Step 4: Abstract, aims to identify the principles and general strategies that nature uses to address the selected challenge and abstract these to identify the most potentially successful method or strategy. Looking at how these principles can apply to the design challenge is Step 5: Emulate. The application of principles, strategies and techniques may focus on the mimicry of “form, function or system” (2009), but regardless of where the focus lies, an understanding of other factors that influence the respective effectiveness of the strategy or method is also in order. To subsequently evaluate the successfulness of the application, as identified in Step 6: Evaluate, Hastrich, Benyus, and Baumeister have developed a list of “Life’s Principles” (2009) that outline nature’s basic design characteristics. In order to
facilitate evaluation, these principles are examined further in the *Overview of Strategies in Nature* section later in this chapter.

**General Trends in Biomimetic Application and Solution Generation**

Regardless of the approach utilized, various trends have been identified by Helms, Vattam, Goel, Yen and Weissburg within their study pertaining to the type of process used and the types of solutions generated (2008). Some of the most relevant aspects of their findings are highlighted below.

- Although the problem driven approach was the method presented to the study participants, nearly half of the projects utilize a solution driven approach (2008, p. 6)
- Though functional considerations were highlighted as important, 2/3 of the projects in their study focus on structure (2008, p. 8)
- Of the remaining 1/3 that did focus on function, all work with a problem driven process (2008, p. 8)
- Multi-functionality was only observed in projects which utilize a solution driven approach (2008, p. 8)
- While functional optimization was emphasized, only 11% of projects in the study were framed as a functional optimization problem. (2008, p. 8)
- Biological source identification was challenging for many designers, with some noting a lack of biological inspiration while others note an overabundance. (2008, p. 3)

A later study conducted by Helms, Vattam and Goel (2009), looking at problem and solution driven design as well, found that solution fixation can be problematic in both design approaches. In problem and solution driven methods alike, the source of inspiration may be
limited to the originally selected biological source, which can subsequently limit the integration of additional or alternative sources of inspiration. (Helms, Vattam, & Goel, 2009, p. 17)

By better understanding the general trends present when utilizing a biomimetic approach, the tool designed in this current research can be designed to encourage improvement of the less desirable trends, such as the general lack of focus on function or solution fixation. Additionally, this tool can provide designers with a wide range of potential methods of functional achievement without the immediate introduction of one particular organism or biological source

**Comparative Analysis of Biomimetic and Interior Design Methodology**

While some interior design challenges may take a more solution driven approach, the majority are more typically defined by the problem at hand. Because the steps involved in this are quite similar to those found in the biological problem driven approaches outlined above, these similarities in the design process may assist designers with the transition to working with biomimicry. A comparison of these processes is outlined in Table 5.
TABLE 5

Comparison of Biomimetic and Interior Design Processes

<table>
<thead>
<tr>
<th>Problem Driven / Challenge to Biology</th>
<th>Interior Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Hastrich, Benyus, &amp; Baumeister, 2009)</td>
<td>(Slotkis, 2006, p. 119)</td>
</tr>
</tbody>
</table>

**Identify**
- Determine the basic function or functions that define and dictate a successful solution via functional decomposition or functional optimization

**Programming**
- Identify any constraints or requirements relevant to the project by gathering and analyzing data

**Interpret**
- Identify biologically equivalent functions by reviewing the methods successfully utilized in nature to redefine the required function in biological terms.

**Schematic Design**
- Analyze the requirements of project and identify the overarching design concept.

**Discover**
- Analyze natural strategies to locate natural sources of inspiration

**Emulate**
- Analyze and document the design concept through furniture layout, material selections, spatial allocation, etc.

**Design Development**
- Refine the design documents to show scale, increased levels of detail, etc.

**Abstract**
- Identify the general natural methods and principles most relevant to the design challenge

**Emulate**
- Incorporate *Life’s Principles* (Benyus, 1998) into design requirements to “deepen the conversation” (Hastrich, Benyus, & Baumeister, 2009) through mimicry of form, process and ecosystem

**Evaluate**
- Analyze design’s success based on *Life’s Principles* (Hastrich, Benyus, & Baumeister, 2009) and refine as needed via repetition of design process

**Contract Documents**
- Generate final drawings, specifications and other documentation for client approval
As shown in the chart above, there are many similarities between these processes that can facilitate a more seamless integration of biologically inspired design into the traditional interior design process. For example, within both the “Identify” and “Programming” stages the main objectives are the identification of the basic requirements of the design solution. Similarities in main goals exist too between the “Interpret”, “Discover” and “Abstract” steps found in the Challenge to Design spiral and the “Schematic Design” stage of Interior Design. In each respective field, the identification and clarification of the basic form of the project’s solution are the primary aims. The step “Emulate” and the “Design Development” stage share the process of refining the proposed solution to incorporate greater levels of detail. Finally, the “Evaluate” step and “Contract Document” stage both focus on ensuring that the project’s solution is accurate and addresses all necessary requirements through attention to detail and evaluation against project requirements.

Looking more closely at design in nature and the typical design process is research by Rossin (2010), which supports the integration of biomimetics into the practice of interior design. In his assessment, Rossin uses the Challenge to Biology Design Spiral as well to represent the biomimetic approach and the interior design methodology from “Designing Interiors”, an interior design textbook by Kilmer and Kilmer (1992). While the terminology used by Kilmer and Kilmer differs slightly from that used in the process shown in Table 5, the basic steps are similar.

Echoing the findings of Chapter 1, Rossin’s research highlights the potential for more sustainable design solutions through the integration of biomimicry as well. As quoted by Rossin from the Kilmer and Kilmer text, “Nature provides a vast biological toolbox of solutions for the interior designer to use in resolving problems of sustainability” (Kilmer & Kilmer, 1992, p. 560).
One of the primary finding of Rossin’s research addresses the ideal location within the interior design process to integrate biomimetic thinking. According to Rossin, in order for designers to properly “biologize” (Rossin, 2010, p. 561) the design problem, the programming stage is the preferable stage. Another key finding in his analysis is that the primary difference between biomimetic and interior design processes hinges primarily on one question. While interior design asks “What do you want to design?, biomimicry asks “What do you want your design to do?” (Rossin, 2010, p. 563) Additionally, Rossin also stresses that potential solutions should be evaluated against the principles outlined in “Life’s Principles” to help ensure emulation of natural design attributes. (Rossin, 2010, p. 563)

By better understanding the biomimetic and interior design processes as well as the similarities between them, the tool designed through the research presented in this thesis can more effectively support the integration of biomimicry into the interior design process.

Identification and Application of Biological Sources of Inspiration

The identification of relevant, appropriate sources of biological inspiration can be a challenge for designers and research conducted by Vakili and Shu (2001) offers some potentially beneficial guidelines.

Focusing on biomimetic concept generation, their research offers guidance on both biological source selection as well as functional extraction. Vakili and Shu outline the following steps toward biological analogy identification and the subsequent conclusions of their research:

- Selection of biological information source (Vakili & Shu, 2001, p. 4)
- The authors note that the source selection can limit solution identification, which in their case was limited to an introductory biological text.

- **Functional synonym identification (2001, p. 4)**
  
  Vakili and Shu found that the use of synonyms for engineering terms did increase their success rate, however note that the generation of biological synonyms could yield even more results.

- **Identify a bridge between differing terminology used in different disciplines, in Vakili and Shu’s research this was between engineering and biology. (2001, p. 4)**
  
  Since the authors utilized written as opposed to digital text, their search bridge was the glossary.

- **Search for synonyms and keywords in bridge (2001, p. 4)**
  
  Owing to the limitations presented by reliance on the glossary instead of a full text search, the authors noted that many other potential solutions could have been identified.

- **Locate and research potential biological solutions (2001, p. 4)**
  
  Moving from the more general information presented in their initial source material toward more specific information created challenges in comprehension due to unfamiliarity with the subject and the highly technical nature of their subsequent research.

As with the various challenges found by other researchers, the issues noted by Vakili and Shu are of importance to the design of this tool – particularly in regards to the format it will take owing to the limitations that they encountered when relying on non-digital information.
sources. Also of particular interest to the design of the tool presented in this current research is the idea of a synonym and keyword search feature, owing to the aforementioned differences in terminology.

**Methods of Biological Transfer**

In addition to understanding the approaches taken to applying biomimicry to a design challenge, it is also necessary to understand in greater detail the main steps in process. One of the most important steps in the problem driven process is the transition from a specific functional requirement to a more abstract neutral one.

Based on the idea that the full potential of biologically inspired design is only fully realized when the strategy found in the biological source is abstracted and applied in a new, novel way, one study by Mak & Shu (Abstractions of biological analogies for design, 2004) examined the design drivers and types of transfers used when applying, either successfully or unsuccessfully, biologically inspired design to design challenges. One area of focus for this study was the classification of descriptions of biological phenomena into three levels: form driven, behavior driven, and principle driven.

- **Forms:** The lowest level of this categorical hierarchy is form, which provides a general description, without delving into the details of how or why a phenomenon occurs. (Mak & Shu, Abstractions of biological analogies for design, 2004, p. 2)

- **Behaviors:** The second highest level describes the processes found in the biological source of inspiration. As noted by Mak and Shu, this level looks more closely at the behaviors, methods and processes that occur within the biological source of inspiration. (Mak & Shu, Abstractions of biological analogies for design, 2004, p. 2)
• Principles: This is identified as the highest level and seeks to identify the underlying principles that are responsible for a specific process and why they have adopted the particular behavior or perform a particular process. (Mak & Shu, Abstractions of biological analogies for design, 2004, p. 2)

Progression to the highest level provides greater insights into why an organism or system behaves as it does. This progression leads from the general inquiries into what form a biological element takes to answering deeper questions as to why it has adopted a particular behavior or performs a particular process. Moving down in the hierarchy from the highest level, “Principles”, to the lowest, “Forms”, leads to an increasing understanding of how an organism or system achieves the phenomenon referred to in the level above. During this study, four main types of similarity relationships were also identified during the application of biomimicry: Literal implementation; biological transfer; analogy and anomaly. Each of these strategies yields differing degrees of overall accuracy of strategy and successful abstraction of the source of inspiration.

• Biological transfer
  
  o Provides both low levels of biological abstraction as well as low strategic accuracy. Direct utilization of the biological source of inspiration to solve the problem rather than abstraction of the phenomenon would exemplify this relationship. (2004, p. 3)

• Anomaly:
  
  o Lacks strategic accuracy and biological abstraction may be based on misinterpretation of biological phenomenon. (2004, p. 3)
• Literal Implementation:
  
  o Has a high degree of accuracy of strategy, yet showing a poor degree of biological abstraction. Similar to biological transfer in direct use of biological phenomenon, but usage is more focused on direct strategic application. (2004, p. 3)

• Analogy:
  
  o Combines a more accurate strategic application with a high degree of biological abstraction. (2004, p. 3)

Of these different relationships, analogical transfer was found to be the most effective form of transfer when working with biomimetic design, showing both high levels of abstraction of biological abstraction while demonstrating a high degree of strategic application. (Mak & Shu, Abstractions of biological analogies for design, 2004, p. 4)

The usage of each of these types of similarity relationships within each level of biological description revealed some general trends in types of concepts generated. When working at the lowest descriptive level, form, a majority of the responses were based on literal interpretations. The second level, behavior, tended to generate concepts that were strategically inspired – a trend that was also noted to an even greater degree in the third, highest level, principle. Principle driven designs also had the highest potential to exemplify analogical transference. (Mak & Shu, Abstractions of biological analogies for design, 2004, p. 4)

Based upon the results of the study, Mak and Shu also note that while it is relatively simple to move down the hierarchy – when moving from principle driven to more form driven
design, designers may encounter difficulties when moving upwards due to a lack of information and knowledge concerning higher level processes and strategies.

By understanding the methods that yield the most effective transfer of biological sources of inspiration to the generation of design solutions, the tool developed in this current research can be structured to most easily facilitate the application of these methods and potentially increase the efficacy of the resulting concept generations.

**Analogical Transfer and Biologically Inspired Design**

There are a few different studies, reviewed below, that focus on analogy within design concept generation that have relevancy to the specific aims of this research, either with regards to biomimetic analogies or to methods of representing these analogies.

Multiple studies conducted by the research team of Vattam, Helms and Goel looking at compound analogical design offer some interesting findings pertaining to the relationship between problem decomposition and analogical transfer (2008; 2009). Addressing the complexity inherent in much biologically inspired design within their 2008 study, Vattam, et al. have sought to explain the method by which compound biologically inspired solutions are generated. The basis that Vattam, et al. identify for the generation of compound solutions stems from the interaction between analogical transfer and problem decomposition. Within their research, compound solutions are defined as those whose overall solution is made up of multiple biologically inspired solutions. In fact, nearly 2/3 of all of the design solutions generated within the context of this study were compound solutions. (Vattam, Helms, & Goel, 2008, p. 5)

Although not the primary focus of their research, the authors did confirm the findings of other research studies examining the process of applying biomimetic design. These include:
The problem driven process tended to be the prevalent method used when introducing biomimicry to designers. (Vattam, Helms, & Goel, 2008, p. 5)

The selection of the biological source of inspiration generally directed the subsequent design process, regardless of whether the process was problem or solution driven. In cases of problem driven design, this was found to be particularly detrimental, as it tended to become a source of design fixation. (Vattam, Helms, & Goel, 2008, p. 5)

The main outcome of Vattam, Helms and Goel’s research was the creation of a framework for compound biologically inspired design. In order for their proposed framework to be successful, it needed to meet a few basic requirements, with the foremost being:

- Be capable of analogical transfer and retrieval across different domains (Vattam, Helms, & Goel, 2008, p. 7)
- Allow for the retrieval of sources from multiple domains (Vattam, Helms, & Goel, 2008, p. 7)

In addition to fulfilling the aforementioned requirements, another key feature of their biomimetic framework lies in its ability to support the interplay between analogy and problem decomposition. (Vattam, Helms, & Goel, 2008, p. 8) This interplay focuses mainly upon the methods of decomposition used as well as how these influence, and are influenced by, the analogies used. In this research, Vattam, Helms and Goel outlined two different types of compound analogical design – one simple and the other more complex. In the most basic, straightforward, approach the designer simply breaks the overall problem down into smaller sub-problems, generally determined by functional demands. (2008, p. 9) Once solutions to the functional requirements are identified, they are combined to create one final, all-encompassing solution. In the context of an actual design challenge, this process is typically...
not straightforward and Vattam, et. al. are quick to point out that complications, including
difficulty in decomposition, often occur. (2008, p. 9) Issues pertaining to decomposition,
ranging from inability to determine the most effective strategy of problem division or simply
general dissatisfaction with the resulting sub-problems may necessitate the search for an
analogy based upon the highest order problem. Once a potential solution to one or more
sub-problems have been identified, the designer must decide how best to proceed with this
new information – according to Vattam, et. al., the evaluation of this solution may lead to
further sub-problem identification and analogical identification. (2008, p. 10) This tends to be
a more dynamic approach and is highly context dependent. The overall findings of their
research show that successful biomimetic design is dependent upon the interplay between
the decomposition of the problem and the analogues which are retrieved and that each level
of problem decomposition provides important cues and knowledge varying in degrees of
abstraction which can assist with further decomposition and analogical identification.
(Vattam, Helms, & Goel, 2008, p. 18)

Additional research has also been conducted by the research team of Linsey, Wood and
Markman (2008) that examines both representational strategies within analogies as well as
the combination of functional modeling and sketching. The first area they address within
their research is the process of mental representation, which is identified as having four
main parts per research conducted by Markman (1999). These four components that make
up mental representation are:

- The representation itself, either in the form of a physical or mental construct (Linsey,
  Wood, & Markman, 2008, p. 4)

- The domain which is represented (Linsey, Wood, & Markman, 2008, p. 4)
• The rules that dictate how the parts of the representation are to be mapped onto the item being represented. (Linsey, Wood, & Markman, 2008, p. 4)

• The set of processes that utilize the information contained in the representation. (Linsey, Wood, & Markman, 2008, p. 4)

In addition to outlining the aforementioned components, this research also outlines the generally accepted structure of these mental representations. The form that these tend to take is that of a predicate-argument structure, which is comprised of a statement that makes a claim about some aspect of the subject (the predicate) and an argument that is the subject of the predicates assertion. An attribute is defined as a predicate with only one argument while relations are predicates with two or more arguments. As referenced in research by Falkenhainer, Forbus, and Gentner (1989), this is noteworthy because most analogies generally involve similarities between multiple domains within a descriptive set of relations. (Linsey, Wood, & Markman, 2008, p. 5)

Additional research within Linsey, Wood and Markman’s research pertain to analogical retrieval. One finding with particular relevance to the research addressed within this thesis looks at the ease of analogical retrieval between general and specific relational terms. The authors note that representations based on general terms such as “fill” or “travel” will be easier to retrieve than more specific terms such as “inflate” or “walk” (Linsey, Wood, & Markman, 2008, p. 9). An example of this provided by the authors is as follows: “…a domain represented using the relation walk will only be similar to domains that use some kind of locomotion, but a domain represented using the more general relation move will also be similar to relations like drive or fly. (Linsey, Wood, & Markman, 2008, p. 9)"
Further research within this study by Linsey, Wood and Markman (2008, p. 11) have also been conducted which examine how effectively analogical design is utilized based upon the level of experience of the practitioner – in reviewing these studies the authors bring up some important points. The success of an analogically-inspired design is influenced, at least in part, by the experience level of the designer – those with greater experience generally derive deeper, more insightful, solutions whereas less experienced designers tend to focus more on superficial similarities. (Linsey, Wood, & Markman, 2008, p. 18)

Within Linsey, Wood and Markman’s study, focus is also given to the cognitive processes that designers use when working with analogies to generate concepts. This process, as outlined by the authors, is composed of the following general steps (Linsey, Wood, & Markman, 2008, p. 41):

1. Encode the source
2. Retrieve the appropriate analogy
3. Map between target problem and analogical source
4. Develop solution based on inferences from mapping

The first step, encoding specificity, referencing work by Tulving and Thompson, is based upon a principle of memory retrieval that theorizes that the extent to which a memory is retrieved is relative to the degree of similarity between the context at retrieval and the context at encoding.

Of these steps, the next step – analogy retrieval – seems to be the most difficult for designers, per Linsey, Wood and Markman’s findings. The authors further theorize that this difficulty stems from the designer’s focus on the specificity of the problem solely within the context of the exact aspect of the problem currently being addressed. One of the main
findings of Linsey, Wood and Markman’s study was that in order to effectively generate design concepts using analogies, there is a need for support of this process through tools and methodological support (Linsey, Wood, & Markman, 2008, p. 26).

**Common Errors in Applying Biomimicry**

Helms, Vattam and Goel further explored various aspects of these approaches in subsequent research studies (Helms, Vattam, & Goel, 2009; Vattam, Helms, & Goel, 2007; Vattam, Helms, & Goel, 2008) and many of their other findings have relevance to the current research. Within their research, they identified a number of common errors that designers make when working through the biomimetic design process.

- **Vague definition of problem:**
  
  o Problems that are too vaguely defined tended to limit the designers abilities to identify functional descriptions or resulted in overly large search areas.

- **Poor solution selection:**
  
  o Designers chose biological solutions based upon superficial or otherwise unsuitable similarities.

- **Functional oversimplification:**
  
  o Underlying principles were overlooked due to assumptions that oversimplified the biological behavior, adaptation, etc.

- **Utilization of the organism, not the principles:**
  
  o Rather than look to how the selection biological solution performs the relevant action, designers would utilize the organism itself. In their findings, the example
the authors used as that of using fireflies to produce light rather than the principles of bioluminescence.

- Optimization simplification:
  - Instead of looking at the overall complexity inherent in biological solutions, designers frequently focused only on a single functional aspect.

- Solution Fixation
  - The first potential biological solution identified was frequently a source of fixation, to the exclusion of both further investigation and comparison to alternate solutions. In their findings, the authors note that only 11% of the designers in the study chose an alternate solution over their initial source selection.

- Analogical misapplication:
  - Flawed solutions resulted from attempts by designers to utilize high level or superficial analogies to improper solution space. The example the authors cited was that of the application of a two-way traffic optimization algorithm to a one-way traffic optimization problem.

- Improper transfer of analogies:
  - Unnecessary or inapplicable aspects of the biological source are transferred to the final solution.

Through a better understanding of these common mistakes and trends found by Helms, Vattam and Goel, the biomimetic design tool developed in this current study can be
designed to reduce the occurrence of these errors and support more comprehensive, multi-
functional solutions.

**Guidelines for Successful Application of Biomimicry**

Not every design solution is the ideal solution and the same holds true with the adoption and adaptation of bio-inspired design solutions as well. In many cases, direct emulation and mimicry of natural form or function may yield less than ideal results due to a variety of factors, including the lack of a complete and comprehensive understanding of all the underlying elements at work within inspiring organism or simply because of inherent differences between the actual and intended function of the element being copied.

Yielding similar findings to those of Mak and Shu (Abstractions of biological analogies for design, 2004), is research by Forbes (2006) that finds that among successful applications of naturally inspired designs most seemingly rely on nature for general design inspiration as opposed to specific. Forbes also notes that the more comprehensive the understanding of the underlying science of an organism, function, etc., the more narrowly targeted the resulting item is. Conversely, more broadly applicable items may be generated when our knowledge of the underlying science is less than complete. Through the use of the tool generated from the research presented here, designers will benefit from guidance pertaining to the identification, evaluation and application of biomimetic principles and sources of inspiration as well as hopefully avoid some of the more common errors and missteps that may occur when drawing inspiration from biological sources.

**Overview of Strategies in Nature**

In order to provide designers with guidance pertaining to biological principle and strategy identification within the design of this tool, it is necessary to provide designers both with an
overview of some of the guiding principles in nature as well as illustrative examples of some specific strategic methods. Through providing this information, designers will be better equipped to recognize functional trends between different biological sources of inspiration and also to identify other potential sources of inspiration with relevancy to their current and future design challenges.

Focusing on the primary types of functional and structural adaptations found in nature the Biomimicry Institute has created a biomimetically-focused biological taxonomy as part of their research (The Biomimicry Institute, 2008). Due to the overall length of the Taxonomy, a representative sample is shown in Table 6 and it is shown in its entirety in Appendix A. While this particular taxonomy does not directly pertain to interior design issues or challenges, virtually all of the functions outlined within it have parallels within interior environments and spaces. Owing to its comprehensive, logical structure, this taxonomy serves as the basis for the biological solution portion of the design tool generated within the current research. Further analysis of the benefits and drawbacks of the AskNature biomimicry database (The Biomimicry Institute, n.d.) that is based on this Taxonomy within the context and perspective of the interior design process can be found in Chapter 2: Review of Literature.

**Table 6**

*Example of Biomimicry Institute Biological Taxonomy*

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move or Stay Put</td>
<td>Attach</td>
<td>Permanently</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temporarily</td>
</tr>
<tr>
<td>Move</td>
<td></td>
<td>In/On solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In/On liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In gases</td>
</tr>
<tr>
<td>Maintain Physical Integrity</td>
<td>Protect from biotic factors</td>
<td>Animals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plants</td>
</tr>
</tbody>
</table>
TABLE 7

Example of Biomimicry Institute Biological Taxonomy, cont.

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protect from abiotic factors</td>
<td>Fungi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microbes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of gases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fire</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nuclear reaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dirt/Solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical toxins</td>
</tr>
</tbody>
</table>

The highest level of their taxonomy, Group, contains eight main categories that represent the main types of general functions identified in nature. These are: Move or Stay Put; Maintain Physical Integrity; Maintain Community; Modify; Make; Process Information; Break Down; and Get, Store or Distribute Resources. Each primary group is then comprised of Sub Groups, the second level, which break down the general functional category into more specific groupings with a total of 30 sub-groups in the Taxonomy (The Biomimicry Institute, 2008). These Sub Groups are then further distilled in the third and most detailed level, Function, where they are grouped into a total of 162 highly specific functional categories. Under a majority of the third level Function headings listed within their taxonomy, the Biomimicry Institute outlines specific examples of natural adaptations that address these functional challenges. Crucial to many of these biological adaptations are the specific materials and methods which nature utilizes to achieve these various functions.
Numerous resources exist which outline specific types and examples of design in nature, ranging from technical studies pertaining to nano and molecular scale material design and composition to broader scope sources focusing on general protective adaptations or investigations into the impacts of stress and strain on organisms and materials. Some areas, genus and species within this field have been particularly well documented while other organisms and adaptations are notably less well-understood. As a consequence, the listings of potential strategies presented in this version of the tool are inherently limited in some areas by virtue of a lack of available information. Some general strategies and approaches can, however, be more readily identified.

**Nature’s Building Materials**

In order to provide designers with a better understanding of some of the potential which biomimicry has to offer, it is important that designers have a basic understanding of some of the major principles, methods and functions that are commonly found in natural organisms. While the design tool presented here will provide biological guidance, links and additional information about these processes, possessing a basic familiarity with some of the more common adaptations may allow designers to even more rapidly recognize potential sources of information, or perhaps offer fresh directions for concept generation.

Taking a general view of design in nature, research conducted by the Benyus (1998) has identified certain basic principles, *Life’s Principles*, which govern natural design and processes:

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything
• Nature rewards cooperation
• Nature banks on diversity
• Nature demands local expertise
• Nature curbs excess from within
• Nature taps the power of limits

Examining these principles identified by Benyus within the context of engineering is research conducted by Thompson (1999), who creates a slightly modified version of these principles, entitled “Nature’s rules for sustaining ecosystems” (1999, p. 24). Thompson subsequently outlines areas in the design and manufacturing sectors in which each of may be applicable.
TABLE 8

Nature’s rules for sustaining ecosystems (Thompson, 1999, p. 24)

<table>
<thead>
<tr>
<th>Rule</th>
<th>Applicable Area(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use waste as a resource</td>
<td>Alternate raw material sources for manufacturing, re-manufacturing parts and design-for –disassembly processes</td>
</tr>
<tr>
<td>Diversify and cooperate to fully use the habitat</td>
<td>Formation of alliances between companies and communities</td>
</tr>
<tr>
<td>Gather and use energy efficiently</td>
<td>Utilize low-energy demanding materials and efficiently use heat within the manufacturing process</td>
</tr>
<tr>
<td>Optimize rather than maximize</td>
<td>Design modular products to extend product life cycles</td>
</tr>
<tr>
<td>Use material sparingly</td>
<td>Reduce and optimize materials used within products and processes</td>
</tr>
<tr>
<td>Don’t foul nests</td>
<td>Reformulate products, materials and processes to eliminate waste and reduce pollution</td>
</tr>
<tr>
<td>Don’t draw down resources</td>
<td>Utilize resources at the rate of replenishment and explore alternate material designs based on renewable resources</td>
</tr>
<tr>
<td>Remain in balance with the biosphere</td>
<td>Maintain a balance within the ecosystem in part through decreasing the use of fossil fuels</td>
</tr>
<tr>
<td>Run on information</td>
<td>Apply interconnectedness between companies, segments and sectors to reduce waste</td>
</tr>
<tr>
<td>Shop locally</td>
<td>Utilize resources based on local availability to negate the need for long distance transport of materials</td>
</tr>
</tbody>
</table>

Through the application of these principles within the life cycle of products, Thompson finds, improved environmental performance can be obtained from both manufacturing facilities and products alike. (Thompson, 1999, p. 30) Another researcher examining natural principles and approaches to design is Vogel (1998). Within his research, Vogel has conducted comparisons on a variety of different aspects of natural and human technological methods. These general comparisons are shown in Table 9.
TABLE 9

Natural versus Human Technologies

<table>
<thead>
<tr>
<th>Category</th>
<th>Nature’s Strategies</th>
<th>Human Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Characteristics</td>
<td>Wet/Flexible Structures</td>
<td>Dry/Stiff Structures</td>
</tr>
<tr>
<td>Metal Usage</td>
<td>No Metal</td>
<td>Uses Metal</td>
</tr>
<tr>
<td>Wheel Use</td>
<td>No wheels</td>
<td>Wheels with rotary motion</td>
</tr>
<tr>
<td>Engine Types</td>
<td>Engines contract or slide</td>
<td>Engines expand or spin</td>
</tr>
</tbody>
</table>

These principles and constraints shape both the form and function of natural systems, processes and products and the general understanding of these principles can provide useful insights for designers in regards to production and design methods and factors.

Vogel also examines a variety of different methods and strategies found in nature, and while it is impossible to elaborate on every type of functional adaptation, a brief overview of a few of the strategies with particular relevancy to interior design will provide some insights into the general nature of many of these adaptations.

**Stresses and Structures**

Regardless of whether the structure is made by nature or created by man, the same stresses still apply. The main forces acting upon structures include tensile stress (pulling), compressive stress (pushing) and shearing. Nature and man have developed different, yet similar, structures to address each of these stresses: ties are those elements affected by tensile stress while struts are impacted by compressive stresses. While obviously similar in function, these elements do take on somewhat different forms – some examples of these different approaches are outlined in research by Vogel (1988). Serving as ties in nature, are elements such as muscles, tendons and strands of silk. (1988, p. 290) Equivalently functioning man-made elements include cables, ropes, belts and some rods and bars. Some
examples of natural struts are bone, hard coral, tree trunks and insect cuticle (1988, p. 72) while man-made ones include some rods and bars, walls and columns.

In a test of tensile strength, the shape of the sample material is relatively inconsequential – pulling on any material, regardless of shape, will result in elongation along the direction of the force. (Vogel, 1988, p. 128) In contrast, sample shape does make a difference when measuring compressive strength. Compression to a sample that is wider than it is tall will result in bulging running perpendicular to the direction of the force. (1988, p. 135) If the sample is more narrow than tall, it will cause the sample to bend to one side and, if enough force is applied, eventually break. One major area of potential applicability within interiors is the design of furnishings, since the components typically undergo frequent periods of stress and strain.

**Protective Coatings**

Nature has evolved a few different methods of ensuring that the organism is protected from potential harm from the external environment and these adaptations are classified as the integumentary system. The integumentary system has evolved in six major forms (Hoagland, Dodson, & Hauck, 2001):

- Layers of epidermal cells
- Thin layer of cuticle over epidermal cells
- Calcium carbonate cells
- Wax coated chitin cuticle over epidermal cells
- Thin, spine coated epidermal cells
- Keratinized skin
Regardless of the form it may take, the integumentary system is a highly multifunctional organ – some of its more primary functions include protection of the internal organs, infection prevention, moisture regulation, thermal sensation and regulation. In some organisms, it may also store vital elements as well as sense touch and pressure. Further exploration into these strategies can have applications in a variety of areas within interiors including wall and floor coverings, healthcare and protective surface finishes.

**Other Functional and Adaptive Strategies in Nature**

Based upon the Biomimicry Institute’s “Biomimicry Taxonomy” outlined in the beginning of *Overview of Strategies in Nature*, research was conducted to identify some of the more common, general types of adaptive strategies which nature utilizes to perform each function. There are, particularly at a micro-scale level, innumerable different methods of functional achievement and the following list shown in Table 10 serves to highlight only a select few of these adaptations.

**Table 10**

*General Strategic Adaptations*

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Function</th>
<th>Strategies Utilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attach</td>
<td>Permanently</td>
<td>Adhesive flexible anchors hooks suckers</td>
</tr>
<tr>
<td></td>
<td>Temporarily</td>
<td>Adhesive hooks suckers</td>
</tr>
<tr>
<td>Navigate</td>
<td>Through air</td>
<td>Echolocation or Sonar See or Respond to different wavelengths of light See or Respond to magnetic fields Smell</td>
</tr>
<tr>
<td></td>
<td>Over land</td>
<td>Electrosensitivity See or Respond to different wavelengths of light Smell</td>
</tr>
<tr>
<td>Send Signals</td>
<td>Sound</td>
<td>Sound Amplification or Deadening via Anatomical Adaptations Sound Amplification via Environmental Adaptations Sonar</td>
</tr>
</tbody>
</table>
Although a significant amount of further research is required to identify the general strategic adaptations for all of the functional categories within the Biomimicry Taxonomy, since currently no single, concise resource exists to identify these. For those functions in which a listing of general strategic adaptations does exist however, these strategies will be included within the biomimetic tool designed here.

**Information Seeking Methods, Behavior and Procedures**

In order to design a biomimetic tool which is useful to interior designers, it is necessary to research various information collection and distribution methods, the various types of information seeking behavior as well as the merits and potential drawbacks of these methods and processes. There are many different tools and methods for information search and retrieval – these can range from traditional sources such as indexes in books and library card catalogs to relatively more recent approaches utilizing digital and internet-based resources and search methods. The pervasiveness and general accessibility of computers, laptops and other handheld devices however supports the construction of this tool on a digital platform.

Within the realm of digital technology, there exists a wide range of program options to support the construction and utilization of this tool. These various methods and processes are not equally well suited though to provide the ideal framework and functionality required for this tool to be successful.

In order to determine which program is ideal, it is first necessary to outline the desired features and functions to be included in this tool. To allow it to be utilized to its full potential, there are a few different requirements the tool should meet.
• It should be user friendly through a simple, intuitive, user interface

• Necessitate minimal training or prior knowledge

• Be stand-alone - not requiring specialized software or internet access to be functional

• Simple to modify and update

• Support multi-modal search techniques

• Provide visually enhanced search capabilities and graphical search results

By fulfilling these requirements, it is possible to create a tool that is both easy to understand and convenient for designers to use, which will consequently further the exploration and adoption of biomimetics by interior designers.

**Software Options and General Tool Design**

Within the context of the digital environment, two common methods of data storage and retrieval are spreadsheets and databases. There are a number of different database and spreadsheet programs currently on the market, however to allow this tool to reach the broadest possible audience, working with one of the more commonly used programs is preferable. Of the range of potential programs, two of the most easily accessible to the general user are Microsoft Access, a database program, and Microsoft Excel, a spreadsheet application, both programs that are commonly installed on machines running Microsoft Office. Other programs, such as Filemaker Pro, were considered as well, but these would necessitate the purchase of specialized software that may render the program inaccessible to a many potential users.

In addition to the availability of the program needed to run the tool, consideration was also given to the familiarity of the typical user with the program. One study, conducted by Jeanne
Baugh (2004), looked at the skills and knowledge of undergraduate students in spreadsheet and database programs using Microsoft Excel and Access, respectively. In Baugh’s study, students were tested for competency in both programs and the overall results showed a greater percentage of students were successful with those tasks associated with Excel then with Access.

In addition to the potentially greater ease of use afforded this tool by the relatively higher degree of general familiarity with Excel, the use of a spreadsheet based program offers other benefits as well.

**Spreadsheet and Software Capabilities**

There are quite a few benefits afforded by the use of Excel, and spreadsheet based programs in general, that provide the tool with an enhanced degree of flexibility and usability that would be difficult to achieve with other program options.

Instead of organizing data into separate records, as is typical with databases, spreadsheets organize data in a tabular format. The data visibility and accessibility consequently found in spreadsheets through the entry and storage of data all on one sheet or, in the case of large amounts of data, in one workbook means that users can easily locate, review and, if necessary, modify the data in question. Changes and additions to data are also typically straightforward since there is no need for re-coding or modification of the underlying structure of the sheet. Having all data visible on one sheet, in conjunction with other sorting and filtering options, also allows for easy organization of records and information. Because all data is stored within the Excel document file, there is no need for digital packaging of images or fonts if the file is being transferred to another system. In addition to ease of portability between systems, Excel files can also be easily copied or imported into other systems.
Microsoft Office programs owing to the compatibility between programs in the Office Suite. This same flexibility also allows data from other Microsoft programs to be copied or imported into Excel as well.

Spreadsheet programs like Excel are commonly used for numerical data and formulas as opposed to imagery and textual data, however there are some relatively simple enhancements that can provide Excel with additional search and imagery related capabilities. These enhancements, macros and Visual Basic, which are two of the advanced features of Excel, can subsequently provide a nearly limitless range of functional capabilities. In the design of this tool, Visual Basic is primarily utilized to improve the search feature with macros adding functionality, primarily through the addition of hyperlinks, to the images representing each main category and the functional sub-categories.

**Search Strategies**

Another important consideration with the design of this tool is related to the way users search for and locate information, as this will shape the overall form of the tool. Modern technology is constantly evolving and along with this comes a change in the way which information is found – even something as commonplace as looking for a book in the local library has transformed from thumbing through a card catalog to a more rich, interactive experience. In fact, it may not even require a trip to the library or, with eBooks becoming more common, even checking out a physical book at all.

In order to identify the characteristics and elements that will most effectively support information seeking behavior of the biomimetic tool users, two different research studies have been examined. Research conducted on this subject by Weiler (2005) comparing various aspects of information seeking behavior of Generation Y students identified a few
noteworthy trends. While most of Weiler’s findings pertain to college student research behavior, the findings show that Generation Y tend to be visual learners and tend to be more receptive to different search techniques if the use of these approaches will save time. Finally, ease of use is also found to be highly important when looking for information (Weiler, 2005). Another, more in-depth, multi-year study of research behavior of students shows similar findings, noting a high level of technological competency along with a willingness to seek information and research advice from others including peers and supervisors.

**The Current Biomimetic Database, Search Engines and Other Resources**

For designers currently seeking to explore biomimicry or locate sources of biomimetic inspiration, their potential search options are limited. These options are centered primarily around biological or engineering specific texts or the sole biomimetic database currently available on the internet.

To fully explore the printed resources pertaining to biomimicry and biologically sources of inspiration, extensive research into biological, engineering and botanical texts is typically required. While these sources are abundant, the sheer volume of potential literary sources and the differences in terminology between disciplines can deter exploration. Internet based databases and search engines, while more straightforward in regards to direct access to relevant information, are notably less abundant.

There is currently only one web-based database and search engine focusing on biomimetic sources, AskNature which is located at [http://www.asknature.org](http://www.asknature.org), the biomimetic database created by the Biomimicry Institute and various collaborators. (Biomimicry Taxonomy, 2008) There are numerous beneficial attributes afforded by the design of this database however,
there are also many potential opportunities to enhance its effectiveness to designers, specifically interior designers and the design process in general.

The site consists of five different categories:

- People provides contact information for biologists, designers and others interested in biomimicry
- Groups is comprised of dozens of different groups focusing on biomimetics within a wide range of areas and sectors
- Forum discussions provide discussion boards for many biomimetic related topics
- Products identify various products which have utilized biomimetics ranging from theoretical products to prototypes to products currently mass produced
- Strategies examine a wide variety of natural adaptations based upon the functional groups identified in the Biomimicry Taxonomy

This format provides designers with a number of different benefits. People and groups can assist users with connecting with like-minded individuals and similarly focused groups. Forum discussions can further this dialogue and within AskNature.org there are forums devoted to biomimicry within a wide range of fields and areas.

The AskNature site (The Biomimicry Institute, 2008) tutorial lists four primary ways to use the site

- Explore by visiting strategy pages
  - Examples of these include:
    - **Mating call is amplified**: Bornean tree-hole frog
- **Scales enhance wing color: swordtail butterfly**

- Explore similar strategies by browsing through other entries in the biomimicry taxonomy via a link to the biomimicry taxonomy through a pop-up window located on the strategy page.

- Browse directly through the biomimicry taxonomy.

- Search by keyword, challenge, name or other relevant terms via a search box.

The first method of usage, via exploration of strategy pages, is both potentially beneficial and potentially detrimental to designers attempting to apply biomimicry using a problem-driven approach. An example of a typical strategy page is shown in Figure 6.
FIGURE 6

AskNature Strategy Page
Of benefit to designers in the AskNature site is the great deal of species specific information contained within the strategy pages as well as listings of additional references and sources of information. At the same time, as shown in the research earlier in this chapter, this immediate identification of a particular strategy within the context of a specific organism frequently leads to a fixation on the strategy or species and may potentially limit the variety and creativity expressed in the potential solutions.

Another noteworthy issue in regard to the design and content of the strategy pages is the lack of helpful imagery. Given the preference toward visual learning displayed by designers there is a noteworthy lack of detailed or relevant imagery on many of the strategy pages. Some strategies do not show any visual imagery, others provide only semi-relevant or less then helpful images and only a relatively small number of pages with detailed imagery of potential benefit to interior designers.

Looking at examples, shown in Table 11, of a few of the photographs found on various AskNature strategy pages, it is difficult to identify the specific strategy or functional adaptation portrayed through the image alone.
TABLE 11

AskNature Strategy Image Examples

<table>
<thead>
<tr>
<th>Representational Image</th>
<th>Depicted Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scales enhance wing color: Swordtail butterfly (The Biomimicry Institute)</td>
<td></td>
</tr>
<tr>
<td>Walls keep insect feet from sticking: Pitcherplants (The Biomimicry Institute)</td>
<td></td>
</tr>
<tr>
<td>Dense underfur insulates: Reindeer (The Biomimicry Institute)</td>
<td></td>
</tr>
</tbody>
</table>

This lack of clarity in many of the images representing each strategy and the lack of visual aids in general within the AskNature biomimetic database is the subject of discussion in one of the forums on the AskNature website. This discussion, located in the Biomimicry Visuals forum (The Biomimicry Institute), focuses on the role of imagery within the strategy section of the AskNature database. The consensus of many of the forum participants is that visuals would be a great asset, with posters noting that text alone often provides inadequate descriptions of the various strategies and processes featured. (Ritter & Southcott, 2009)
In light of both the benefits, noted in Chapter 2, provided by the visual presentation of information as well as the user preference for images rather than textual information, the tool designed here will incorporate visual aids.

Another usage method identified within the AskNature site tutorial (The Biomimicry Institute, 2008) is the option of exploration through browsing directly through the various strategies.

**Figure 10**

*Biomimetic Strategy Browsing*

Beneficial to designers in this method is the ability to reasonably quickly select the most relevant strategy to the problem being addressed and immediately view a list of organisms that have successfully addressed this challenge. As with the strategy pages, there are some
of the same drawbacks in the design of this page as well. Most notably there is a lack of relevant visual imagery, though selection of a particular function in the column on the right side of the screen will bring up a preview of the strategy page. This page design can also lead to fixations since there is no simple way to identify the underlying methods of functional achievement. Additionally, with literally thousands of different strategies to browse through, a significant amount of time would be required to browse through all potential strategies to identify the most likely relevant solution to the design challenge.

Search by keyword is another option within the AskNature database and this option too comes with some positive and negative issues. An example of a keyword search for the word "protect is shown in Figure 11.

**Figure 11**

*AskNature Keyword Search*
While this search yields an abundance of potential strategies, many of the same issues that plague the other sections of the AskNature site are found here as well. Most notably, these include the lack of visual imagery and an overabundance of potentially relevant strategies to search through. The search for the keyword “protect”, shown in Figure 11, resulted in 354 different strategies.

In light of these issues, there is a great need for a biomimetic tool that more effectively supports the visual preferences and design processes practiced by interior designers. In order to design a tool that successfully met those demands, more research was conducted on a variety of elements and features to identify those that would be most beneficial to include.
Chapter 3: Methods and Procedures

To create a tool that most effectively supports the design process of interior designers, it was necessary to first outline the preferred features and requisite functions the tool would ideally need and subsequently identify the best method of achievement for these requirements. There are a few main requirements identified for this tool pursuant to the findings of the researchers noted in Chapter 2 including Vattam, Helms and Goel (2008), Weiler (2005), and Benyus (Biomimicry: Innovation inspired by nature, 1998).

Based on the findings of Helms, Vattam, Goel, Yen and Weissburg (2008), Rossin and Histrich, Benyus, & Baumeister (2009), this tool is designed to support a problem driven approach. This is achieved through the use of a visually non-representational functional taxonomy based on the Biomimicry Taxonomy (The Biomimicry Institute, 2008). A neutral, non-representational approach will allow designers to more effectively apply the search strategies identified by Helms, et.al. (2008). The search strategies most effectively supported by this generalized approach include “Adjust Constraints” and “Find Variations”. Additionally, this will also deter any fixation on a particular method, strategy or organism.

The research and findings of Vakili and Shu (2001), and Weiler (2005) support the creation of this tool on a digital platform and also highlight the need for a search method that can address differences in terminology.

As shown in research by Mak and Shu (Abstractions of biological analogies for design, 2004) as well as Vattam, Helms and Goel (2009), biomimicry is ideally applied in a principle driven approach as opposed to merely mimicking form. Consequently, this tool is designed to initially provide a broad overview of potential functional methods with the introduction of specific organisms occurring later in the biologically source identification process. As with
the use of non-representational imagery, this will also discourage fixation on specific strategies or species.

General Tool Content and Layout

After determining the general requirements and overall structure of the tool, the basic contents of each page were mapped to allow for organization and visualization of the main sections of the tool. To be optimally effective, each section of the tool needs to accomplish a slightly different set of functions.

- Main Page
  - Offer designers a preliminary introduction to biomimicry
  - Provide a centrally located search option to allow for intuitive, cross disciplinary keyword searching
  - Permit easy access to the tool’s biomimetic content
  - Visually identify the basic groups outlined in the highest level of the Biomimicry Taxonomy and provide
  - Support the preference for visual information seeking behavior of designers.
  - Provide instructions on how to use the tool

- Secondary Pages
  - Visually depict the sub-group and function levels of the Biomimicry Taxonomy
  - Provide links to additional information on strategies and biological sources of inspiration.
To achieve these goals, a number of different strategies were employed. To aid with clarity, memorability and the overall ease of navigation, a simple, consistent style is used throughout. Also providing guidance pertaining to the navigation of the tool itself is a link to a brief user's guide detailing both the main functions of the tool and how to use the features contained therein. Further assisting designers new to the concept of biomimicry is the addition of a brief introduction to biomimetics.

There are numerous ways that the concept of biomimicry can be introduced within this tool. Some of these methods include the insertion of explanatory and descriptive text pertaining to biomimicry within the main content area of the initial page of the database, as a sidebar on the initial page or contained on a separate page that is accessed via a link on the initial page. For designers new to the concept of biomimicry, this information should be easily located in the database, preferably on the main page. For those already familiar with the concept, the placement of this information should not hinder or impede their access to the records and information in the main body of the tool. Since the research and information seeking studies reviewed in Chapter 2, Search Strategies, have identified general preferences for expediency and easy navigation when using new systems of research, requiring users to click multiple links and navigate to new windows to gain an introduction to biomimicry could potentially deter users from accessing this information.

In light of this need for easily accessible yet unobtrusive information, the introductory information about biomimicry is located in a sidebar on the initial database page allowing it to be quickly located by new users of the site while still allowing the predominate content of the main page to be devoted the various access points of the actual database.
Within the context of the initial database page, there are a few options for sidebar placement, which are illustrated in Figure 12.

**Figure 12:**

*Sidebar Placement Options*

Based upon the dual requirements of easily accessible and unobtrusive along with the need for the biomimetic introduction to be immediately visible to new users, this information will be located on the right-hand side of the page. This placement ensures that the introduction is immediately obvious to those needing the information, but does not interfere with the main content of the page.

Because this tool is reliant on visual imagery, it is necessary to design icons and imagery that effectively illustrate the Groups, Sub-Groups and Functions, it is necessary to both what information needs to be conveyed within the images and to also understand how we recognize and interpret objects and visual forms.

In the case of the various categories of information used within this tool, the imagery associated with them need to clearly communicate the general function each represents without explicitly illustrating one specific system or method of achievement. (The crossed arrows icon used to represent “Move” is an example of this – illustrating what is being done as opposed to how the action is being achieved.) To effectively design these icons, research
was conducted on various methods used to design icons and also into the general principles of icon and symbol design.

**Icon & Information Design**

To effectively incorporate imagery into the design of this tool, it is necessary to better understand the elements and characteristics of successful icon and imagery design, since information can be presented in a variety of different ways and in a variety of styles utilizing visual and textual information. As the findings in the various studies examined within this current research support, visual imagery is typically identified and processed more quickly than text. When viewed in conjunction with the tendency toward visual learning styles commonplace among designers this encourages the use of a more visually based design for this biomimetic tool.

The properties and characteristics of an image can greatly affect its readability as well as the viewer’s overall perceptual understanding of it. Given that one of the overall goals of this database is to introduce users to potential biological sources of inspiration as well as impart a basic overview of the functional and mechanical properties of these organisms, it is crucial that the accompanying imagery be clear, concise and easy to understand.

There are numerous artistic and visual styles that could be applied to the imagery in this tool, each of which would convey differing levels of information and vary in their overall readability and information content. While there is not necessarily one specific style or visual approach that is consistently most appropriate for conveying the greatest amount, there are common attributes that all well designed graphical elements share. Quite a bit of research has been conducted on the impact and effectiveness of various aspects and characteristics
A study by Sarkar & Chakrabarti (2008) examined the effectiveness of various visual and non-visual representation methods on the quality and quantity of design idea generation. The influence and efficacy of the selected representation types - including imagery, video and text, were examined through the use of these representation types as design triggers. The authors define a trigger as “an agent that encourages exploration and search of design spaces to begin or increase” (Sarkar & Chakrabarti, 2008, p. 107). Among the findings outlined in their research, Sarkar and Chakrabarti note that the effectiveness of a trigger depends both upon the context in which it is used and also on how it is represented. After examining the impact of various types of representations on idea generation, they find that non-verbal representations, specifically images, yield both greater variety and greater numbers of ideas generated by the designers studied. Their findings also indicate that the combination of non-verbal and verbal may further increase trigger effectiveness. Finally, designers were also observed to utilize similar idea generation approaches based upon trigger type with non-verbal triggers resulting in more ideas being generated non-verbally and verbal triggers resulting in more textual based ideas. (Sarkar & Chakrabarti, 2008, p. 115)

In light of this research, to effectively support the interior design process, which traditionally relies on imagery for concept generation, the use of visual, illustrative imagery within the tool is preferential.
Image Design

Because the functionality of this tool relies heavily on visualizations and visual attributes, well-designed imagery and iconography is crucial for its clarity and usability. In order to design effective, legible images and icons, research was conducted on numerous aspects of pictorial design. The initial step in this process was to identify the general type of graphic elements best suited to present the desired information. There are many different types of visual imagery that could be utilized within this tool and a variety of research pertaining to icon design and imagery is reviewed below to identify the preferential icon and image characteristics.

An in-progress work by Payne and Starren (2006) looks at one potential design method, called “Presentation Discovery”. Their research seeks to develop an icon design method as part of their research into alternate design methodologies of graphical interface components. Within the framework of their research, Payne and Starren reference the Peircean Triad, which is a method of representing the three main components that make up an effective icon or symbol design. The example the authors use to visually illustrate this is the diagram of a printer icon, shown in Figure 13.
The framework proposed by Payne and Starren as illustrated in the Peircean Triad is based upon three main elements: an object, the representamen and the interpretant. The object is defined by the authors as the concept to be represented, the representamen is the sign that represents the object and the interpretant is the end-user's interpretation of the concept. (Payne & Starren, 2006, p. 2). The authors hypothesize that incorporation of all three of these relationships is necessary for effective graphical user interface design and evaluation methodologies and the preliminary results of their study support this theory.

Although still a work in progress, Payne and Starren’s initial study consists of four primary components:

1. Domain concept identification (Payne & Starren, 2006, p. 3)
2. Survey of domain experts to obtain “candidate graphical primitives”, which are defined by the authors as “the most representative graphics within a prototype set”. (Payne & Starren, 2006, p. 4)

3. Sorting of “candidate graphical primitives” into categories based upon visual characteristics. (Payne & Starren, 2006, p. 4)

4. Derive prototypical representative graphics from sorted graphics. (Payne & Starren, 2006, p. 4)

While not all aspects of their study can be directly applied to the design of the iconography used in the tool presented in this current research, the general methodology offers a unique approach to icon design. In lieu of a survey of biomimetic and icon design experts, a search will instead be conducted of existing, conventional, icons that correspond to the main category headings found on the initial page of the tool to determine the common trends in design and representation.

Looking at icon and image design methods from the perspective of semiotics is research by Abdullah and Hubner (2006), who have written a guide to information graphics that provides a thorough overview on the topic. Semiotics, the study of symbols and how they are used, is the first area they recognize. They identify four different branches of semiotics: semantics, sigmatics, syntactics and pragmatics.

Semantics, which focuses on signs and meanings, looks at the conditions in which a sign is understood including: context, knowledge, culture and social circumstances.

The next area, sigmatics, deals with the relationship between the sign and what it signifies. More specifically, the degree of representation or abstraction between the sign and what it
represents. Abdullah and Hubner identify three main sigmatic categories: icons, symbols and indexes. (Abdullah & Hubner, 2006, pp. 14-15)

Icons, as defined by the authors, have visual connections with what they signify. These can range from realistic representations, such as photos, to more abstract representations such as paintings or illustrations. Regardless of the degree of abstraction however, icons still bear a direct visual resemblance to the signified object. This visual relationship is exemplified through similarity in form, color or other types of visual attributes. (Abdullah & Hubner, 2006, p. 14)

Symbols are the second category; these are purely representational and lack any syntactic relationship to the subject being represented. One example of this type cited by Abdullah and Hubner is the use of a green letter "F" to indicate a fire extinguisher – neither the color nor the form bears any resemblance to an actual fire extinguisher. Abdullah and Hubner point out that if the letter had been red, then this would have exemplified a highly abstracted type of icon. (Abdullah & Hubner, 2006, p. 15)

The final category, indexes, are signs that can be either symbols or icons and also have direct spatial and possibly temporal references to what is being represented. A sign on the door leading to a restroom would be an example of spatial reference, note Abdullah and Hubner (2006, p. 15). A place sign can be considered time sensitive in the sense that it will only be accurate for as long as the town’s boundaries remain the same.

Because the goal of this tool is to provide explanations and examples of functional concepts and methods through visualizations, iconographic imagery is more appropriate than symbolic.
Visual Components and Composition

In addition to the methodological findings of Payne and Starren and the visualization categories identified by Abdullah and Hubner (2006), additional research is also necessary regarding the various aesthetic and compositional elements that make up an icon. Consequently, a few different sources were consulted to determine the appropriate form and style of the images designed for the biomimetic design tool designed here.

The first of these sources is research by Schroder and Martina (2008) investigating the effects of icon design in the context of semantics. Looking at icon design for mobile phone applications, their research examined icon concreteness, icon complexity and age of user. In a majority of cases, the icons most quickly linked to their represented function were those that were concrete and simple. Concreteness is defined by the level of abstraction and simplicity is measured by the amount of detail represented. Generally, those icons most readily identified are those that bear a visual similarity to the function being performed and/or the element that was affected. For example, the most effective icon for headset showed both a head and headphones as opposed to solely depicting the headphones. Vibration was another icon that readily illustrates this, Shroder and Martina found that imagery of both a phone and vibration lines was more effective than just vibration lines.

Consequently, these findings support the inclusion of both the function and object being impacted by it within the design of the imagery for the biomimetic design tool presented in this thesis. For example in the imagery depicting the concept “Protect from Excess Liquids”, shown in Figure 14, increased legibility may be gained from the inclusion of a simple object within the symbolic image of protect.
Because of the variable nature of the potential type of object or system being designed, the images are inherently more abstract, since higher levels of concreteness toward one specific type of item may lead to confusion or ambiguity of applicability to the problem at hand.

To further ensure the design of effective icons, a few different sources were consulted on the characteristics and components of successful image and icon design and the various findings of this research are outlined below.

The first of these sources is the research conducted by Ware (2000), which provides a good overview of a variety of aspects of information visualization pertaining to the benefits of using visualizations, design of visual imagery and the comprehension and perception of visualizations. Some of the main benefits afforded by visualizations versus purely text based descriptions include:
• Visualizations can facilitate immediate comprehension of large amounts of data (Ware, 2000, p. 2)

• Visualizations can highlight previously unnoticed trends or characteristics (Ware, 2000, p. 2)

• Visualizations can assist with data comprehension of both large and small scale aspects of data (Ware, 2000, p. 2)

• Images are preferable for showing structural relationships (Ware, 2000, p. 319)

In his research, Ware identifies two different types of visualizations: Sensory and arbitrary (Ware, 2000, p. 10). Sensory images are inherently understood and do not need to be taught, consequently they are understood across different cultures and times. Arbitrary visualizations, on the other hand, must be learned to be understood and derive meaning from their respective places in culture and time.

One well-known theory that Ware refers to is the Geon Theory, which was developed by Hummel and Biederman in 1992. (Ware, 2000, p. 249) This theory provides insights into the order of visual perception. Within the context of Ware’s research, he provides a brief overview of the main steps of object recognition that are explained by this theory.

• Image edges are the first elements recognized when perceiving objects (Ware, 2000, p. 249)

• Component axes, vertices and oriented shapes are recognized next (Ware, 2000, p. 249)

• The third set of elements, called geons, are the basic 3 dimensional forms such as boxes, spheres and cones (Ware, 2000, p. 249)
• The extraction of the underlying connective structure is the final step, which results in object recognition (Ware, 2000, p. 249)

This initial recognition of contour elements within object recognition supports the idea of a concise graphical style for the imagery designs within the biomimetic design tool.

Also looking at the visual characteristics of document design and icons is the work of Kostelnick and Roberts (1998). Their research outlines many different elements and aspects that inform the visual characteristics of imagery within the biomimetic design tool presented here.

Within their research, Kostelnick and Roberts examine what they term “Visual/Verbal Cognates” (Kostelnick & Roberts, 1998, p. 14). They identify six cognates, shown in which they organize in pairs based on the portion of the document that they affect.

**Table 12**

*Visual/Verbal Cognates*

<table>
<thead>
<tr>
<th>Cognate Pairs</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrangement / Emphasis</td>
<td>Affect the organization and visual format of the document</td>
</tr>
<tr>
<td>Clarity / Conciseness</td>
<td>Affect the efficiency and legibility of the document’s design</td>
</tr>
<tr>
<td>Tone / Ethos</td>
<td>Affect the response of the reader to the document’s visual language and quality of the document</td>
</tr>
</tbody>
</table>
Scope

Another focus of Kostelnick and Robert’s research is scope. Scope looks at how much information is shown in the image and in what context. As noted by the author, a wider scope will contain a greater quantity of information though there is a point at which this can become overwhelming to the viewer. For the design of the imagery used in this tool it was necessary to limit the scope to show only a simplified overview of the general functions being identified within the Biomimicry Taxonomy.

Another source of research on icon and pictorial design is that of (Pettersson, 2002), which focuses on a wide range of topics including message, text, image, graphic design and cognition. Of particular importance toward the design of the icons and imagery in this tool is the information pertaining to image design and cognition.

In looking at image design, both Pettersson (2002) and Kostelnick and Roberts (1998) examine image creation through a number of basic components. Those elements with particular relevancy to the linear style used for the creation of the icons in the biomimetic design tool include line, area, perspective and color usage.

Line

As noted by Pettersson (2002), line can be an extremely important visual element, playing a number of important rolls within the image. It can influence not only the overall clarity of the image, but also the viewer’s visual understanding and comprehension of the information presented by the graphic. The direction of a line can impart a variety of meanings within an image and the icons within this biomimetic design tool leverage many of these conceptual constants. Examples of some of these, identified by Kostelnick and Roberts (1998), include:
• Horizontal Lines (Kostelnick & Roberts, 1998, p. 116)
  o Perceived as calm, stable, restful and relaxing
  o Representative of the horizon

• Vertical Lines (Kostelnick & Roberts, 1998, p. 117)
  o Represent power
  o Stop eye movement

• Diagonal Lines (Kostelnick & Roberts, 1998, p. 118)
  o Create a sense of motion and energy
  o Draw the eye

In his research, Ware (2000) also looks at the role of line in visualizations and visual processing. Within his findings, he notes that the extraction of linear features is one of the most important components of visual processing and furthermore, when the viewer has limited time to study an image “…simple line drawings may be most effective for quick exposure” (Ware, 2000, p. 320). Additionally, research by Inaba, Parsons and Smilie (2004) finds that higher contrast, simple illustrations are typically more effective than photographs, since photographs may be ambiguous due to a lack of contrast and visual clutter. Also comparing illustrations in the form of line drawings and photographs is research by Ryan and Schwartz (1956), which finds that objects portrayed as line drawings are more quickly recognized than photographs of the same objects. Because lines play such a strong role in visual recognition and understanding, the iconography designed for this tool will be primarily comprised of line drawings.
Area

Area is another element examined by Pettersson (2002). As defined by the author, area includes a shape formed by the joining of lines or an element of a differing shade, pattern, or color then the surrounding space. Pettersson also cautions against the use of five or more different shades, colors or patterns within the same picture particularly if the image is to be reproduced on a copy machine, as similar colors may not yield distinct color fields. (Pettersson, 2002, p. 130) Consequently, if different colors, shades or patterns are to be used, they should ideally be highly distinct from one another to preserve visual clarity.

Perspective

Within his research, Pettersson cautions “…depth can add unwanted complexity and bulk, especially to icons” (Pettersson, 2002, p. 366). In addition to the findings of Pettersson, Kostelnick and Roberts (1998) also note that the addition of perspective and depth can decrease the overall legibility of graphic elements.

Color Usage

Further elaborating on the use of color, Pettersson notes that while color can be crucial to eth comprehension of an image, there may be instances when its use is not always warranted or desirable. “Color is important in a visual when it carries information that is vital to the contents in the visual.” (Pettersson, 2002, p. 131)

Because of the generally abstract nature of the information presented and subsequent design of the images for this tool, the addition of color would typically impart little if any useful information to the viewer regarding either the general functional category of the method of adaptation used to achieve this function. Consequently, the visuals presented in this tool will be limited to black and white except for instances where the use of color and
shading plays a vital role in the viewer’s comprehension and understanding of the images and concept being presented.

**Graphical Conventions**

As noted in the research by Payne and Starren (2006), the use of conventional graphical elements can aid in viewer comprehension. This same concept is examined more closely in research by Matthews (2000), which looks at various methods and approaches for illustrating technical ideas and principles.

Initially, Matthews provides five principles to guide in the creation of effective technical graphic presentations.

- Use graphical means where possible (2000, p. 3)
- Use diagrams, graphics or geometric models in conjunction with mathematical formulas and notations (2000, p. 3)
- Use visual models to illustrate ideas and concepts (2000, p. 3)
- Use approximations where appropriate (2000, p. 3)
- Use graphics, diagrams or sketches (2000, p. 3)

In order to effectively illustrate technical information, Matthews suggests it is beneficial to understand what type of information is being presented. Consequently, he outlines three main types of information: guidance-only, symbolic/schematic, and prescriptive.

**Guidance-Only**

(Matthews, 2000, pp. 5-7)
Guidance-only information does not necessarily illustrate a specific object or theory, but rather provides more general information or approximations. Examples of the types of approximations this might include are:

- Basic relationships between objects, processes, etc.
- Size or motion trends
- Object or component arrangement, shape or layout
- Dimensions

*Symbolic/Schematic*

(Matthews, 2000, pp. 7-8)

This category is comprised of two similar types of information: symbolic and schematic. The author defines these terms as follows:

- Symbolic: Information is represented through the use of symbols, which use convention, resemblance or association to convey meaning. (Matthews, 2000, p. 7)
- Schematic: Information is represented through the arrangement of generally symbolic objects. (Matthews, 2000, p. 7)

One of the main benefits of the use of symbolic/schematic representations is that they allow for the presentation of complex information in a more easily understood manner. Matthew’s provides a few examples of the types of information that is commonly displayed this way, which include:

- Process instrumentation diagrams
- Circuit diagrams, including pneumatic, electrical, hydraulic, etc.
• Structural or functional diagrams

• Symbolic imagery

**Prescriptive**

(Matthews, 2000, pp. 8-10)

This final category of information outlined by the author is composed of highly accurate, highly technical representations. As further described by the author, this type of information “sets down firm rules, or provides an exact description of something”. (Matthews, 2000, p. 8)

Examples of this type of representation include:

• Mathematical and algorithmic routines

• Manufacturing processes

• Instructional manuals

• Technical information included in step-by-step problem solving.

In addition to discussing the basic principles that make up effective information design, Matthews also looks at various components and types of technical illustration. While the majority of his explorations into technical illustration were stylistically more complex and realistic then the more abstract,iconography used within this tool, Matthews (2000) overview of some conventional elements used within technical illustration does inform the design of some images in this tool.
**Table 13**

*Conventional Technical Illustration Components*

<table>
<thead>
<tr>
<th>Component</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (Point &amp; Distributed)</td>
<td>(Matthews, 2000, p. 189)</td>
</tr>
<tr>
<td>Force Transmission</td>
<td>(Matthews, 2000, p. 193)</td>
</tr>
<tr>
<td>Torsion</td>
<td>(Matthews, 2000, p. 200)</td>
</tr>
<tr>
<td>Pressure</td>
<td>(Matthews, 2000, p. 262)</td>
</tr>
<tr>
<td>Flow and Turbulence</td>
<td>(Matthews, 2000, p. 259)</td>
</tr>
<tr>
<td>Deflection and Distortion</td>
<td>(Matthews, 2000, p. 201)</td>
</tr>
</tbody>
</table>
TABLE 14

Conventional Technical Illustration Components, cont.

Kostelnick and Roberts (1998) also look briefly at the use of conventional symbols and codes – noting that their usage can be beneficial, particularly if the audience is widely diverse since some conventions, such as the shape and color of stops signs, tend to be globally recognized. In addition to providing additional clarity and legibility, imagery that utilizes conventional elements is also perceived as more credible according to the authors. (Kostelnick & Roberts, 1998, p. 380)

**Visual Style**

There are numerous unique visual styles that could be applied to the icons used in the biomimetic design tool presented here, ranging from precise, geometric computer generated images to sketchy hand-drawn icons. While highly precise imagery is preferable in some areas of design, in this case a looser, hand-drawn approach is preferable. In biological and botanical fields, as well as in interior design, there is a strong tradition of hand drawn
sketches and illustrations, which support the adoption of this style within the iconography of this tool. This trend is also supported by Matthews, who identifies, among a wide variety of technical illustration styles, the “Life Geometry” style. (Matthews, 2000, p. 169) Matthews notes that this style, which at first seems at odds with the presentation of technical, inanimate objects, is actually well suited for this task. He goes on to state that not only do all technical objects follow the laws of physics, which are nature’s laws, but that many of these technical systems mirror those already found in nature. (2000, p. 169) Hallmarks of this style include an abundance of curves and angles as well as the use of freehand illustrations, since as Matthews points out, “because there are not many straight lines in nature” (2000, p. 169)

Text and Icons

In order to enhance the understanding of the information presented in the imagery, some textual elements may be desirable. As noted by Kostelnick and Roberts, text can assist with “defining, clarifying and modifying information contained in the images” (Kostelnick & Roberts, 1998, p. 321). In the case of the textual labels used in the imagery in this tool, the text helps to minimize any potential ambiguity surrounding the images.

Kostelnick & Roberts (1998) also provide a thorough overview of the various textual elements that makes up a line of text. While the decision to apply certain elements or to select text with certain characteristics is dictated in part by the medium and message, the authors do offer some general guidance on appropriate usage and potential pitfalls. One main element they examine is intra-level textual elements, which include the characteristics of the font and letterforms. (Kostelnick & Roberts, 1998, p. 121) Regarding serif or sans serif text, the authors note that serif type can create visual noise when viewed
at lower resolutions, though it can help to lead the eye when reading longer lines of text. Within each relative style of font, there are numerous potential fonts that could be used, and the authors offer some guidance here as well. For text used in the body of a document, 11 point font is preferred, though this can be dependent upon the context of the message. Smaller size fonts can quickly become difficult to read, particularly on computer screens. In regards to more aesthetic characteristics of fonts, generally, text that is set entirely in upper case, bold, or italics can be difficult or even frustrating to read. Additionally, the overuse of these stylistic characteristics can also decrease the credibility of the message, and potentially even of the messenger.

The tone created by the font choice and format is another category examined by the authors. While this area is typically somewhat subjective, some fonts tend to impart varying degrees of formality and/or technicality to the message being presented. Characteristics of formal fonts may include the use of uppercase for headings and potentially body texts, as well as a script style font – Old English and Zap Chancery are noted by the authors as exemplary of this. (Kostelnick & Roberts, 1998, p. 148) Conversely, reduction in these characteristics yields more informal feeling typefaces. The degree of technicality of a font tends to be more subjective, though the authors do note that sans serif fonts tend to seem more “technical and objective”.

In his research, Smithshuijzen (2007), looks as well at the elements of good textual design and some of his findings inform the design of the text labels included with the categorical graphics. In regards to visual perception and font select, the author recommends the use of either Opentype or True Type fonts, since these are the most stable and consistent between different platforms.
As a result of the findings outlined above, the iconography used in the biomimetic design tool outlined here will utilize a loose, hand-drawn style paired with appropriately sized Arial True Type font. This will provide both an interesting, subject appropriate, visual style in addition to integrating concise, easily identifiable icons.

**Color Coding**

Although color plays little role in the design of the iconography illustrating the various categories within the biomimetic design tool outlined here, it does have merit in regards to improving the user’s cognitive retention of the structure and arrangement of the different groups and sub-groups of this tool. In order to better facilitate this, each main group and sub-group will be color coded to permit users to better recall the category and location of a particular functional adaptation or approach, since at this time no method for saving items for future reference is integrated into this tool. Both Ware (2000) and Kostelnick and Roberts (1998) have devoted some research to the efficient and effective use of color within the context of color coding and both demonstrate that it’s use can improve memorability and user recall – both desired requirements/attributes for this tool.

In order to aid in user recall as well as provide additional visual consistency, each of the main functional categories within the tool outlined here will be color coded, with each color serving as both the background color and as accent colors, where necessary, within the informational graphics for each subsequent page within the category and subcategory. These color choices were not made at random however, in *Information Visualization*, Ware identifies twelve recommended colors for color coding, based upon common cross culturally identified colors and relative placement with the color space. (Ware, 2000) Within the design tool outlined in this research, each of these colors, with the exception of black (being the text color), white (being the primary background color) and grey (being the secondary
background color) will be associated with one of the main categories on the tool’s primary page.

**TABLE 15**

*Color Coding*

<table>
<thead>
<tr>
<th>Color</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Move or Stay Put</td>
</tr>
<tr>
<td>Green</td>
<td>Maintain Physical Integrity</td>
</tr>
<tr>
<td>Yellow</td>
<td>Maintain Community</td>
</tr>
<tr>
<td>Cyan</td>
<td>Modify</td>
</tr>
<tr>
<td>Blue</td>
<td>Make</td>
</tr>
<tr>
<td>Orange</td>
<td>Process Information</td>
</tr>
<tr>
<td>Brown</td>
<td>Break Down</td>
</tr>
<tr>
<td>Purple</td>
<td>Get, Store or Distribute Resources</td>
</tr>
</tbody>
</table>

Because Kostelnick and Roberts also caution against the use of too many colors within the coding system, the color palette will be limited to the distinct range of colors previously identified by Ware and as shown in Table 15, with shades, tints and tones of these colors used as needed in the subsequent sub-group pages.

**Final Icon Design**

The resulting final icon designs are informed by the aforementioned research into the stylistic and formal design characteristics. These icons all share many general attributes in addition to those noted above, including the use of a limit range of abstract symbols and the repeated use of common elements (such as the use of closely space diagonal lines to represent solid objects). The designs of the icons used to illustrate the groups, sub-groups and function are shown in Figures 15 through 41.

---

2 Biomimetic Tool Image Sources: Red- (Bellam, 2003); Green- (Chasqui (Luis Tamayo), 2006); Yellow- (cygnus921, 2008); Blue- (Purser, 2008); Orange- (Sam_catch, 2009); Brown- (quinn.anya, 2008); Purple- (Juvertson, 2007); Cyan- (Lavinsky, 2010)
FIGURE 15

Icons representing “Move or Stay Put”
Figure 15

Icons representing “Maintain Physical Integrity”
Figure 16

Icons representing "Maintain Physical Integrity", cont.
FIGURE 17

Icons representing “Maintain Physical Integrity”, cont.
Figure 18

Icons representing “Maintain Physical Integrity”, cont.
**Figure 20**

Icons representing “Maintain Physical Integrity”, cont.

**Figure 19**

Icons representing “Maintain Community”
FIGURE 20

Icons representing “Maintain Community”, cont.
FIGURE 21

Icons representing “Maintain Community”, cont.
**Figure 22**

Icons representing “Maintain Community”, cont.

**Figure 23**

Icons representing “Modify”
Figure 24

Icons representing "Modify", cont.

Modify Pressure  Modify Density  Modify Phase

Modify Buoyancy  Modify Light, Color  Modify Material Characteristics

Modify Number of  Modify Speed  Modify Position
Figure 25

Icons representing “Modify”, cont.
FIGURE 26

Icons representing “Modify”, cont.
Figure 27

Icons representing “Make”, cont.

Make

Reproduce

Self-Replicate

Physically Assemble

Physically Assemble Structure

Generate or Convert Energy

Generate or Convert Magnetic Energy

Generate or Convert Chemical Energy

Generate or Convert Mechanical Energy
FIGURE 30

Icons representing "Make", cont.
FIGURE 28

Icons representing "Make", cont.
Figure 29

Icons representing “Process Information”
FIGURE 30

Icons representing “Process Information”, cont

- Send Signals - Sound
- Send Signals - Tactile
- Send Signals - Chemical (Odor, taste, etc.)
- Send Signals - Vibratory
- Send Signals - Electrical or Magnetic
- Process Signals
- Differentiate Signal from Noise
- Transduce or Convert Signals
- Respond to Signals
Figure 31

Icons representing “Process Information”, cont

- Sense Signals or Environmental Cues
- Sense Light (Visible Spectrum)
- Sense Light (Non-Visible Spectrum)
- Sense Electricity or Magnetism
- Sense Touch and Mechanical Forces
- Sense Chemicals (Odor, taste, etc.)
- Sense Atmospheric Conditions
- Sense Sound and Other Vibrations
- Sense Temperature
FIGURE 32

Icons representing “Process Information”, cont

Sense Disease  Sense Motion  Sense Pain
Sense Balance, Gravity, Orientation  Sense Shape and Pattern  Sense Time and Day Length
Sense Body Awareness  Learn  Encode or Decode
FIGURE 33

Icons representing “Break Down”
**Figure 34**

*Icons representing “Break Down”, cont*

![Diagram](image)

**Figure 35**

*Icons representing “Get, Store or Distribute Resources”*
**Figure 36**

Icons representing “Get, Store or Distribute Resources”, cont.
**FIGURE 40**

*Icons representing “Get, Store or Distribute Resources”, cont.*
Search Capabilities

Since one of the objectives of this tool is to facilitate cross-disciplinary searching between design and biology, it is necessary to include some search capabilities within the design of this database. As a comparison of entry level design and biology texts can illustrate, the terminology of design and biology can differ markedly, with commonly used terms in one discipline being less commonly used in the other. One example of this can be found in the area of repelling moisture – in design terms such surface would typically be described as water resistant or water repellent whereas in biological text the terms hydrophobic or superhydrophobicity may be used instead.

Because of these potentially differing linguistics, traditional keyword search methods may yield less than ideal results – lacking either comprehensiveness or accuracy due to the use of incorrect, less common or less preferred keywords within the search terms. To compensate for these differences, this database contains a search field that allows users to
enter their desired function in the linguistic terminology most relevant to their particular field (in this case interior design) and return the biological function group most relevant the searched term.

**Figure 38**

*Keyword search field*

To achieve this, a spreadsheet was created in Excel using the main groups and sub groups from the Biomimicry Institute’s Biomimicry Taxonomy as headings and sub-headings. For each of these sub-heading groups, a list of synonyms and troponyms was compiled using common language terms for each function.

**Figure 39**

*Keyword listings*
To arrive at each respective list of synonyms and troponyms, first each main functional keyword was identified, which then provided the list of primary functional actions. A few different sources were consulted to compile a list of alternate keywords. These sources included interior design textbooks, various design related websites and thesauruses. Being created primarily for internal reference, this page will not be visible to the end user, hence aesthetics were of little concern in its design. One additional benefit to the approach within the context of Excel is the ability to easily add words if additional search terms are lacking in main list.

**Search functionality**

Once users have entered their search word in the search field, clicking “Search” will take them to the main group page that is most relevant to their term. When entered, the keyword is compared to a list of synonyms and troponyms relevant to each main group. If the searched keyword is found on the referenced list, the user will automatically be directed to the appropriate page based on column’s main heading. For example, a search for the term “direct” will take the user to the main page for the group “Process Information”, which contains the sub-group “Navigate”. The technical processes that allow this are done using Visual Basic, the details of which are explained in Appendix A.

If the searched word is not found, the user can manually enter the searched term into the appropriate column located on the referenced keyword list found in the tab labeled “Keyword”.


Chapter 4: Overview and User's guide to the Design Tool

While a more comprehensive overview of this tool is provided through the User's Guide later in this chapter, this design tool has two main sections—the Main page and the Sub-Group pages. Based upon the general tool content outlined in Chapter 3, each of these sections contain a few key elements and components.

- **Main Page**
  - The initial page of the tool will represent "Group" the highest level category of biomimetic functions, in accordance with the Biomimicry Institute's taxonomy.
    - Each of the main categories will link to a page of sub-categories illustrating the “Sub-Groups” as defined by the biomimetic taxonomy.
  - Additional, a sidebar on the main page provides an introduction to, and additional information on, biomimetic design.
  - Another feature, still in the developmental stage, on the initial page is a search field to identify the desired category based upon synonymous or otherwise related keywords.
**Figure 40**

Biomimicry Design Tool Main Page Representative Screen Shot

The Designer’s Guide to Biomimicry

**How to use this Tool**

What is Biomimicry?
In nature, everything—from bacteria to bios—plays an integral role in something beyond itself.

By looking to nature and natural processes for inspiration through a design approach called biomimicry, designers can create products, processes and spaces that seamlessly and harmoniously integrate themselves within the larger environment.

This tool will assist designers with the exploration, identification of biological sources of inspiration and application of biomimicry to design challenges.

For more information on biomimicry, check out the following links:
www.4Allnature.org
www.biomimicry.org.uk

---

Search using the box below or click on the desired function to view general trends and examples from nature.

Move or Stay Put
Maintain Physical Integrity
Maintain Community
Modify
Make
Process Information
Break Down
Get, Store or Distribute Resources
• Sub-Group Pages

  o Each Sub-Group page contains more in-depth information on types and methods of achievement pertaining to the main category.

    ▪ Each Sub-Group category, when selected, will visually display the various “Functions” associated with it

    • Selection of one of these Functions will then open a pop-up window containing links to specific organisms and examples

As noted previously, there are eight different sub-group pages that are color coded corresponding to the icons on the main page. These pages are illustrated below as follows:

Figure 45.  Move or Stay Put
Figure 46.  Maintain Physical Integrity
Figure 47.  Maintain Community
Figure 48.  Modify
Figure 49.  Make
Figure 50.  Process Information
Figure 51.  Break Down
Figure 52.  Get, Store or Distribute Resources
FIGURE 41

Move or Stay Put Sub-Group Page Representative Screen Shot
Figure 42

Maintain Physical Integrity Sub-Group Page Representative Screen Shot
Figure 43

Maintain Physical Integrity Sub-Group Page Representative Screen Shot

[Diagram showing various icons and labels related to maintaining community, such as "Coordinate", "Provide Ecosystem Services", "Regulate Habitat Response to Disturbance", etc.]
FIGURE 44

Maintain Physical Integrity Sub-Group Page Representative Screen Shot
**Figure 45**

*Make Sub-Group Page Representative Screen Shot*
Figure 50

Process Information Sub-Group Page Representative Screen Shot
**Figure 46**

*Break Down Sub-Group Page Representative Screen Shot*
Figure 47

Maintain Physical Integrity Sub-Group Page Representative Screen Shot

Get, Store or Distribute Resources

Capture, Absorb or Filter

Store

Distribute

Expel

Capture, Absorb or Filter Organisms

Capture, Absorb or Filter Solid Particles

Capture, Absorb or Filter Bulk Solids

Capture, Absorb or Filter Gases

Capture, Absorb or Filter Liquids

Capture, Absorb or Filter Energy

Capture, Absorb or Filter Chemical Entities
User’s Guide Overview

In order for this tool to be efficiently and effectively utilized by designers, a user’s guide would be beneficial. There has been some research conducted into the hallmarks of effective instructional design, and one resource that has proven helpful in the design of the user guide for this tool is “Guidelines for Developing Instructions” (Inaba, Parsons, & Smillie, 2004). Here the authors outline the various principles and guidelines that make up successful instructional design.

The role of instructions are to fulfill four basic requirements:

- The action to be performed and when it should be performed
- The order to perform the actions
- Where the action occurs
- The appearance of the action

In order to meet these requirements, instructions are comprised of “basic units of instruction” (Inaba, Parsons, & Smillie, 2004, p. 9), which define the amount of detail included within the instructions. The basic unit of instruction as defined by the authors is the step, which contains one or more actions with a clear starting and stopping point. Inaba, et al., denote two different levels of detail included in instructions, with action being defined as the lowest, most detailed, level and tasks making up the higher level.

Actions have a couple of basic characteristics – they serve to describe the most basic requisite action and do so through the use of command verbs. An example provided by the authors to illustrate this is the removal of a car engine. “The statement Remove the Engine
does not define the lowest level of instructions because a sequence of steps is required to remove the engine.” (Inaba, Parsons, & Smillie, 2004, p. 10). Consistency is also necessary when composing action steps due to the “read-look-do” (2004, p. 10) approach used by most users, since this consistency facilitates both comprehension and memorability.

Tasks, the higher level of instructions are comprised of groups of steps. The typical task will contain between 3 to 10 steps, with each step containing between one to three actions. Tasks can subsequently be combined to form a larger sequence.

When using graphics within a set of instructions, Inaba, et al (2004) note that the text and the graphics both fulfill different aspects of the basic instructional requirements. The textual portions indicate the action to be performed, the method of performance and the order in which the actions should be performed. Graphics are then used to show where the action occurs and its appearance. As noted by Inaba, et al., graphics play an integral role in instructions, since their inclusion allows the user to rapidly and effectively locate the object identified in the text describing the action to be performed.

Consequently, the User’s Guide presented here to accompany the tool will both provide step by step instructions as well as a graphical overview of the tool itself to better acquaint the user with its overall form and function.
A Designer’s Guide to the Biomimetic Design Tool

Biomimicry is a design process that looks to natural strategies, principles and functions to find solutions to design challenges. This tool is designed to assist with the exploration and application of biomimicry within interior design by providing assistance with the identification of potentially inspiring functional strategies.

An Overview of the Tool

There are two important areas within this tool:

- The Main Page
- Sub-Groups Pages

**Main Page**

The Main Page is the sheet that is initially visible when this tool is opened and is found in the tab labeled “Main Page”.

There are a few important elements on this page that can assist with the effective exploration and application of biomimicry to your design challenge. The screenshot on the following page will acquaint you with the location and general function of these elements.
Moving clockwise around the main page, the first element is the **Introduction to Biomimicry**, which also contains Links to Additional Information.

The next element is the **Keyword Search Box**, which permits searches for specific functions using both natural language and design terms.

The final element on the main page is the links to the **Main Functional Groups**. These represent major functional categories such as “Process Information” and “Break Down” and “Modify”. It is through the functional groups that the identification of biological solutions can be identified.
Using the Tool

Are you familiar with biomimicry?

No - If this is an unfamiliar design approach, reviewing the information found in the Introduction to Biomimicry section will provide you with an introduction to the topic.

Yes – If you are already familiar with biomimicry, then you can skip this section…

Applying Biomimicry to your Design Challenge

The first step in applying biomimicry to your design challenge is to first identify the main function or functions your solution should achieve. To identify these, it may be helpful to ask “What do you want your design to do?” Your answer to this question will most likely represent an action or function, such as protect, move or maintain.

Once you have identified the desired functions of your solution there are two different ways to locate the appropriate

Option 1. If you are not certain which category your desired function falls into, enter the word that best describes it into the search field at the top of the screen and click “Search”.

Option 2. If one of the main categories relates to your desired function, click on the icon to explore this category further.

Once a category has been selected, you will be taken to the second key section of this tool – the Sub-Group pages.
Sub-Group Pages

These pages contain more specific types of functions within the main functional category previously selected. For example, the sub-page for “Move or Stay Put”, shown below, contains the sub-groups “Move” and “Attach”.

Click on one of the Sub-Groups to reveal an array of even more Specific Functions. In the example shown below these are “Move in Gases”, “Move in Liquids” and “Move on Solids”.

Selecting one of these specific functions will open a pop up window displaying general methods of achievement and/or specific examples of successful achievement in nature.

After a specific functional strategy has been identified, the principles and methods used to achieve it in nature can be abstracted and applied to your specific design challenge.
Chapter 5: Summary and Discussion

Overall, the tool presented within this research has, in its current state of design, a number of both positive and negative issues that affect its usability. There are some improvements and further developments that could be made to increase its overall effectiveness of this tool. These pertain primarily to a few main aspects of the tool and are outlined below.

Illustrations

One area that could benefit from further refinement is the pop up information that opens upon selection of a more defined function from the main sub-category page. Currently, this information is presented in text format, relying on links and general descriptions to convey the various processes associated with functional achievement. Further work on this tool could potentially see the addition of illustrations to accompany this text, which would allow for a more accurate portrayal of the specific methods of functional achievement described. For example, if the text mentions the structural color found in a feather, the user could click to see a larger image of exactly how this is accomplished.

Keyword Search Tool

Currently, this feature is limited in functionality due to both an incomplete range of synonyms and troponyms in addition to a lack of advanced search options. While the range of words associated with each main category is currently fairly narrow, this is an issue that the user can potentially assist with the refinement of. As it is designed now, the user has the option of adding relevant key words to the listings for each main category. One possible direction for future work on this tool would be to allow unidentified words to automatically be added to the list, only prompting the user to select the correct category or categories to assign the word to and subsequently opening the chosen category. Another issue which future work on this
tool should address is the issue of duplicate keywords - possibly through the use of a simple selection box that would open on entry of a repeated keyword.

While the tool presented here, as noted above, could benefit from some additional refinements in regards to both its design and functionality, there are still numerous benefits to be gained from usage in its current form.

For designers, particularly those unfamiliar with the concept of biomimetic design, this tool offers numerous benefits pertaining to biomimetic design in general, as well as the actual process of applying biomimetic design. On a broad scale, this tool serves an important function of introducing designers to a potentially new, novel approach to design. With new approaches may come new insights and new perspectives on the problems being addressed, which, in turn can lead to new and novel solutions.

Because this particular approach, biomimicry, carries with it some inherent aspects of sustainability, the implications of its introduction to the designer’s repertoire may yield many far-reaching benefits beyond those typically associated with design methodology and process. Due to the potentially greener attributes of biomimetically inspired products and processes, this tool brings with it the potential to reshape both the way goods and systems are designed and produced as well as the subsequent utilization of resources in the production of these goods. In light of current issues surrounding resource availability, climate concerns and general environmental well-being, the need for a shift in thinking is necessary – a shift which this tool can help to encourage.

On a more design focused level, biomimetic design can give designers a competitive edge in the marketplace. With the current consumer interest in green and sustainable design, providing designers with an approach to design that is not only greener but also has great
potential to generate consumer interest due to the novelty and unique environmentally inspired product design and development story can be a powerful advantage. From the client perspective these assets can, with the help of word of mouth and good public relations, potentially increase sales and profits.

Looking at the benefits afforded by this tool at an even more design focused level; it also assists with the design process in a few important ways. By clearly and succinctly illustrating the main functional categories through generic, abstract, forms, designers are quickly able to visually identify the most relevant function to their specific problem without being hampered by lengthy textual descriptions or by imagery that focuses on a specific type of product, which may impede the recognition of potentially relevant solutions. Although not currently optimally functional, the keyword search option can efficiently direct designers to the appropriate categories in addition to identifying previously unexplored, yet similar, possible design solutions. The addition of written examples and hyperlinks to more information pertaining to specific methods of functional adaptations at the sub-category level will provide designers with not just an efficient method for identification of specific sources of inspiration but also with resources to instantly learn more about these sources.

From the standpoint of the design of the tool itself, through the usage of Excel users are able to modify or add to the tool with relative ease. This adaptability may be particularly beneficial in regards to refining and improving the accuracy of the keyword search and also in updating the external links to additional sources (since this is a currently expanding area of research, more resources are continually being added to the internet).
## Appendix A

**TABLE 16:**
*Biomimicry Institute Biological Taxonomy, cont.*

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move or Stay Put</td>
<td>Attach</td>
<td>Permanently</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temporarily</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In/On solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In/On liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In gases</td>
</tr>
<tr>
<td>Maintain Physical Integrity</td>
<td>Protect from biotic factors</td>
<td>Animals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fungi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microbes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of gases</td>
</tr>
<tr>
<td></td>
<td>Protect from abiotic factors</td>
<td>Fire</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nuclear reaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dirt/Solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical toxins</td>
</tr>
<tr>
<td></td>
<td>Manage structural forces</td>
<td>Impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turbulence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal shock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical wear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Creep</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compression</td>
</tr>
<tr>
<td>Regulate physiological processes</td>
<td>Cellular processes</td>
<td>Homeostasis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reproduction or growth</td>
</tr>
<tr>
<td>Prevent structural failure</td>
<td>Buckling</td>
<td>Deformation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fatigue (rupture)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melting</td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup</td>
<td>Function</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Maintain Community</td>
<td>Coordinate</td>
<td>Groups (self-organize)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Systems</td>
</tr>
<tr>
<td></td>
<td>Cooperate or Compete</td>
<td>Within the same species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Between different species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Within a (eco)system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Between ecosystems</td>
</tr>
<tr>
<td></td>
<td>Provide ecosystem services</td>
<td>Regulate habitat response to disturbance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulate hydrological flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pollinate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generate soil/renew fertility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detoxification/purification of air/water/waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control erosion and sediment</td>
</tr>
<tr>
<td></td>
<td>Modify physical state</td>
<td>Regulate water storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cycle nutrients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulate atmospheric composition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulate climate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disperse seeds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintain biodiversity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biological control of populations, pest, diseases</td>
</tr>
<tr>
<td></td>
<td>Modify chemical or electrical state</td>
<td>Size/shape/mass/volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phase</td>
</tr>
<tr>
<td></td>
<td>Modify physical state</td>
<td>Buoyancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light/color</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Material characteristics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speed</td>
</tr>
<tr>
<td></td>
<td>Modify chemical or electrical state</td>
<td>Energy state</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Free radical reactivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concentration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical potential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reactivity with water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oxidation state</td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup</td>
<td>Function</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Modify, cont.</td>
<td>Modify chemical or electrical state, cont.</td>
<td>Electric charge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conductivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface tension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solubility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electron transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemically generate flow of electrons</td>
</tr>
<tr>
<td>Adapt/optimize</td>
<td></td>
<td>Adapt genotype</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adapt phenotype</td>
</tr>
<tr>
<td></td>
<td>Coevolve</td>
<td>Adapt behaviors</td>
</tr>
<tr>
<td></td>
<td>Optimize space/materials</td>
<td></td>
</tr>
<tr>
<td>Make</td>
<td>Reproduce</td>
<td>Self-replicate</td>
</tr>
<tr>
<td></td>
<td>Physically assemble</td>
<td>Structure</td>
</tr>
<tr>
<td></td>
<td>Generate/convert energy</td>
<td>Electrical energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnetic energy</td>
</tr>
<tr>
<td></td>
<td>Generate/convert energy</td>
<td>Chemical energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical energy</td>
</tr>
<tr>
<td></td>
<td>Generate/convert energy</td>
<td>Thermal energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiant energy (light)</td>
</tr>
<tr>
<td></td>
<td>Chemically assemble</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metal-based compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specific stereoisomers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mineral crystals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>On demand</td>
</tr>
<tr>
<td></td>
<td>Chemically assemble</td>
<td>Inorganic compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attach a functional group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detach a functional group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Catalyze chemical reactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Molecular devices</td>
</tr>
<tr>
<td>Process Information</td>
<td></td>
<td>Through air</td>
</tr>
<tr>
<td></td>
<td>Navigate</td>
<td>Through water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Through solids</td>
</tr>
<tr>
<td></td>
<td>Send Signals</td>
<td>Light (visible spectrum)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light (non-visible spectrum)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sound</td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup</td>
<td>Function</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Process Information, cont.</td>
<td>Send Signals, cont.</td>
<td>Tactile</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical (odor, taste, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vibratory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical/magnetic</td>
</tr>
<tr>
<td></td>
<td>Process Signals</td>
<td>Differentiate signal from noise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transduce/convert signals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Respond to signals</td>
</tr>
<tr>
<td></td>
<td>Sense signals/environmental cues</td>
<td>Light (visible spectrum)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Light (non-visible spectrum)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electricity/magnetism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Touch and mechanical forces</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemicals (odor, taste, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Atmospheric conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sound and other vibrations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balance/gravity/orientation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shape and pattern</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time and day length</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Body awareness</td>
</tr>
<tr>
<td></td>
<td>Compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Learn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Encode/Decode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Break Down</td>
<td>Cleave heavy metals from organic compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cleave halogens from organic compounds</td>
</tr>
<tr>
<td></td>
<td>Chemically break down</td>
<td>Other organic compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other organic compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Catalyze chemical reactions</td>
</tr>
<tr>
<td></td>
<td>Physically break down</td>
<td>Abiotic materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biotic materials</td>
</tr>
<tr>
<td></td>
<td>Get, Store or Distribute Resources</td>
<td>Capture, absorb or filter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organisms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid Particles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bulk solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup</td>
<td>Function</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Get, Store or Distribute</td>
<td>Capture, absorb or filter, cont.</td>
<td>Liquids</td>
</tr>
<tr>
<td>Resources</td>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical entities</td>
</tr>
<tr>
<td>Store</td>
<td></td>
<td>Bulk solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
<tr>
<td>Distribute</td>
<td></td>
<td>Chemical entities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solid Particles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquids</td>
</tr>
<tr>
<td>Expel</td>
<td></td>
<td>Solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases</td>
</tr>
</tbody>
</table>
The keyword search option in this tool relies on Visual Basic coding to achieve the desired functionality. For readers interested in the specific coding used, the commands in this process are shown in Figure 53 and explained below.

The first section of code identifies the location and boundaries of the data being searched (StartRow, StartCol, NumCols and NumRows). The next section identifies the location of the data which it is searching for, which is in this case the text entered into the text box adjacent to the search field (Text = TextBox). The next lines of code identify the sheet that the source data is found on and the range of this data (Sheet(“Keywords” and “J”, “K”).

Now that both the user entered keyword and the data that is being searched have been identified, the subsequent lines of code are responsible for the actual search function. The search word is compared to each column on the sheet “Keywords” and if it is found, the user will...
automatically be directed to the sheet for the column’s main heading. For example, a search for the term “direct” will take the user to the main page for the category “Navigation”.
Bibliography


Bellam, S. *Bed of Red Petals.* Flickr.


Cory. *Swordtial butterfly, Graphium sarpedon nippon*. Wikimedia Commons.

cygnus921, J. *Yellow Pear Tomatoes 012*. Flickr.

da Vinci, L. (1505). *Codex on the flight of birds*.


Denovich, M. *Nepenthes alata, pitcher plant*. Flickr.


http://explorationforchange.net/attachments/056_RoT%20Year%201%20report%20final%20100622.pdf. (n.d.).


Juvertson, S. *Purple Urchins*. Flickr.


Lavinsky, R. *Turquoise-250225*. Wikimedia Commons.


Purser, D. Foaming Blue Bubbles. Flickr.

quinn.anya. Pinecone. Flickr.


Wilson, A. *Woodland Caribou*.


