



Bio-Inspired Design: Robotics, Prosthetics, Behaviors, and Materials

Anna Rabinowicz
Associate Professor, Product Design
Parsons The New School for Design

Patricia Voto
Product Design
Parsons The New School for Design

Amanda Huffingham
Product Design
Parsons The New School for Design

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Project Premise

As educators develop new teaching methods, the tools of biomimetic exploration prove increasingly germane.

Analysis of natural systems and animals, from mechanical, biological, and behavioral perspectives, can lead to design solutions that are truly sustainable:

*Materially economical
Less energy consumptive
Dependant on cooperative behavior, and
Less impactful on the environment*

Taking lessons from the most successful aspects of nature, such explorations can result in products and systems that empower humans.



Project 1: Bio-Inspired Prosthetics and Robotics

ANIMAL LOCOMOTION: TAKING STEPS TOWARD BIO-INSPIRED PROSTHETIC AND ROBOTIC DESIGN

Anna Rabinowicz

Associate Professor, Product Design, Parsons The New School for Design
New York / United States

Amanda Huffingham

Product Design, Parsons The New School for Design
New York / United States

Abstract

Analysis of the locomotion of extremely efficient animals, studies of neural stimulation amongst amputees, and recent breakthroughs in tissue engineering have resulted in radical advancements in the field of human prosthetics. Closely related to and integral to prostheses, the field of robotics is currently taking inspiration from examination of animal mobility. Scientists and researchers who study the motion of such animals, often via high-speed motion tracking, are determining the biomechanical origins of running and energy efficiency.

In conjunction with biological analysis, such findings are driving the creation of prosthetic limbs that enhance human function beyond natural abilities. For example, double-amputee sprinter Oscar Pistorius was banned from the Beijing Olympics because his prosthetic legs (based up on the mechanics of a cheetah, the world's fastest land mammal) gave him a competitive advantage over the other runners.

This type of research ultimately lends human function the best mechanical qualities of the animal and engineering worlds. For instance, examining the intricacies of the running motion of highly energy-

Project 2: Bio-Behavioral Inspiration

In relating nature to design, classification and behavioral analysis facilitated our review of how biology can translate into product design.

We initially grouped organism behaviors and design outputs into categories based on the following:

Food

Housing

Self-Growth

Self-Preservation



Secondary Classification

We subsequently created the following categories to classify our findings:

Structural Optimization

Super Strength

Bottom Up Manufacturing

Environmental Response

Nutrient Extraction

Self-Patterning

Self-Organizing



STRUCTURE
FOLLOWS
NEEDS

PEST
CONTROL

PITCHER
PLANTS

EVEN
WEIGHT
DISPERSION

STRUCTURAL OPTIMIZATION

KINGFISHER
BIRD

JAPANESE
BULLET
TRAINS

FORMAL
EFFICIENCY

SHARK
SKIN

SHARKLET

WEAVERBIRD
NEST

ARCHITECTURE

SERATED
TOOLS

PARROTFISH

HIGH
STRENGTH
VS.

REPETITIVE
STRUCTURE

SUPER STRENGTH

WEIGHT
RATIO

ABALONE
SHELLS (NACRE)

PERFORM
UNDER
DURESS

MUSSELS

LAMINATES

BODY
ARMOR

SPIDER
SILK

ARTIFICIAL
LIGAMENTS

SUTRES

VACCINE
STORAGE

TARDIGRADE

DRILL BITS

WHEAT
SEEDS

COMMUNITY
PRESERVATION

SELF ORGANIZING

INDIVIDUAL
ROLES

SPIRAL
DRILLING

NETWORKING

ANT
COLONIES

ORGANIZING
ALGORITHMS

LENSES

SOLAR
PANELS

BUTTERFLY
WINGS

REPETITIVE
BUILDING
ACTION

LOTUSAN

LOTUS
LEAF

SELF-PATTERNING

COMBINING
IDENTICAL
ELEMENTS

LARGE
STRUCTURE
& TINY
PARTS

ABALONE
SHELLS (NACRE)

TITANIUM-
ALUMINATE

WEAVERBIRD
NEST

ARCHITECTURE

BUILDING
THROUGH
DISPOSITION

BOTTOM UP MANUFACTURING

TIMED
DEGRADING

CYCLICAL
BUILDING

DAMS

ABALONE
SHELLS (NACRE)

BEAVER
DAM

TITANIUM-
ALUMINATE

DIAGRAM KEY

- CATEGORY
- BEHAVIORS/CHARACTERISTICS
- NATURAL EXAMPLES
- MANUFACTURED EXAMPLES

SMART
TEXTILES

PINECONE

VACCINE
STORAGE

TEMPERATURE
BASED
REACTIONS

TARDIGRADE
DORMANT
VS.
ACTIVATED

ENVIRONMENTAL RESPONSE

CAMOUFLAGE

STARTLED
VS.
UN-STARTLED

CUTTLEFISH
OLEDs

FILTER
FEEDING

FIDDLER
CRAB

FILTRATION
SYSTEMS

NUTRIENT EXTRACTION

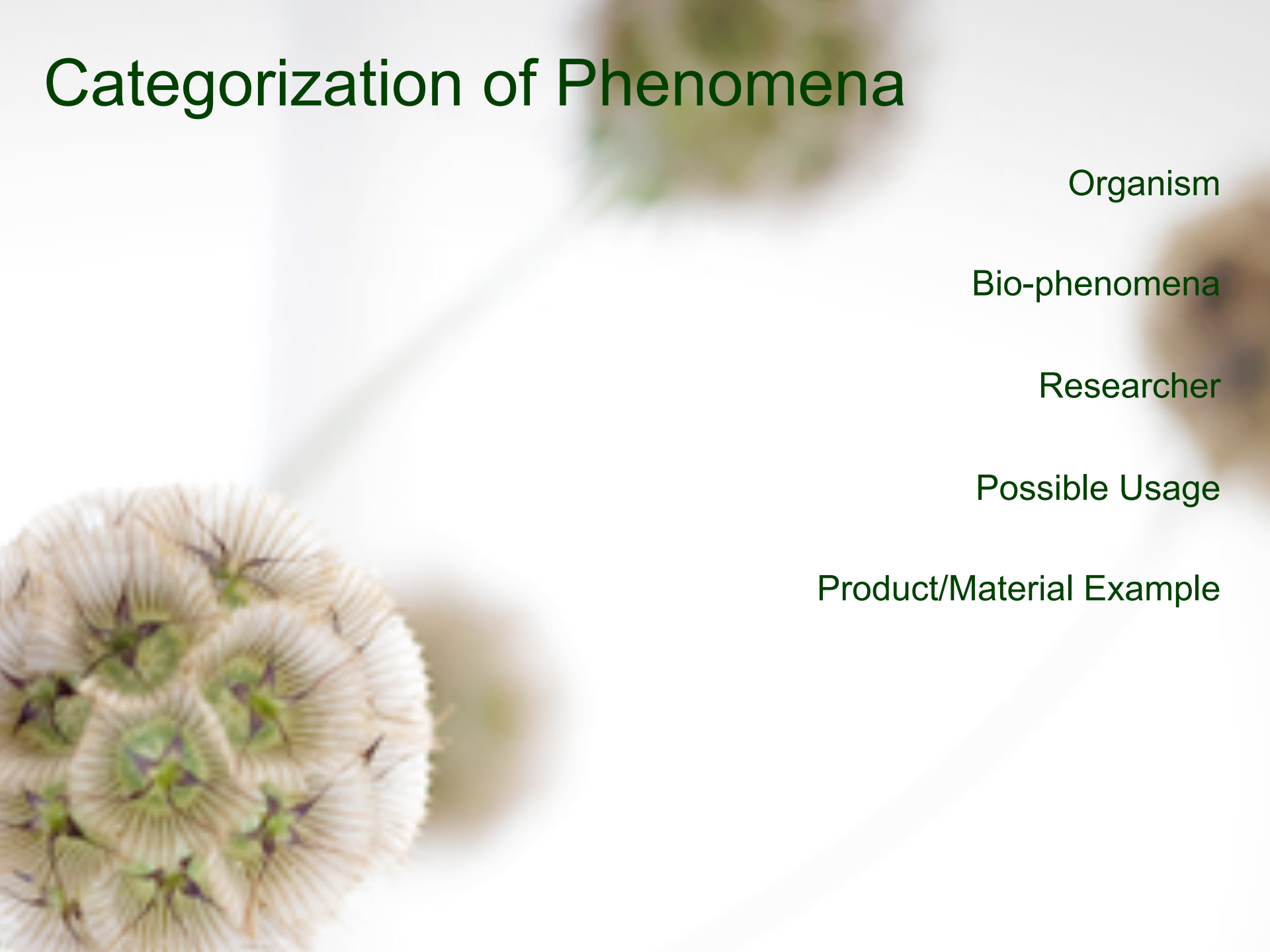
SEA
ANEMONE

ANGLED
WIND
TURBINES

SEPERATION
WHILE
CLEANING

RELATIONSHIPS IN BIO-INSPIRED DESIGN

Categorization of Phenomena

A close-up photograph of a dandelion seed head, showing the intricate structure of the seeds and the green base. A magnifying glass is positioned over the seed head, with its handle extending towards the top right. The background is a soft, out-of-focus white.

Organism

Bio-phenomena

Researcher

Possible Usage

Product/Material Example

Structural Optimization

The background of the slide features a close-up, shallow depth-of-field photograph of several dried, spiky plant heads, possibly from a daisy or similar flower, resting on a white surface. The heads are light brown/tan with green centers and are arranged in a way that creates a sense of depth and texture.

Structure follows needs

Even Weight Distribution

Formal Efficiency

Organism

Kingfisher Bird

Bio-Phenomena

Tapered beak allows for low impact diving and streamlining through the air. Upon contact with water, Kingfishers barely splash and have a clean dive.

Researcher

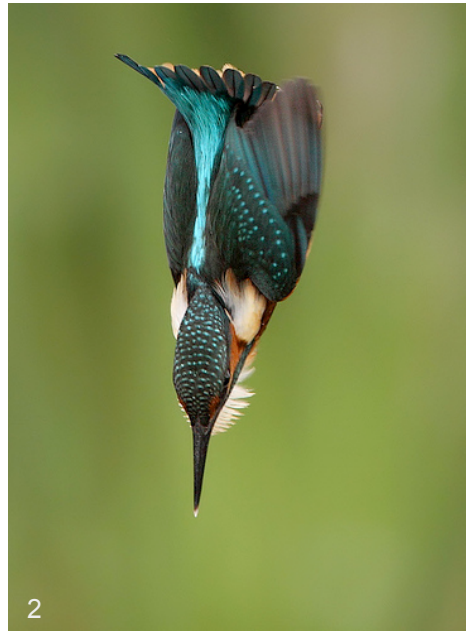
Japanese train designers

Possible Usage

Perfect shape for aerodynamics, Streamlining of trains, planes, and other forms of transportation.

Product/Material Ex.

Forms of transportation, drilling, athletic gear



Organism

Tardigrade or “Water Bear”

Bio-Phenomena

Regenerative- can dry out (tun state) and become rejuvenated over long periods of time. Can travel to space through extreme hibernation.

Researcher

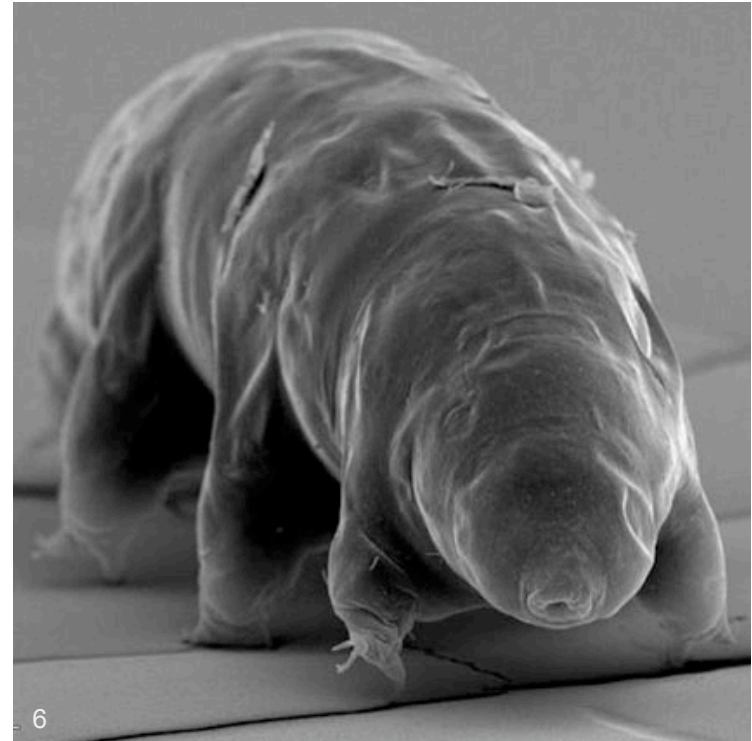
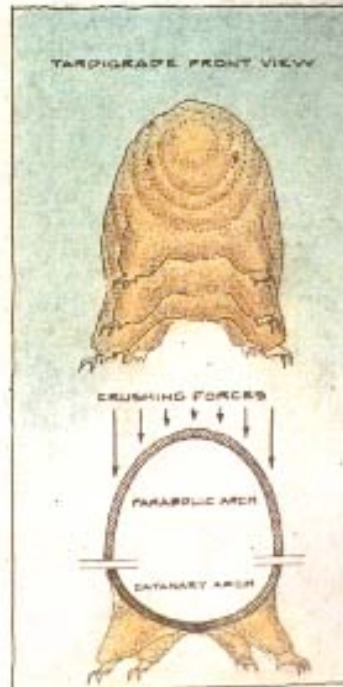
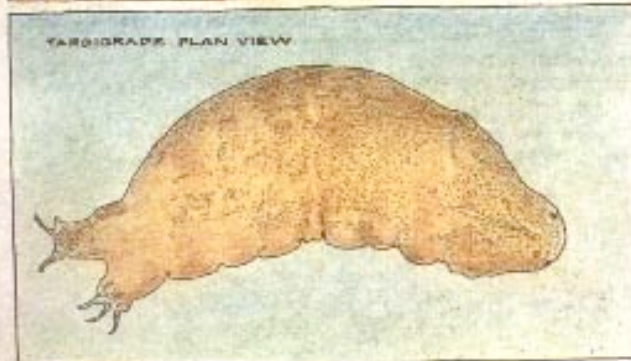
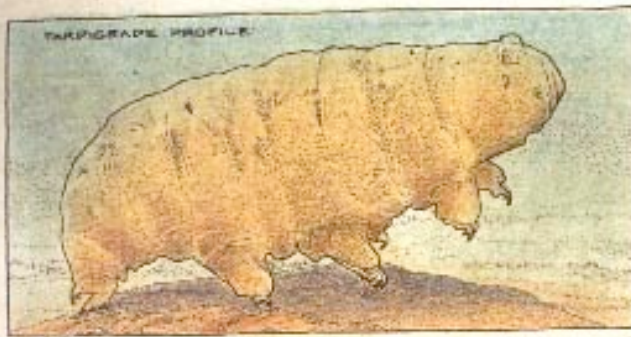
Universities around the world- <http://www.tardigrada.net/tardigradologists.htm>

Possible Usage

Extreme drying could be used to store vaccines

Product/Material Ex.

Could translate into cookware- due to survival of hot and cold temperatures, vaccines.



Organism

Parrot Fish

Bio-Phenomena

Strength- extremely fine, sharp teeth. Teeth are fused together and shaped like a beak. Able to crush coral (cause sand production). Additional teeth at the back of its throat for grinding.

Researcher

American Museum of Natural History, U Exter, U California Davis (funded by US Environmental Protection Association)

Possible Usage

The ability to grind coral helps contribute to underwater ecology- protects coral reefs.

Product/Material Ex.

Could translate into utensils, graters, best used to breakdown to other materials.



Organism

Shark Skin (Sharklet)

Bio-Phenomena

Tiny scales on shark's skin (known as denticles) prevent bacteria from growing due to their diamond patterning with tiny riblets

Researcher

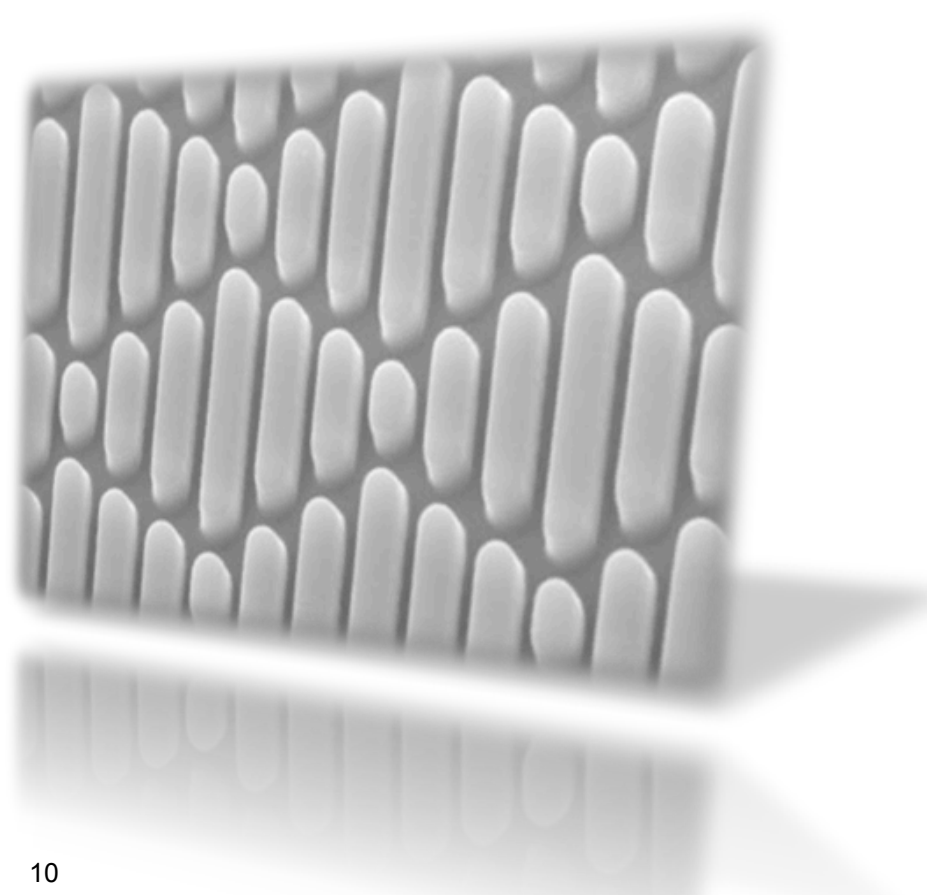
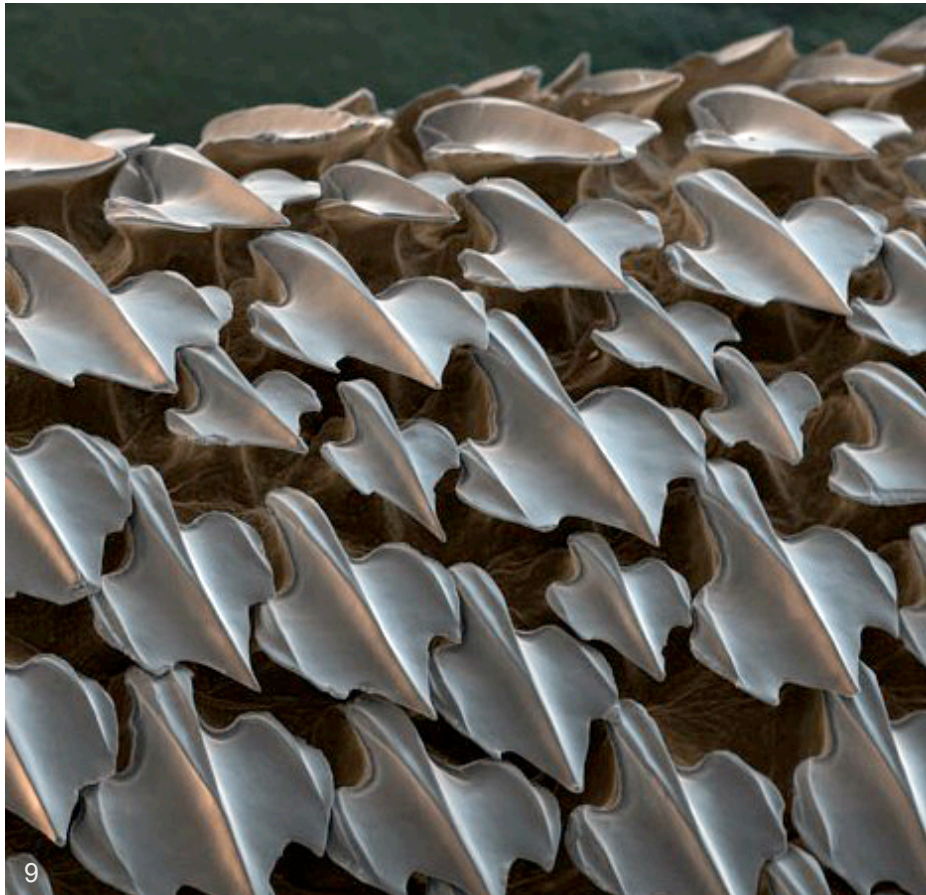
US Naval Researcher, Dr. Brennan

Possible Usage

In "germy" areas to prevent spread of bacteria

Product/Material Ex.

Wall surfaces in hospitals



Super Strength

A close-up, low-angle shot of a dandelion seed head in the foreground, showing its intricate, repetitive structure of many small, pointed seeds. A long, thin stem extends from the seed head towards the top of the frame, where another seed head is visible but out of focus. The background is a soft, out-of-focus white, creating a clean, minimalist aesthetic.

Perform under duress

High Strength to Weight ratio

Repetitive Structure

Organism

Spider (Spider Silk)

Bio-Phenomena

Spider silk- maintains web even after rain or dew. Can deal with stress. Elastic-like can be stretched up to 50% before breaking. Composite material- part crystalline, part-rubber based

Researcher

University of Wyoming (funded by NSF), US Army, UC Santa Barbara, University of California

Possible Usage

Strong flexible material has the ability to protect and flex. Weight for weight similar to steel.

Product/Material Ex.

Armor, vests, storage, hanging mechanisms, suspension cables for bridges, fiber optics



Organism**Abalone Shell (Nacre)****Bio-Phenomena**

Brick work patterning of CaCO_3 are held together by protein secreted by sea mollusks, super strength.

Researcher

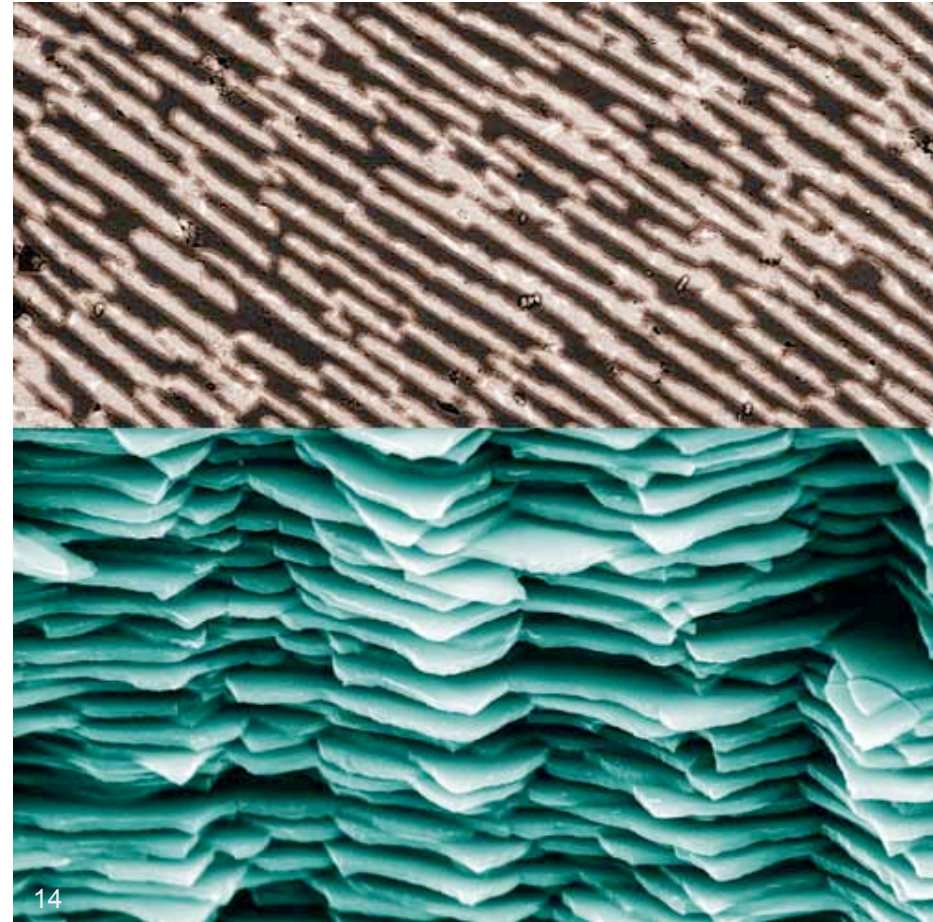
University of California, Dr. Vecchio; University of Michigan

Possible Usage

Creating ceramics, durable composite materials

Product/Material Ex.

Medical applications- artificial bones, hard tissue; body armor; aircraft, automobiles



Organism

Mussels

Bio-Phenomena

Tiny filaments attach to surface, using a polyphenolic protein

Researcher

Nerites in Wisconsin (Medhesive) , J. Herbert Waite is in the Departments of Molecular Cell & Developmental Biology and Chemistry & Biochemistry, University of California, Santa Barbara, Oregon State University, North Western University

Possible Usage

Adhesives, durable structures, bonding agents, Wood glues, Bio-degradable adhesives

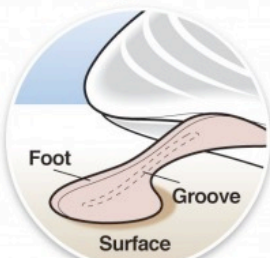
Product/Material Ex.

Bio-adhesives for sutures surgical sealants, auto dissolving solvents and anti-fouling paints

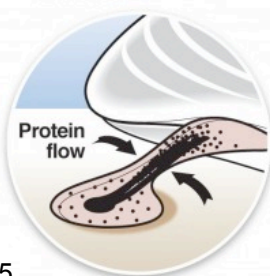
The tough grip of a mussel

A mussel produces an adhesive so strong it can cling to wet and slippery surfaces. Here's how the process works:

- 1** A mussel uses its foot to find a surface to stick to



- 2** The mussel injects liquid protein along a groove in the foot



- 3** When the protein reaches the surface, it hardens and becomes a link, known as a byssal thread, that will serve as an anchor



- 4** The foot releases the thread and retreats; a mussel will repeat the process many times to reinforce its grip



© 2009 MCT
Source: Phillip B. Messersmith,
professor of biomedical engineering,
materials science and engineering, and
chemical and biological engineering,
Northwestern University
Graphic: David Arbanas, Milwaukee
Journal Sentinel



Bottom Up Manufacturing

A close-up, shallow depth-of-field photograph of a dandelion seed head. The foreground shows the intricate, feathery structure of the seed head in sharp detail, with its green base and brownish-yellow seeds. The background is a soft, out-of-focus white, with other blurred seed heads visible, creating a sense of depth and natural growth.

Cyclical Building

Building through Deposition

Timed Degrading

Organism

Weaverbird Nest

Bio-Phenomena

Grass weaving and knotting. Weaverbirds learn to build well - mono material building.

Researcher

Ohio Wesleyan University

Possible Usage

As an ability to resist destruction and having no single area of stress and strain, weaving allows heavy loads to be held and even dispersion of weight.

Product/Material Ex.

Vases, bowls, coverings, upholstery



Organism

Beaver Dams

Bio-Phenomena

Collection of logs, sticks and mud can turn rivers into calm ponds- able to withstand pressure of water

Researcher

University of Alberta, University of Massachusetts

Possible Usage

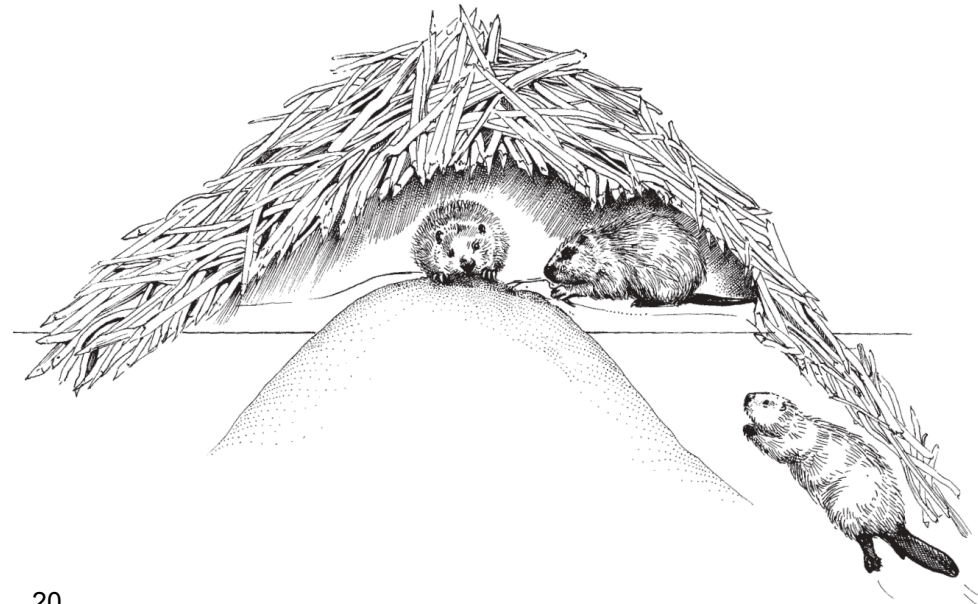
Filtration systems, architecture, flood control

Product/Material Ex.

Structures, vases, drains and stoppers



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Environmental Response



Startled vs. Un-startled

Temperature-Based Reactions

Dormant vs. Activated

Organism

Pitcher Plants

Bio-Phenomena

Leaves with thin layer of waxy material to trap insects or rodents . Wax crystals on the inner walls collect on the feet of insects so they can no longer cling to walls.

Researcher

University of Wyoming, US Army, UC Santa Barbara, University of California

Possible Usage

Form for trapping- adhesive surface to trap or prevent movement- “pitfalls”

Product/Material Ex.

Vases, bug control, building materials



Organism

Pinecone

Bio-Phenomena

Opens petals when wet- closes petals when dry

Researcher

Dr. Veronika Kapsali, the founder of MMT, British clothing companies

Possible Usage

Pinecones act as if it is breathing due to reaction with humidity

Product/Material Ex.

Breathable fabric, ventilation systems



Organism

Cuttlefish

Bio-Phenomena

Change skin color in under a second to hide from predators. Camouflage.

Researcher

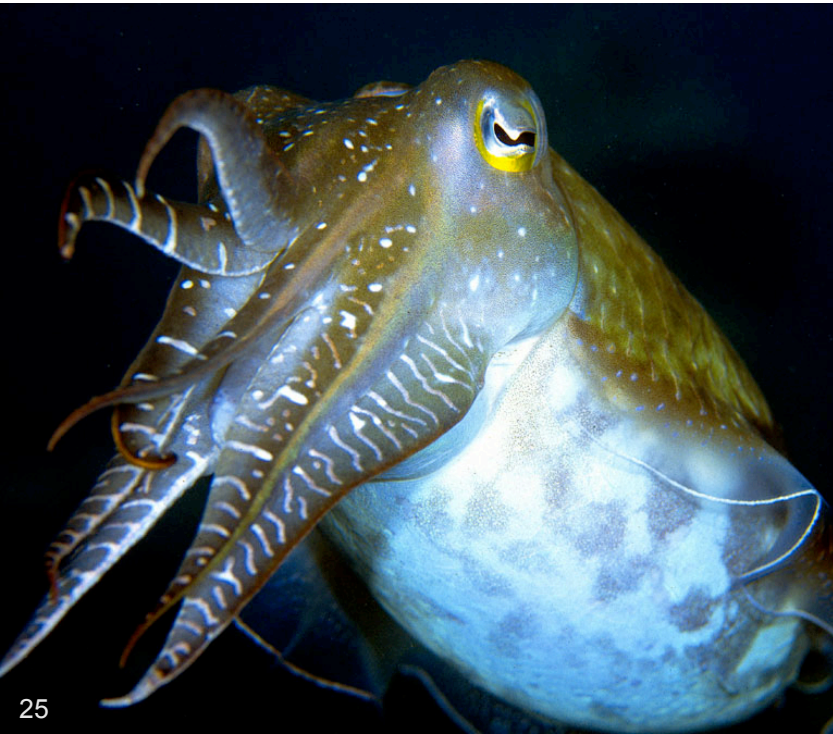
MIT, Microsoft, Sun Chemical Corp., and Cornell University

Possible Usage

Color changes could be translated into different lighting effects

Product/Material Ex.

LCD screens, fiber optics, OLEDs, LED



Nutrient Extraction

A close-up, shallow depth-of-field photograph of a dandelion seed head. The foreground shows the intricate, feathery structure of the seed head in sharp detail, with its green base and brownish-tan seeds. The background is a soft, out-of-focus white, with other parts of the plant visible as blurred shapes.

Filter Feeding

Separation while Cleaning

Passive Movement

Organism

Fiddler Crab

Bio-Phenomena

Stiff hair like structures allow fiddler crab to filter sand grains and small bacteria (spoon-shaped setae)

Researcher

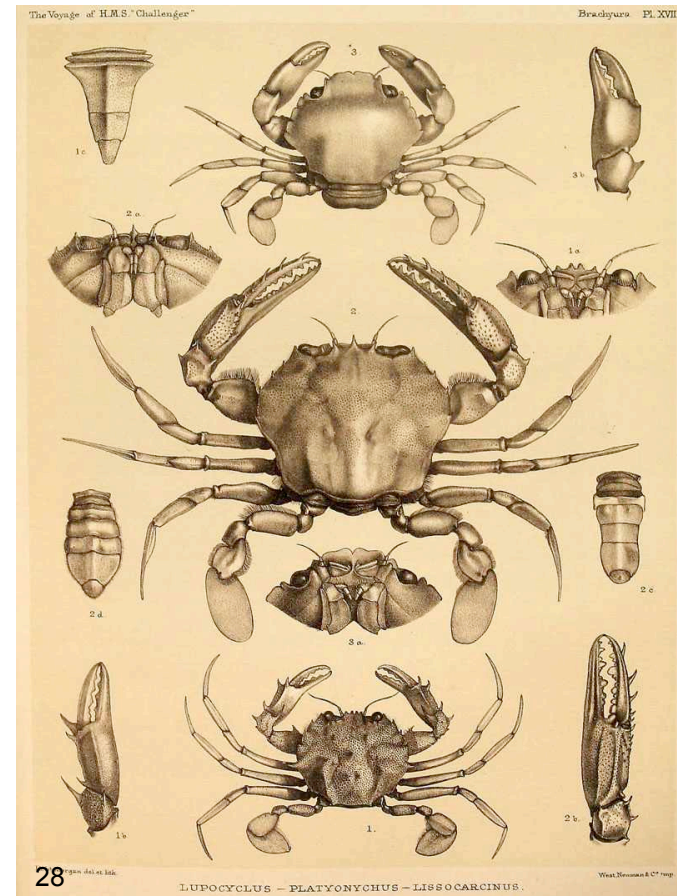
(Macnae 1968; Miller 1961; Ono 1965)." (Hogarth 1999:94-95)

Possible Usage

Fiddler crabs absorb food through setae- small filters and hairs that prevent bad bacteria or sand from entering while eating.

Product/Material Ex.

Filtration systems



Organism	Sea Anemone
Bio-Phenomena	Stalk maximizes feed position and allows top to bend its tentacles. Very stable base
Researcher	<i>Daphne Faunter, University California, Oxford University, California State</i>
Possible Usage	Soft neck allows for flexibility and rotational movement base on environmental needs
Product/Material Ex.	Wind turbines, tents



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MECHANICAL DESIGN IN SEA ANEMONES

25

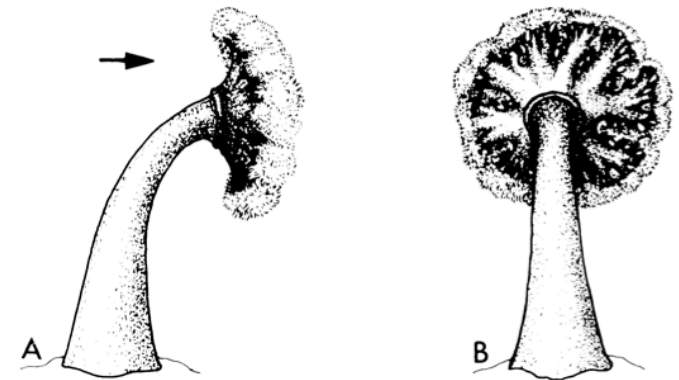


Figure 2. *M. senile* bent over in a tidal current. A. Side view (arrow indicates flow direction), and B. Rear view.

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Self-Patterning

A close-up, shallow depth-of-field photograph of a dandelion seed head. The foreground shows the intricate, radial pattern of the seed head's bracts and developing seeds, which are a mix of green and brown. The background is a soft, out-of-focus white, with other parts of the plant visible as blurred shapes.

Combining identical elements

Large Structure/Tiny Parts

Self-Growth

Organism

Butterfly Wings

Bio-Phenomena

Iridescence in butterfly wings is caused by thousands of tiny overlapping scales that when sunlight penetrates these layers wavelengths blend together/cancel each other out

Researcher

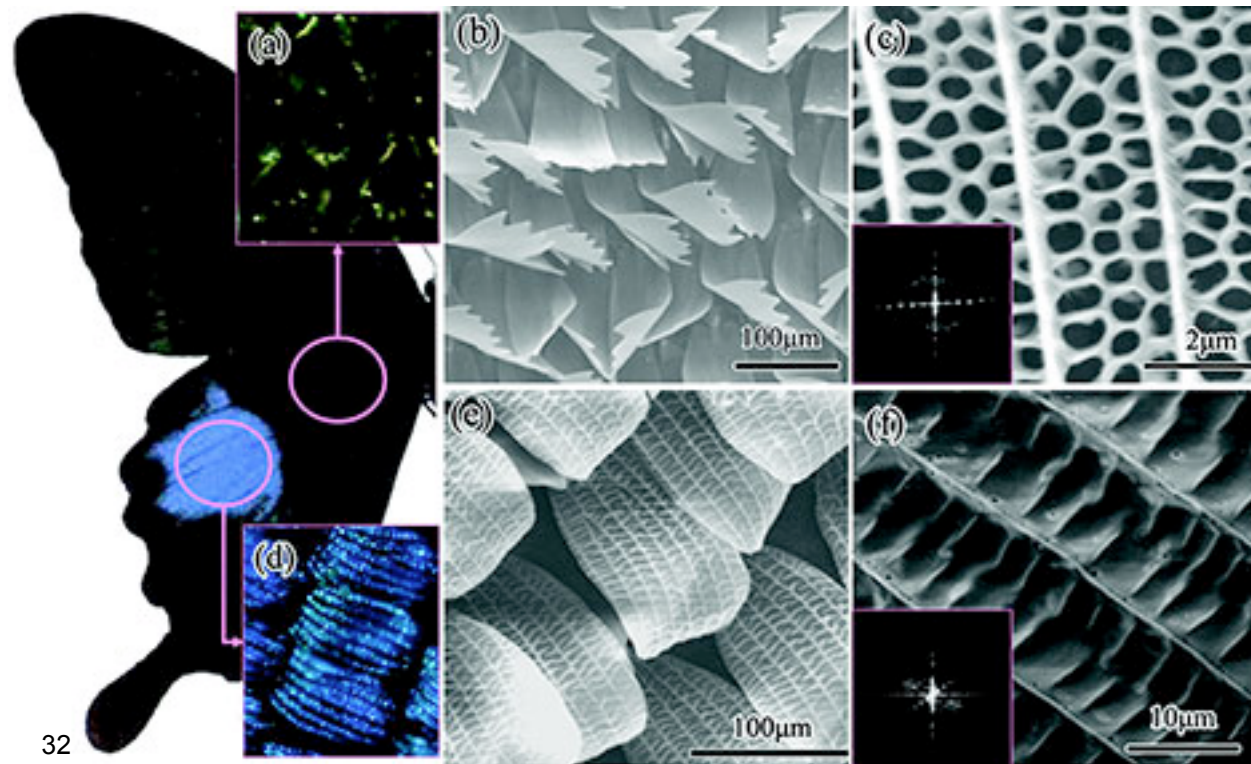
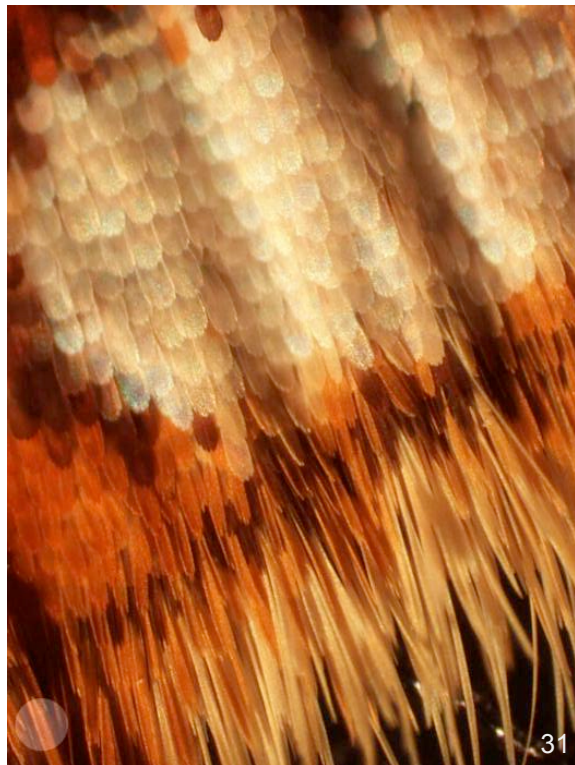
Gratzel (Michael Gratzel), General Electric (funded by DARPA), Qualcomm (Marisol screen), Penn State University, Materials Research Institute of the State University of Pennsylvania, Oregon State University

Possible Usage

Color changes based on environment- scale pigmentation, light waves

Product/Material Ex.

Cosmetics, solar panels, car paint, optical computing, nano-sensors



Self-Organizing

A background image featuring a glass vase filled with water and several dried, pressed flowers. The flowers are light brown and green, with some showing intricate patterns. The vase is partially visible on the left side of the frame.

Community Preservation

Individual Roles

Networking

Biology

Ant Colonies

Bio-Investigation

Ants work together on a non-hierarchical system- there is no leader

Researcher

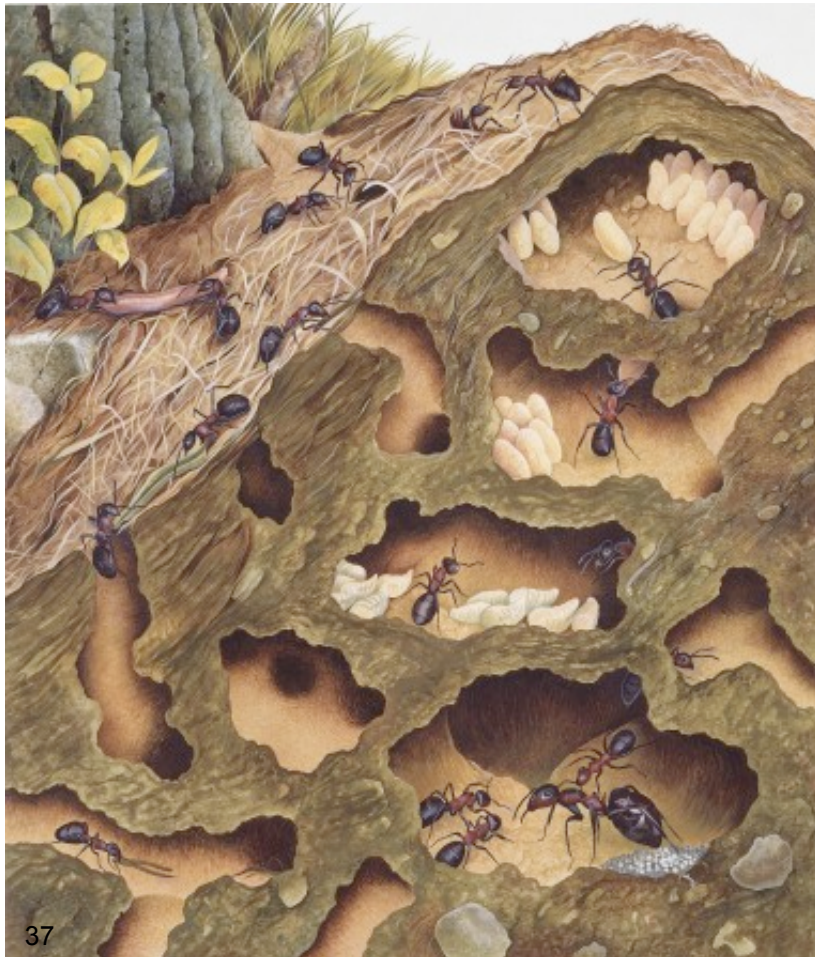
Northeastern University, University of California Santa Barbara

Manifestation

Always work together harmoniously towards the same goal, Creating networks and business models based on non-hierarchical behavior

Product Design

Airplane organization, phone systems



Biology

Wheat Seed Dispersal

Bio-Investigation

Wheat seeds travel through air, when landing on ground have the ability to drill themselves into dirt

Researcher

Department of Agricultural Botany, University College of Wales

Manifestation

Self sustaining systems of life, growth

Product Design

Drilling tools, self planting farms, filtration

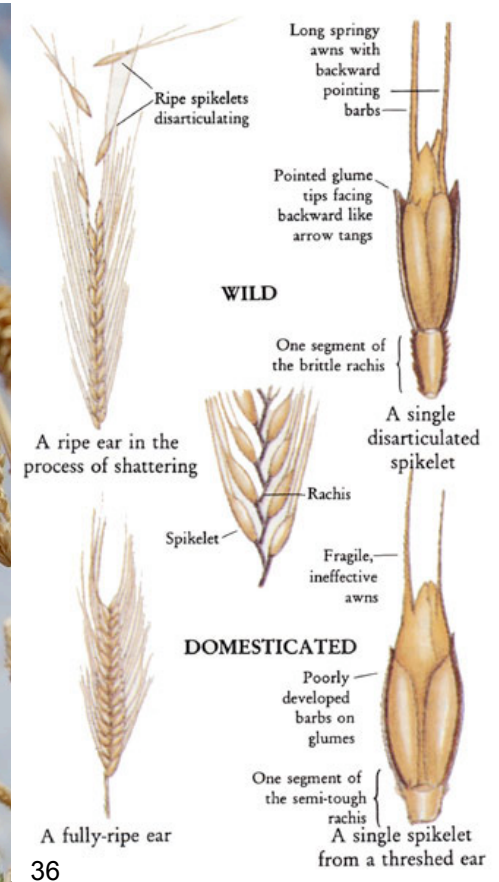


Photo Credits:

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13. <http://www.internetstones.com/abernethy-pearl-little-willie-freshwater-scottish-margaritifera.html>
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24. <http://www.flickr.com/photos/89544908@N00/281020320/sizes/o/in/photostream/>
25. <http://www.rishelp.org/fishpix13.htm>
26. <http://www.davidjander.se/?p=46>
27. <http://www.flickr.com/photos/throkda/2760430579/sizes/l/in/photostream/>
28. <http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/plates/1886-Miers17.jpg>
29. <http://www.flickr.com/photos/xoto/101676146/sizes/o/>
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31. http://homepages.tesco.net/~chris.j.thomas/imm_bolorioa_silene_wing.jpg
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33. <http://ngm.nationalgeographic.com/2008/04/biomimetics/clark-photography> Photo by Robert Clark
34. <http://ngm.nationalgeographic.com/2008/04/biomimetics/clark-photography> Photo by Robert Clark
35. http://upload.wikimedia.org/wikipedia/commons/b/b1/Wheat_blue_sky2.JPG
36. http://www.hort.purdue.edu/newcrop/history/lecture03/fig_3-6.html
37. <http://blog.ecosmart.com/wp-content/84283500.jpg>
38. http://1.bp.blogspot.com/_cvdgPIEKW9k/S8vllpy5wnI/AAAAAAAABlg/7gjkzT8hh78/s1600/antColonyCoop.jpg

The image features a soft-focus background of dried, pressed flowers. In the bottom left corner, a flower head is in sharp focus, showing its intricate structure of small, light-colored florets and green bracts. Several other flower heads are visible in the background, but they are out of focus, creating a sense of depth. The overall color palette is muted, with earthy greens, browns, and tans against a clean white background.

Thank You!