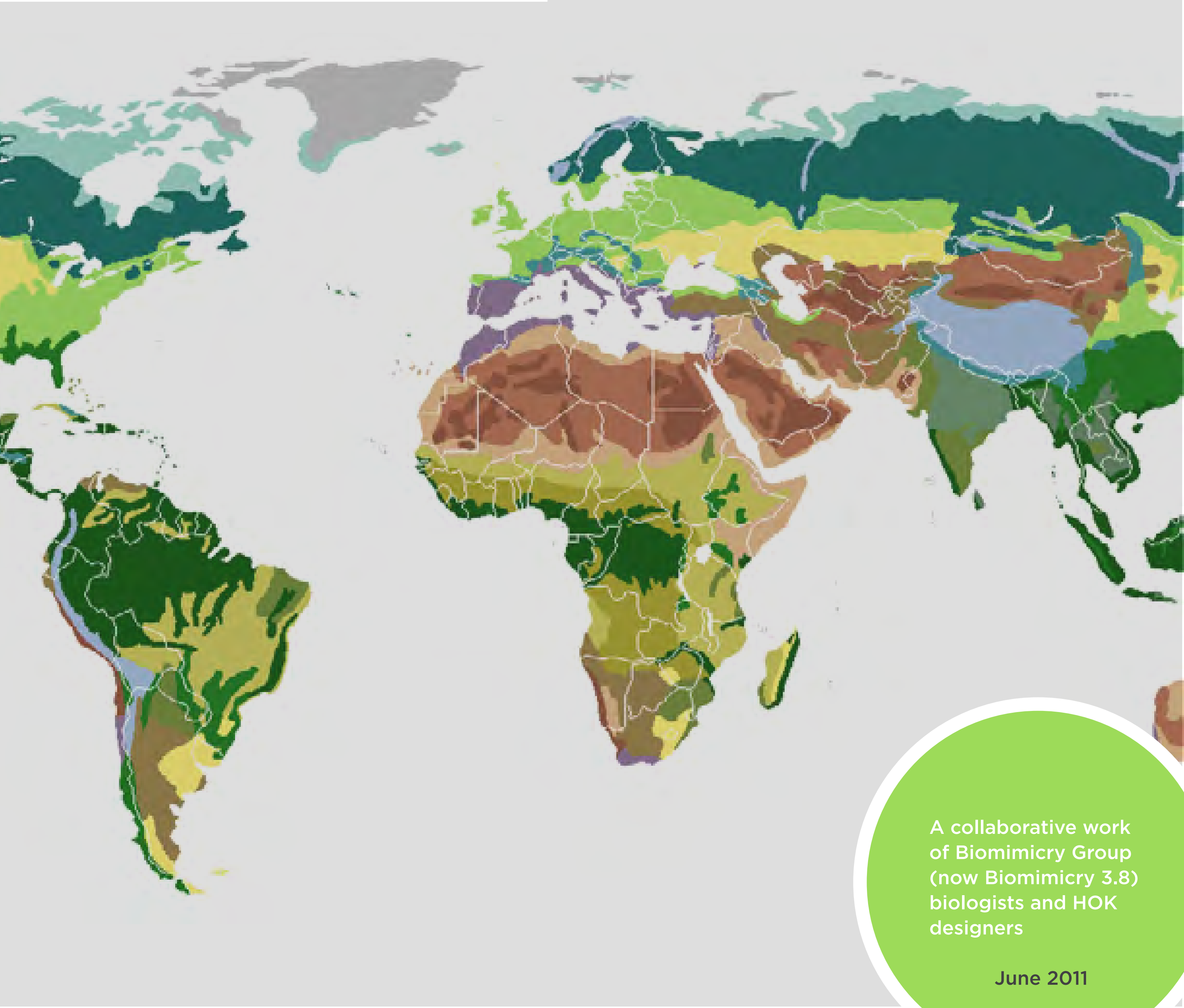
GENIUS OF BIOME

View >

TEMPERATE BROADLEAF FOREST



A collaborative work of Biomimicry Group (now Biomimicry 3.8) biologists and HOK designers

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BIOMIMICRY 3.8

Biomimicry 3.8 (a dba of Biomimicry Group, Inc.)
140 South 4th St West, Suite 2
Missoula, MT 59801

+1 406 543 4108

h+k

HOK Group, Inc
211 N. Broadway, Suite 700
St. Louis, MO 63102 USA

+1 314 754 3927

GENIUS OF BIOME

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SMIT (Sustainably Minded Interactive Technology)

Ivy

what is biomimicry?

Biomimicry is an innovation method that seeks sustainable solutions to human challenges by emulating nature's time-tested phenomena, patterns, and principles. The goal is to create well-adapted products, processes, designs, and policies by mimicking how living organisms have survived and thrived over the 3.8 billion years life has existed on Earth.

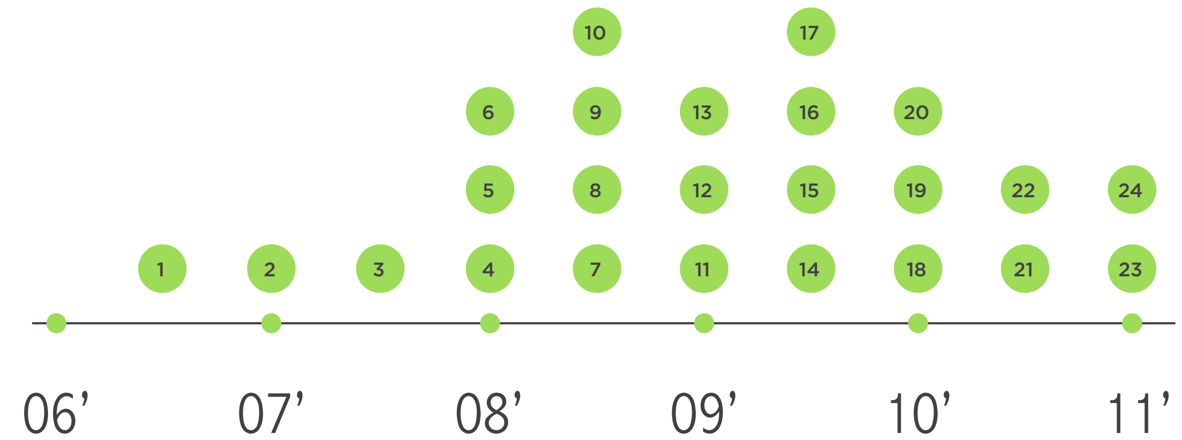
Learning from, modeling, and emulating nature's best designs is the first step to integrating human systems with natural systems. Our biologists showcase elegant and intriguing stories from the natural world that designers can play with as creative fodder.

Ultimately, the deep practice of biomimicry is not just about creating bio-inspired things; it is about emphasizing that humans are a part of, not apart from, nature. It is about viewing and valuing healthy natural systems for their intrinsic worth, not just for what we can glean from them.

Featured AskNature.com Biomimicry Case Study:
SMIT (Sustainably Minded Interactive Technology) Hybrid Energy System

A Brooklyn-based firm, SMIT, has created a product called Solar Ivy, or GROW. Mimicking the look and function of ivy, this technology has wind and solar power generating photovoltaic leaves that can be attached to building facades.

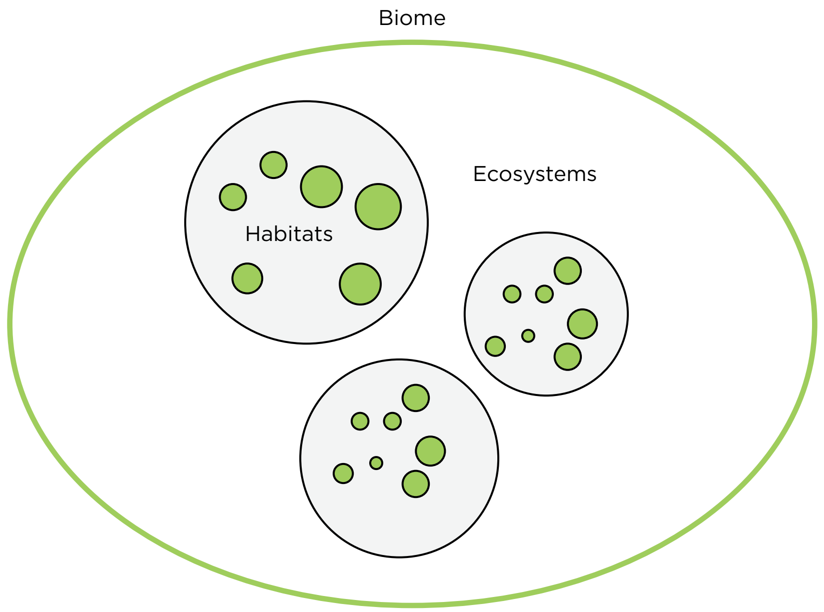
Solar panels take up a lot of space. GROW Solar Ivy is designed to be placed on building facades, taking advantage of vertical spaces just as ivy does.



HOK + Biomimicry alliance

In 2008 HOK and the Biomimicry Group formalized a first-of-its-kind alliance linking the natural and built environment. The alliance represents a natural progression in the relationship between HOK and the Biomimicry Group, which began in 2004. Our goal is to proactively integrate nature's innovations into the planning and design of buildings, communities, and cities worldwide, and to define a new industry standard for what it means to practice sustainable architecture. To make a bio-inspired product is one thing. To make a bio-inspired city will change the world. The collaboration between HOK and the Biomimicry Group turns knowledge into value.

1. Janine Benyus, Co-founder, Biomimicry Guild, attends Vermont meeting
2. Janine attends Planning Group retreat in Houston
3. Janine attends HOK Leadership retreat in Mexico
4. Formal alliance agreement signed
5. History Channel "City of the Future" competition, Atlanta, GA
6. Lavasa Hill Station Community, India
7. Biosphere II Training, AZ
8. ConocoPhillips Campus, CO
9. Deira Island, Dubai
10. KAPSARC, Saudi Arabia
11. FIT™ - NOLA, New Orleans, LA
12. Bohai Bank Tower, China
13. Salt Lake City Airport, UT
14. Wisconsin Energy Institute, WI
15. Zero Carbon Building Charette, virtual training
16. Bandar Seri Begawan Development Master Plan, Brunei
17. Khed SEZ Master Plan, India
18. Chicago O'Hare Airport, New Terminal, Chicago, IL
19. Largo Da Batata, Brazil 2010
20. US-China Green Energy Forum, CA
21. FIT Gathering, Chicago, IL
22. Lang Fang, China Concept Master Plan
23. Liulihe, China COFCO Eco City Project Proposal
24. Genius of Biome, Temperate Broadleaf Forest

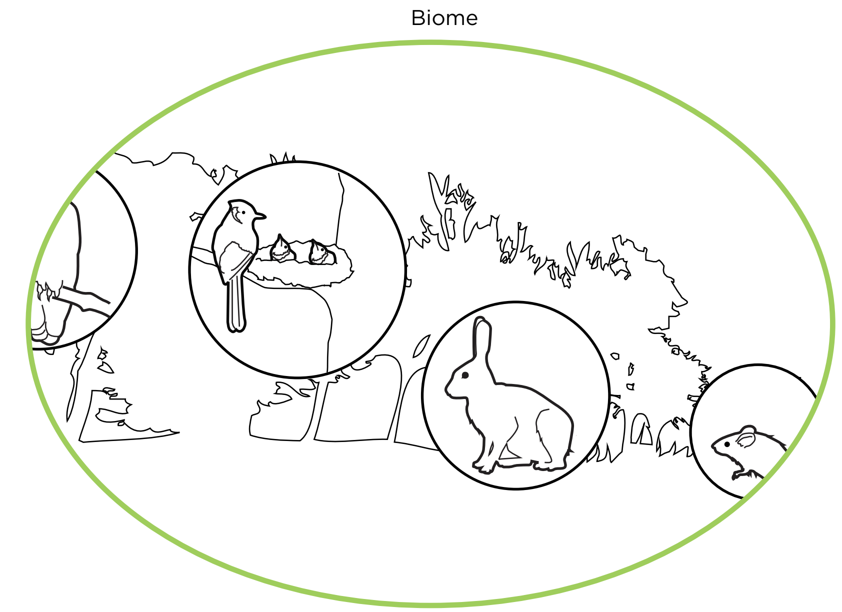


what is a biome?

A biome describes a type of climate and vegetation that exists in specific regions throughout the world. For example, the climate in eastern North America is similar to the climate in eastern China and thus, the trees that thrive in those conditions are broadleaf trees such as maples and oaks, along with conifers such as pines and firs.

The habitats and ecosystems found in a biome function in similar ways. It is the patterns in function that create relevance for human design. If the living organisms in these biomes are challenged by similar climate and conditions, what design ideas can we gain from their examples of adaptations and survival mechanisms?

Many biome classification systems have been devised, all being similar yet different in how they divide climate and ecological conditions. The Biomimicry Group has decided to choose the best classification system that provides the most available biome map that fits our needs. The classification system we chose is a derivative of the World Wildlife Fund classification of terrestrial ecosystems that describes 18 biomes (Hassan et al. 2005; Olson et al. 2011).



what is the genius of biome?

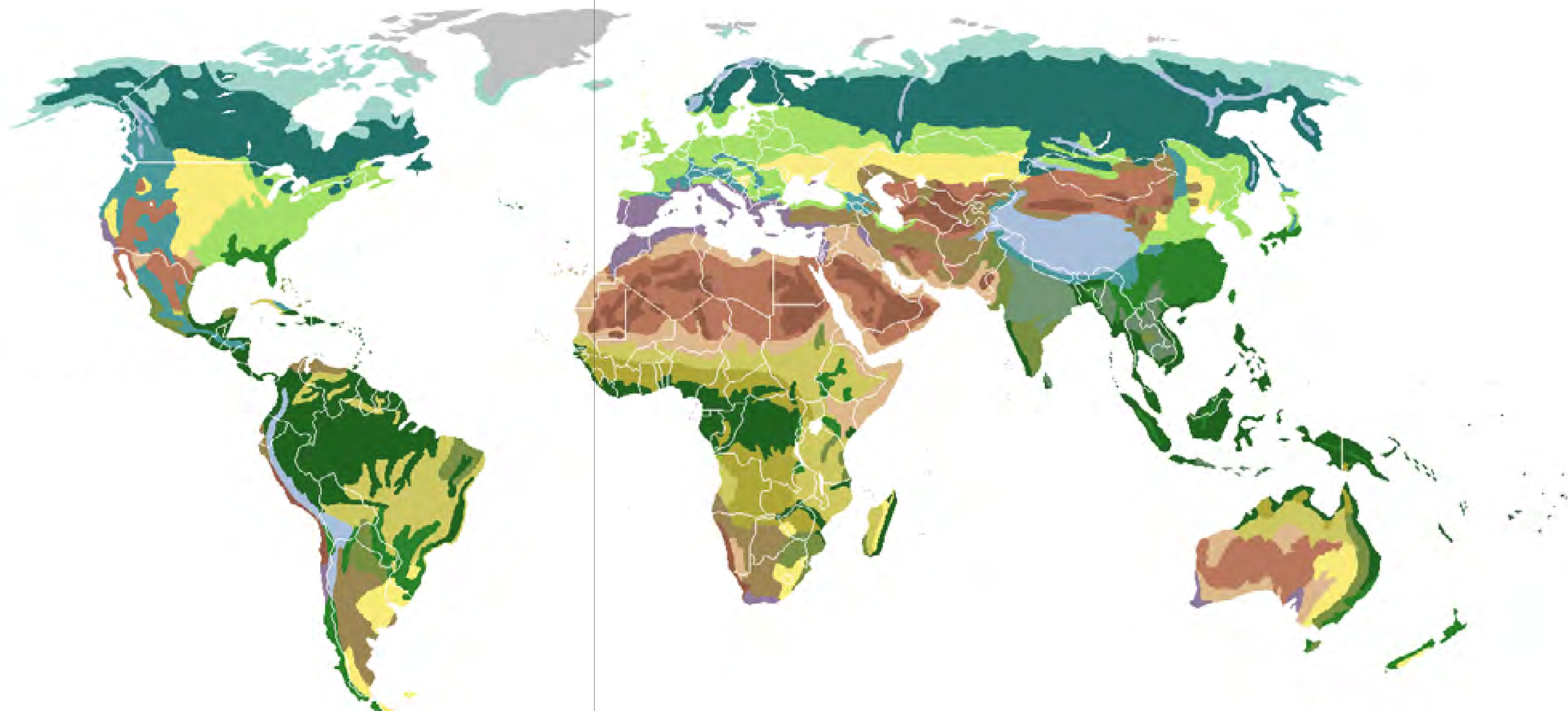
Drawing inspiration from natural systems provides a fresh opportunity to re-think and re-imagine how to solve human design challenges. The Genius of Biome report offers designers, architects, and planners examples of how organisms and ecosystems have adapted to biome challenges of climate, energy, materials, nutrients, and communication. A biome report can be applied to a wide geographic range of projects that fall into the same or similar climate and vegetation.

A Genius of Biome describes the strategies and designs adopted by living organisms found in a worldwide region of similar climate and vegetation. Further, the Genius of Biome also investigates and highlights strategies and designs at the ecosystem level. Ecosystems are made up of living entities along with their abiotic conditions (climate, temperature, soil types, topography). In a biome, the abiotic conditions are just as important as they are to architects, designers, and planners. It is this broad view that the Genius of Biome appreciates and illuminates. Ecology, therefore, offers an additional lens with which we can view nature's genius and learn design principles that adapt to abiotic and biotic conditions present in a biome.

The Genius of Biome describes the biological principles and patterns common to organisms and ecosystems within a biome. This biology is then translated into design principles that can be used to inspire design innovations or identify more specific criteria for place-based design. The goal is to inspire innovation to mimic the successful designs, processes, and patterns found in the larger scale of the natural world—ecosystems. An important part of understanding these biological and design principles and how to mimic them is to know the history of these biomes.

world biomes

- ice sheet and polar desert
- tundra
- taiga
- temperate broadleaf forest
- temperate steppe
- subtropical rainforest
- mediterranean vegetation
- monsoon forest
- arid desert
- xeric shrubland
- dry steppe
- semiarid desert
- grass savanna
- tree savanna
- subtropical dry forest
- tropical rainforest
- alpine tundra
- montane forests



biomimicry process for the genius of biome

This report represents a brief glance at some of the thousands of designs in nature. Nature has had to solve the same challenges as humans. The first step in a biomimetic process is to ask what you want your design to do. This is important to identify function.

The next step is to biologize the question. For example, if the problem is how to insulate against heat loss, we would ask, "How does nature insulate?" We identify the functions and both how nature accomplishes that function and how it does not. Our team of biomimetic researchers dives into the scientific literature and asks, "Whose survival depends on solving this problem?"

For the Genius of Biome we identify the operating parameters of the biome.

- Climate conditions (e.g., wet, dry, cold, hot, low/high pressure, highly variable, high/low UV)
- Nutrient conditions (e.g., poor, rich)
- Social conditions (e.g., competitive, cooperative)
- Temporal conditions (e.g., dynamic, static, aging)

We identify the core biological principle that is used to accomplish function and describe it without using biological terms to form the design principle. The final step in this process is to emulate these principles with sketches for literal, abstracted, or conceptual applications.

The next steps can proceed to a brainstorm session, a matrix or taxonomy of related elements or principles, consulting expert information for a deeper and broader understanding of the mechanism or process, and a repetitive process of testing the design by going back again and again to the original functions and asking "why" several times.

Nature can act as mentor, model, and measure. Life's Principles can provide a guide to assess the potential success of an innovation or idea. Life's Principles are benchmarks of sustainability. Are our designs accomplishing the overarching pattern held in common by living organisms on earth? Life's Principles are the deep patterns of a collection of biological principles abstracted to the broadest level.

Pattern recognition is an art. Finding patterns in nature and adopting these patterns to solve human problems is a significant step toward seamlessly fitting humans into nature.

The examples and sketches in this report emphasize the cohesive, integrated, and optimized elements found in nature's genius. We have framed these stories to help designers understand the elements involved but we cannot guarantee a successful outcome. The next step is to not only grasp these elements but to apply them as well.

life's principles: design lessons from nature

Life seems to follow some common patterns. The fundamental principles underlying these patterns represent nature's strategies for surviving and thriving on Earth. These principles have been compiled into a list we call Life's Principles.

Integrating biology into design involves seeking nature's advice at all stages of design. Discovering nature's blueprints is the first step followed by finding the patterns and principles of how nature manages its challenges. Human designs guided by these principles ensure that they will fit in an ecosystem and are not shallow in their mimicry. The final step is to test a design against principles found in nature. Therefore, Life's Principles serve as an overarching scoping and evaluation tool—nature's own eco-design checklist.

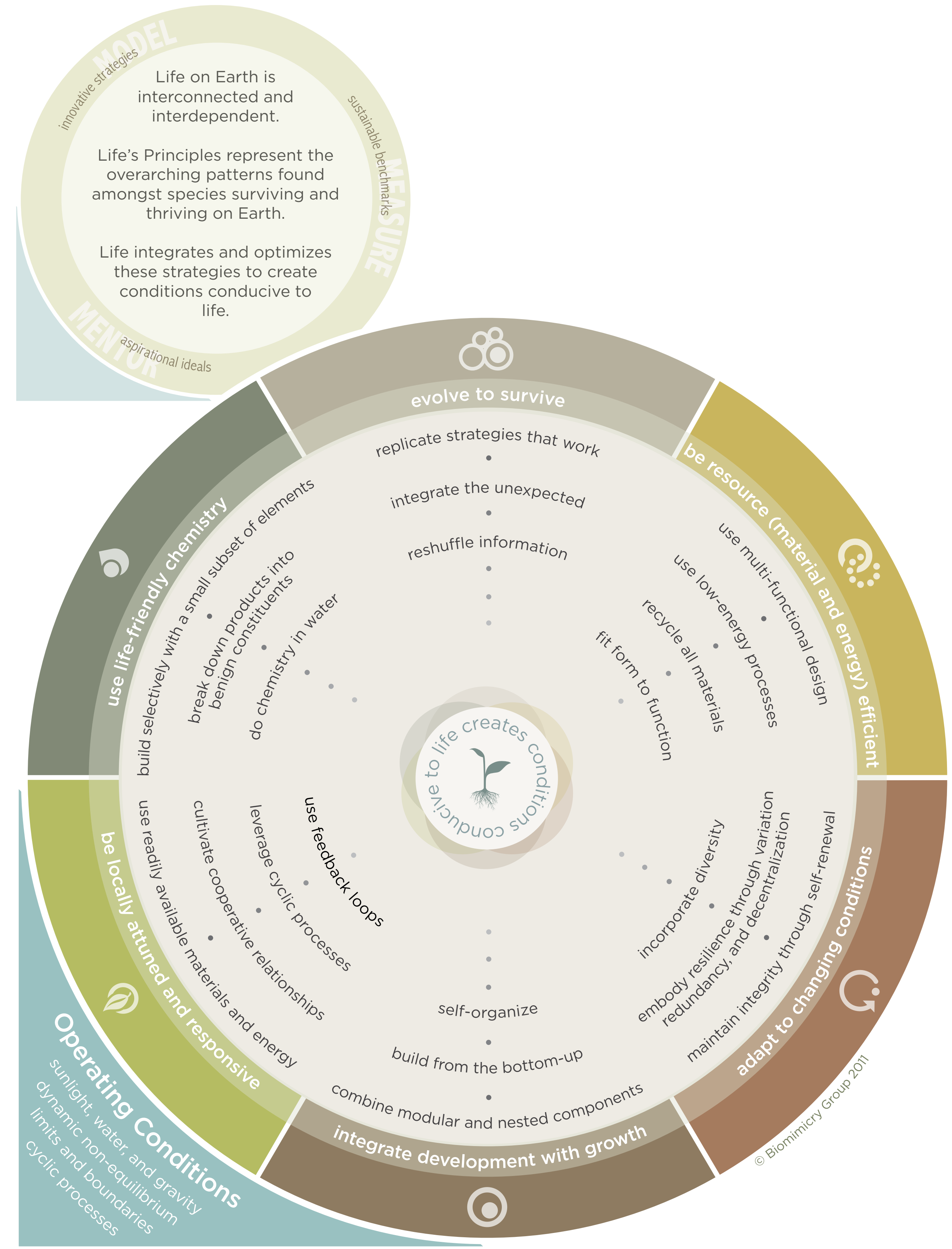
Examples of how Life's Principles can be applied at the design level are given at the beginning of each lens section: Water, Energy, Materials, Social, and Economy.

Life's Principles are presented as a one-page diagram with a set of definitions on the next page.

The small circle in the upper left reminds us to view nature as mentor, model, and measure.

These principles are the result of and subject to the operating conditions of the planet, found in the blue arrow on the lower left side of the circle. The center of the circle is both the aspirational goal and the emergent property of these principles—creating conditions conducive to life.

Just as no principle stands alone, all principles are interconnected. Use the tool and the diagram as it suits you; yet keep in mind that it is the integration and optimization of the collective and collaborative suite of principles that yields life its successes.



LIFE'S PRINCIPLES DEFINITIONS

Evolve to Survive

Continually incorporate and embody information to ensure enduring performance.

Replicate Strategies that Work
Repeat successful approaches.

Integrate the Unexpected
Incorporate mistakes in ways that can lead to new forms and functions.

Reshuffle Information
Exchange and alter information to create new options.

Be Resource (Material and Energy) Efficient

Skillfully and conservatively take advantage of resources and opportunities.

Use Multi-functional Design
Meet multiple needs with one elegant solution.

Use Low Energy Processes
Minimize energy consumption by reducing requisite temperatures, pressures, and/or time for reactions.

Recycle All Materials
Keep all materials in a closed loop.

Fit Form to Function
Select for shape or pattern based on need.

Adapt to Changing Conditions

Appropriately respond to dynamic contexts.

Maintain Integrity through Self-renewal
Persist by constantly adding energy and matter to heal and improve the system.

Embody Resilience through Variation, Redundancy, and Decentralization
Maintain function following disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together.

Incorporate Diversity
Include multiple forms, processes, or systems to meet a functional need.

Integrate Development with Growth

Invest optimally in strategies that promote both development and growth.

Combine Modular and Nested Components
Fit multiple units within each other progressively from simple to complex.

Build from the Bottom Up
Assemble components one unit at a time.

Self-organize
Create conditions to allow components to interact in concert to move towards an enriched system.

Be Locally Attuned and Responsive

Fit into and integrate with the surrounding environment.

Use Readily Available Materials and Energy
Build with abundant, accessible materials while harnessing freely available energy.

Cultivate Cooperative Relationships
Find value through win-win interactions.

Leverage Cyclic Processes
Take advantage of phenomena that repeat themselves.

Use Feedback Loops
Engage in cyclic information flows to modify a reaction appropriately.

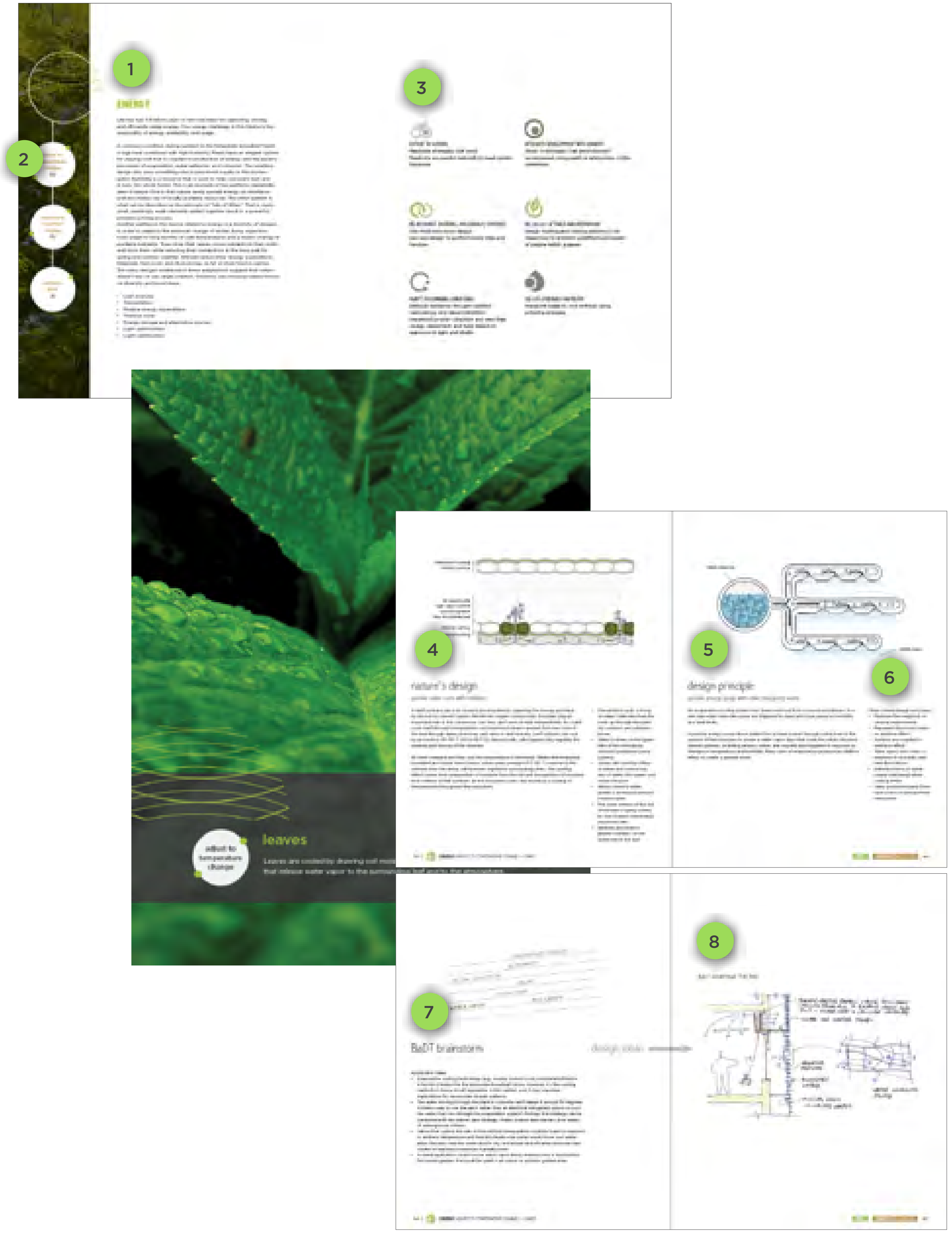
Use Life-friendly Chemistry

Use chemistry that supports life processes.

Build Selectively with a Small Subset of Elements
Assemble relatively few elements in elegant ways.

Break Down Products into Benign Constituents
Use chemistry in which decomposition results in no harmful by-products.

Do Chemistry in Water
Use water as solvent.



how to interpret a genius of biome design

1. **Lens**
   Five challenge areas were identified: Water, Energy, Materials, Social, and Economy. Note that these categories were chosen from the FIT™ Approach.

2. **Biologized Challenge**
   Frames the question in a way that can communicate with biological strategy. “How does nature...?”

3. **Life’s Principles**
   These principles represent the overarching patterns found amongst species surviving and thriving on Earth.

4. **Nature’s Design Description and Summary**
   The design of an organism or ecological process and how it solves the challenge.

5. **Design Principle Description and Summary**
   The elements and processes fundamental to the nature’s design example.

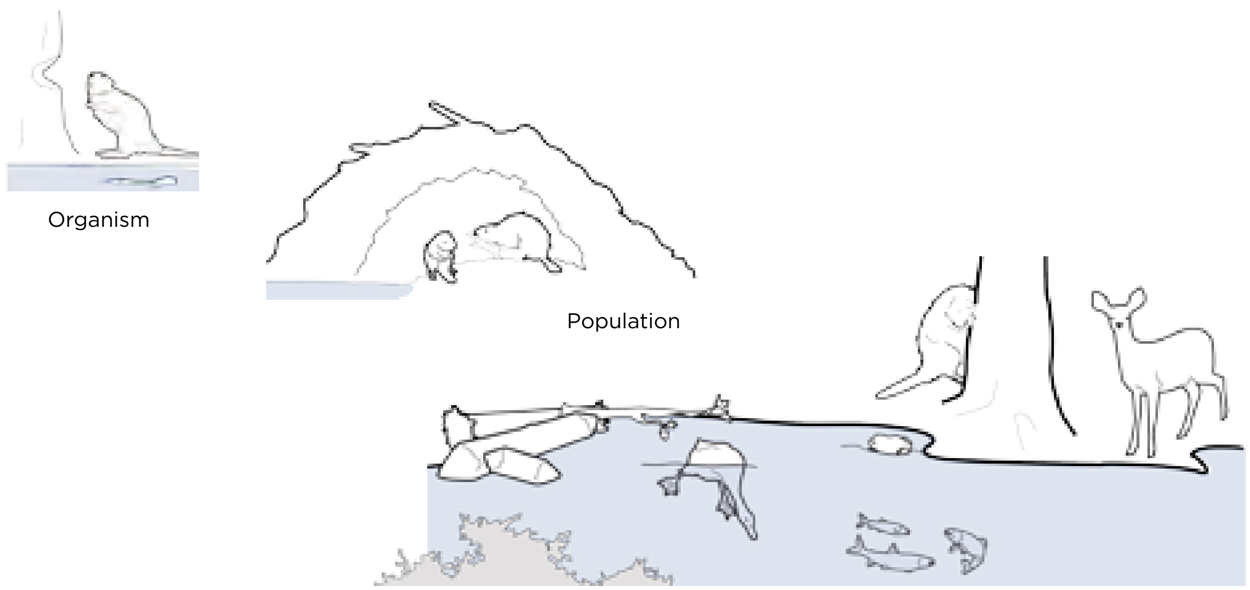
6. **Other Related Design Principles**
   Designs found in nature are always related or interconnected to other designs that are just as valuable. In fact, it is difficult to focus on only one design principle because many mechanisms or processes are linked together in order to function optimally.

7. **Biologist at the Design Table (BaDT) Brainstorm**
   Examples of emulating design principles from nature that can help guide design ideas.

8. **Design Ideas**
   Sketches from HOK designers suggesting ideas that illustrate the principles, patterns, strategies, and functions found in nature that can inform the design.

TEMPERATE BROADLEAF FOREST

SEARCH CHALLENGES



Organism

Population

Community

Ecosystem

ecosystem realities

Temperate broadleaf deciduous forests can be found on six of the seven continents, including the eastern half of North America, north-central Europe, southwest Russia, Japan, eastern China, the southern tip of Chile and east coast of Paraguay, New Zealand, and the east coast of Australia.

No matter which continent, the temperate broadleaf forest biome experiences four distinct seasons, spring, summer, fall and winter. The average annual temperature of this biome is 50° F (10° C), with 30-60 inches (75-150 cm) of rainfall per year, though this can vary widely from one region to another. Winters are cold and dry, spring is cool and breezy, summers are hot and humid, and fall is warm and breezy. The climate type is generalized as “moist continental.” The climactic dynamics of this biome result from prevailing ocean and wind patterns.

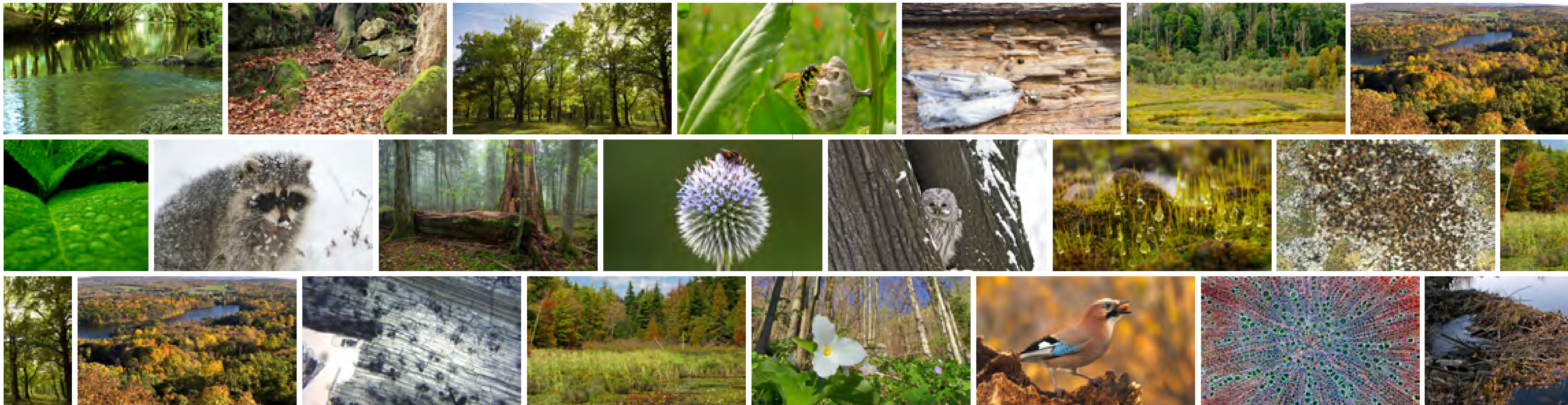
This biome is characterized by broad-leaved trees, evergreen plants such as conifers and holly, and dense shrubs all of which drop their leaves in the fall and are dormant in the winter. Trees have thick bark to protect from cold weather and ice storms. Vegetative growth is limited to the late spring and summer seasons, an adaptation that allows plants to survive cold winters. Many animals hibernate through the winter. Those that remain active are well adapted to eating a wide variety of food sources, which are often very limited. Others migrate south for the winter because their strategy for dealing with the challenges of the long, cold winters is avoidance.

The soil is very fertile in this biome and supports a wide diversity of life. Forest vegetation, the basis of the food web, displays five distinct layers. The first is the ground layer, which is composed of lichen, mosses, bacteria, fungi, and a rich seed bank. The second is the herb layer, including short plants like herbs and grasses. Next is the shrub layer, followed by the small tree and sapling layer. These two layers together are often known as mid-canopy. Finally, the fifth layer is the tree canopy, which can reach heights of 60-100 feet (18-30 m) and is generally dominated by oak, beech, maple, and birch trees. Coniferous trees include pine, fir, and spruce, which populate the mid-canopy and canopy. Vines and other climbing plants connect the different layers. The greatest concentration of biodiversity occurs on or near the ground level in this biome.

The unique microclimates expressed in each vegetative layer create a diverse and dynamic vertical forest structure, which in turn creates ample opportunities for animals to find their own niches. This biome is home to a diverse cast of mammals, insects, birds, reptiles, amphibians, and fungi, many of which are endemic, found only in this biome. The loss of large native predators has had many cascading impacts on forest structure and functionality.

This biome is subject to periodic large-scale disturbances such as fire, ice storms, blow down, insect and disease outbreaks, and increasingly more disturbance from human developments, agriculture, and resource exploitation. While the forest has co-evolved with natural disturbance, most of the species that live in this biome are best adapted for late-succession conditions and the increased frequency and extent of human-caused disturbances are threatening the integrity of many habitats.

The largest temperate broadleaf forest ecoregion that currently exists is found on the eastern coast of the United States. The loss of this temperate broadleaf forest in China has led to seasonal dust storms and disastrous flooding on the Loess Plateau and the North China Plain. Comparing these two ecoregions offers valuable guidance for designers. Nature has built-in mechanisms that adapt to change, but some changes come too fast and are too overwhelming.



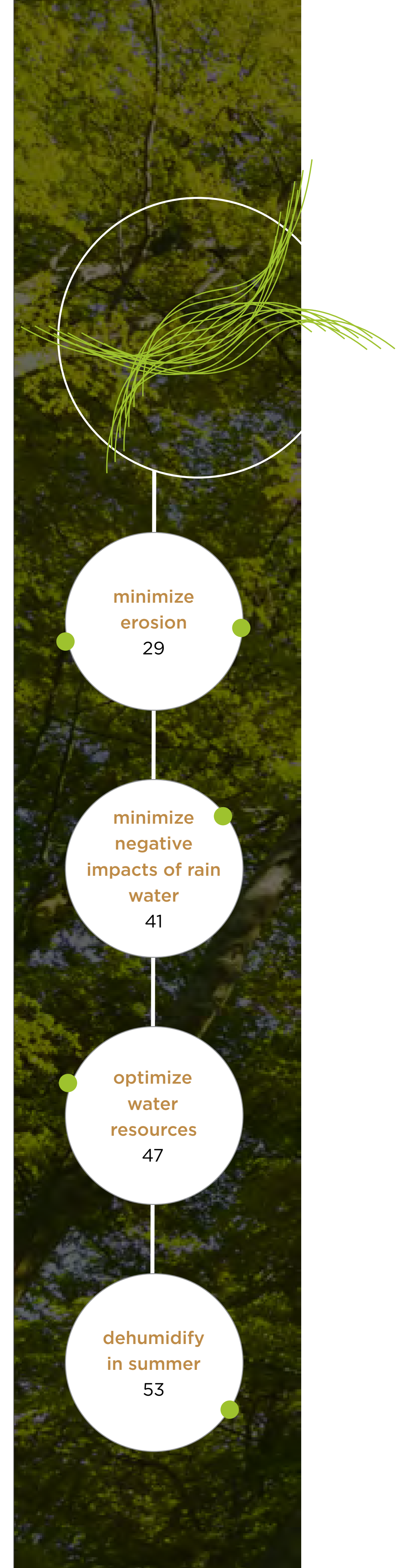
nature's designs

Biomimicry is a design and leadership discipline that seeks sustainable solutions by emulating nature's time-tested ideas. Flourishing on the planet today are the best ideas—those that perform well in context, while economizing on energy and materials. Whatever the design challenge, the odds are high that one or more of the world's 30 million creatures has not only faced the same challenge, but have evolved effective strategies to solve it.

Examples of nature's designs from the temperate broadleaf forest biome can inspire exciting innovation. The organisms that inhabit this biome, as well as the ecosystem processes formed by both biotic and abiotic conditions, evidence the embodied wisdom of successfully living in place. The abstracted design principles and ideas from nature occurring in this biome can tell us more about site conditions than a scientific explanation, and therefore offer inspiration for emulating a well-adapted design.

Living organisms produce designs in nature that can help to solve human problems. Using the beaver as an example, we know that the beaver builds dams to create a safe habitat for itself. A beaver will respond to flooding by strengthening a dam or repairing it; and will allow water to seep through it. From an engineering perspective, a beaver dam holds interesting principles of continual flow, sediment retention, and enhancement of biodiversity by creating more habitat for more living organisms. Nature can be a source of inspiration and innovation.

While a strategy is a behavior or set of behaviors used by an organism to solve a challenge, the Genius of Biome also encompasses designs formed by processes in local communities and ecosystems. We have called these nature's designs. The translation to design principles, and from there an abstraction to design ideas provides the most direct methodology for design inspiration.



WATER

A common pattern of how water flows in nature is “slow it, sink it, store it.” That is, the net effect of rainwater movement in an ecosystem results in water movement slowing as it moves through a system, water sinking into the soil, and water being stored and made available for use when needed. Can designers use these patterns as a template for valuable ideas?

In the following section on water, we see examples of how nature designs mechanisms and processes involving water. We see that beaver dams create habitat that attracts more species and thus adds more biodiversity. Beaver dams increase water infiltration, reduce downstream flooding, and collect sediment that eventually creates new habitat. In other words, a beaver dam is a closed loop system that benefits not only the beaver but also many other organisms that share the same habitat. How can this design be emulated to solve erosion and flooding?

We see that when it rains, the drops fall first on a forest canopy of leaves and branches, slowing the velocity and force. We see the raindrops pooling and then soaking in or starting to flow down the topography of the land. However, they quickly run into plant litter, fallen logs, soil, and pores in the soil. The roughness of the whole landscape of a temperate forest slows the force of water effortlessly and without energy. The land is protected from erosion by a complex set of structures.

Shifting to a microscopic view, we see that many surfaces in nature are rough, such as lichens. This roughness affords yet another benefit—hydrophobicity. Such a design enables a breathable, waterproof surface. What design principles can we learn from the temperate broadleaf forest biome? How can these patterns be emulated to solve our human challenges?

- increase infiltration
- slow water
- create air flow
- purify water
- moderate humidity

WATER

LIFE'S PRINCIPLES

REFERENCE THE DEFINITIONS

EVOLVE TO SURVIVE
Replicate strategies that work
Incorporate surface roughness at multiple scales to slow water and allow it to infiltrate

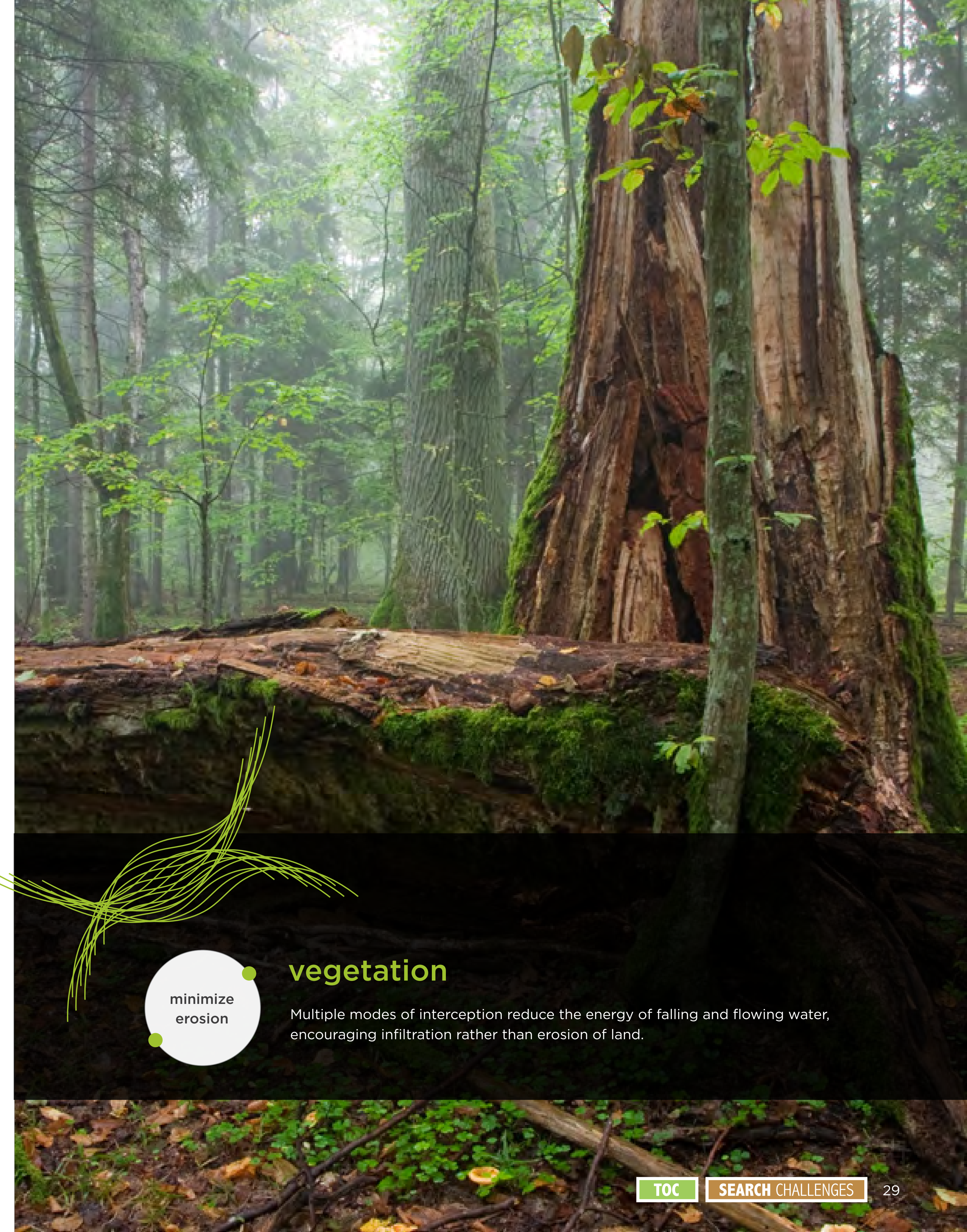
INTEGRATE DEVELOPMENT WITH GROWTH
Self-organize
Design water capture and management systems to allow components to interact with each other and stay flexible to respond to new relationships as opportunities emerge

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT:
Use multi-functional design
Manage stormwater using existing structures and create new ones that have additional purposes

BE LOCALLY ATTUNED AND RESPONSIVE
Use readily available materials and energy
Take advantage of existing structures and local materials, including waste materials to create surface structures for slowing water

ADAPT TO CHANGING CONDITIONS
Embody resilience through variation, redundancy, and decentralization
Create many small structures of different shapes, sizes, and locations to more effectively slow water and allow its infiltration

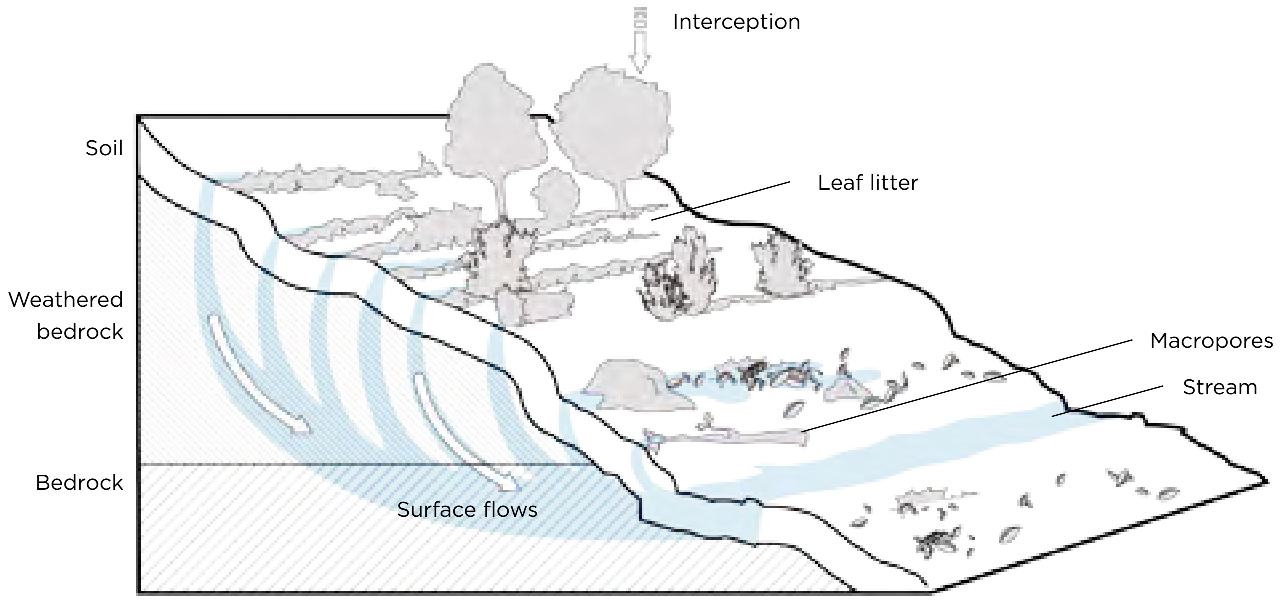
USE LIFE-FRIENDLY CHEMISTRY
Select building materials and processes that does not degrade water quality

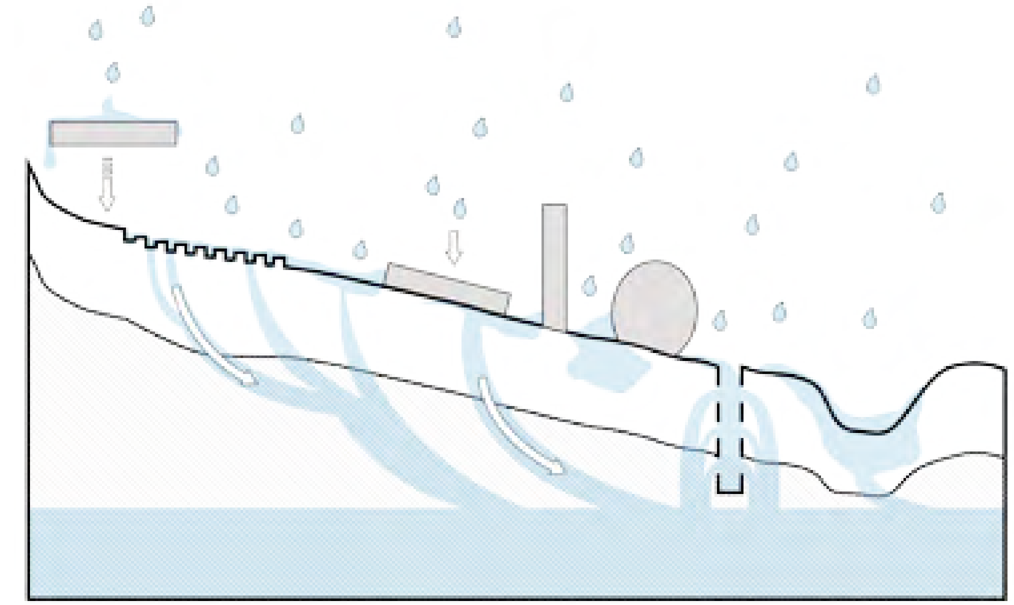


minimize erosion

vegetation

Multiple modes of interception reduce the energy of falling and flowing water, encouraging infiltration rather than erosion of land.





nature's design

surface roughness increases infiltration

Surface runoff is rare in deciduous forests because of the cumulative effect of thousands of small ways that vegetation slows down water flow, especially if the runoff is first slowed in upper watersheds. During rainfall, forest leaves and branches are first to intercept and absorb the energy of raindrops, causing the water that collects to slow and pool below and partially infiltrate into the soil. Plant litter, trunks, stems and stalks add to the dissipation of raindrop energy due to friction, giving the water time to soak in.

Rainwater infiltration is enhanced by the deep, extensive root systems under forests, soil pores associated with plant roots and animal burrowing, and soil mixtures. Rich organic matter in the forest soils allows faster infiltration.

Macro roughness on the soil surface also slows water. Downed trees (logs) that fall across a slope and settle into the ground are highly effective at slowing water and trapping sediments. Decaying logs are highly absorbent, holding water and releasing it slowly during dry periods. Remnants of logs and blown-over trees with up-tipped roots create a pit-and-mound topography that interrupts water flow and traps sediments.

Scaling Issue: The cumulative effects from burrowing creatures to leaves, branches and trunks, soils and topography are responsible for minimizing erosion and flooding.

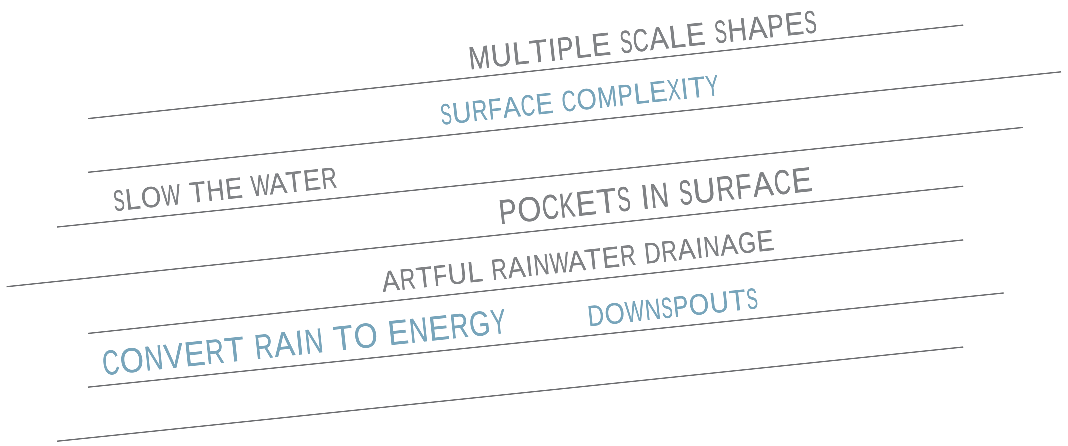
- Canopy and litter interception, stemflow, and throughfall assist in preventing erosion
- Biotic and abiotic forces contribute to soil porosity in forest soils
- Humic acid, the result of breakdown of organic matter, holds water in soils
- A diverse micro- and macro-fauna population breaks down organic materials and creates soil pores
- Most rainfall moves to streams by subsurface flow pathways where nutrient uptake, cycling, and contaminant sorption processes are rapid.

design principle

varied, multiple surface barriers increase infiltration

Varied and multiple structures reduce the velocity and energy of flow. Cumulatively, many structures act to slow flow long enough for it to infiltrate rather than flow overland and erode surfaces. The structures include: horizontal, above-ground and ground-surface structures that intercept; vertical structures placed in the path of flow that cause friction, creating turbulence that slows flow; porous structures in the surface that aid in infiltration and retention; and topographic features on the surface that increase surface roughness, resulting in temporary pooling.

Other related design principles:
- Chemical compounds can increase holding capacity
- Structures capture solid elements
- Local materials decrease water flow



BaDT brainstorm

design ideas

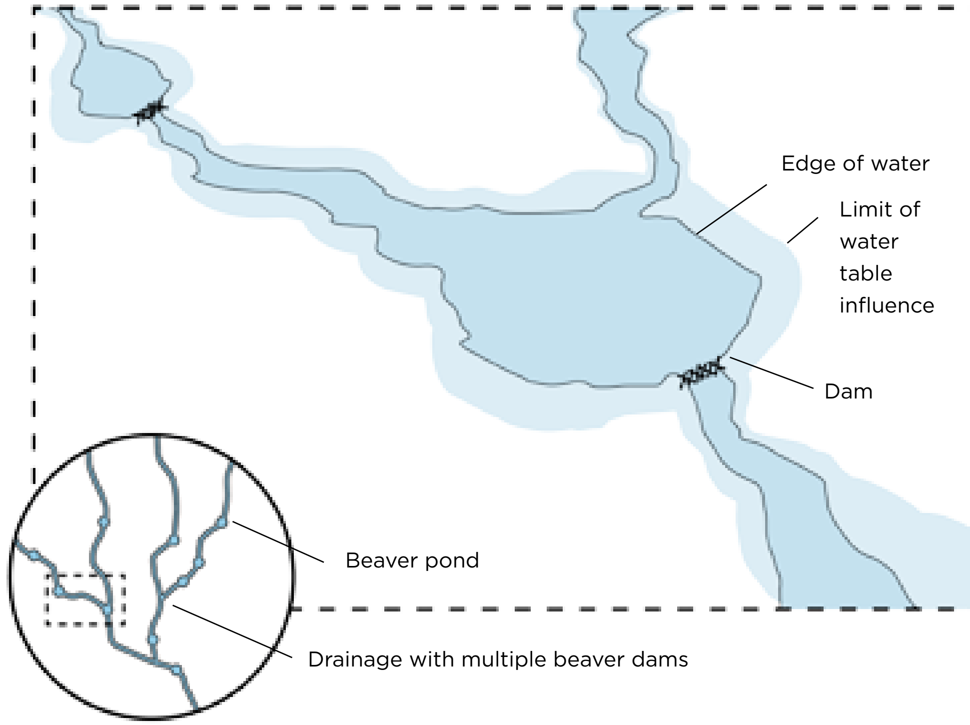
Application Ideas

- Use shape on multiple scales to reduce the flow of water over surfaces. For example, create surface complexity on a roof or building façade.
- Consider vertical and horizontal structures that can slow the movement of water. This could include built elements (buildings, parking structures, awnings, etc.), and/or natural elements (landscaping, water features, terracing, green-roofs, etc.)
- Create a layered or pocketed system that increases infiltration and slows water velocity. For example, rather than direct down-spouts, create a rainwater drainage matrix that is artful and forces the water to “meander.”
- Convert rainwater descending from roofs and gray-water descending through the plumbing of a tall building into energy with micro-hydro technology. In the case of a meandering downspout system, there are even more opportunities to generate energy. Make energy generation information available to building users in real time.

minimize erosion

beavers

Beaver dams are arranged in a stair-step pattern that descends through drainages reducing the kinetic energy of stream flow and benefiting the ecosystem in many ways.

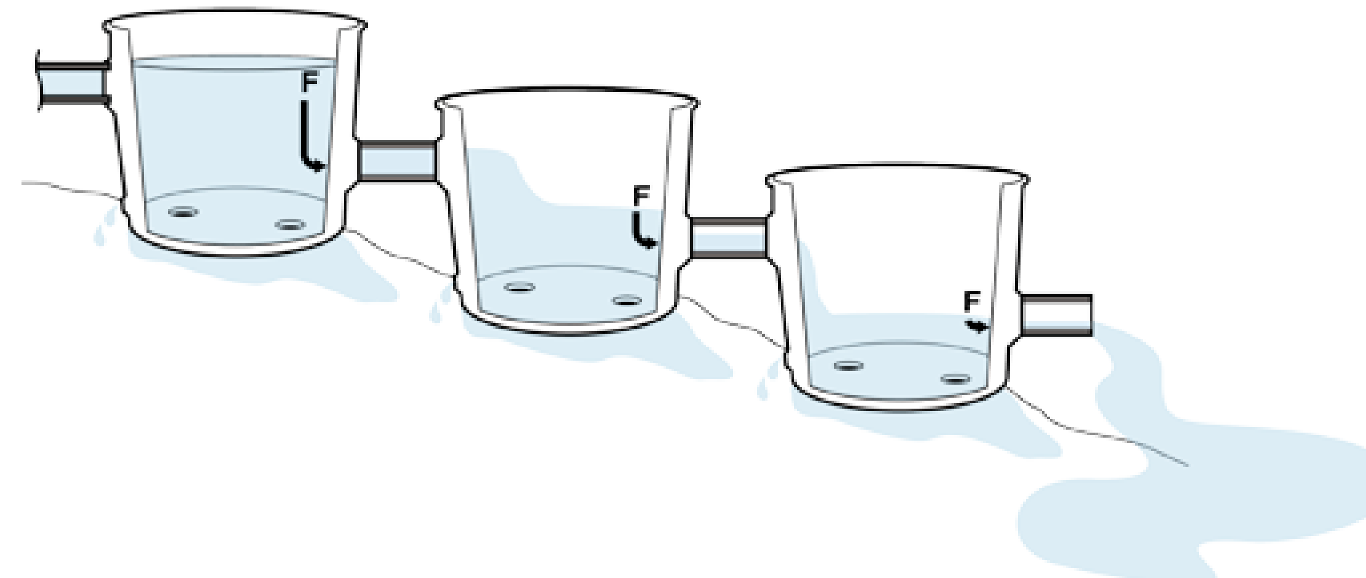


nature's design

series of upstream barriers slow water

Beavers are ecosystem engineers that alter stream and upland habitats by cutting down trees and building dams across rushing streams, modifying streams into series of stair-stepped ponds that descend down landscapes and drainages. These dams create a variety of habitats that many other species rely on in these ponds as well as far beyond the ponds. The backing up of water into ponds creates wetlands that slow water long enough for much of it to spread out, drop sediment and organic matter, infiltrate into the soil, and raise the water table as well as returning moisture into the atmosphere through evaporation. In upper drainages, these ponds reduce flooding in lower drainages. Beaver dams are leaky, slowly releasing water into the stream and reducing the kinetic energy of stream flow, especially farther up in drainages where water gradients are higher. Beavers are considered important keystone species because they create shifting mosaic habitats that are productive and dynamic. Beaver ponds sometimes fail and empty, especially after beavers move to new areas after their food runs out. These ponds may fill with sediment and organic materials, creating new soil for re-sprouting of trees and shrubs, becoming meadows, then forests. The activity of beavers enriches the biodiversity and overall health and resilience of the broader ecosystem.

- Beavers are ecosystem engineers and keystone species
- Dams are leaky structures
- Dams slow and store water, creating wetlands and increasing water filtration and evaporation
- Dams occur in a stair-step pattern
- Beaver ponds can reduce flooding downstream
- Habitats created by beaver enriches biodiversity and health of the ecosystem



design principle

series of upstream barriers slow water

A series of leaky barriers reduces kinetic energy and increases infiltration but does not completely stop the flow of water. Multiple spillways are produced, leaking at both high and low flow. Storing water allows for infiltration into surrounding areas, further slowing flow. Elements are captured instead of flowing away and stored temporarily, resulting in a shifting mosaic of conditions that increases diversity and creates a dynamic community.

Other related design principles:

- Barrier reduces kinetic energy
- Slowing water raises water table
- Slowing water captures sediments
- Small materials in cross-wise pattern provide leaky barrier
- Increases biodiversity by diversifying landscape elements
- Allows flow increases aquifer recharge

LEAKY CISTERNS
HYDRATE THE LANDSCAPE
FROM THE BOTTOM - UP
WATER GUILD
PARTITION RESOURCES
CONSTRUCT UPSTREAM
LANDSCAPE MICROCLIMATE

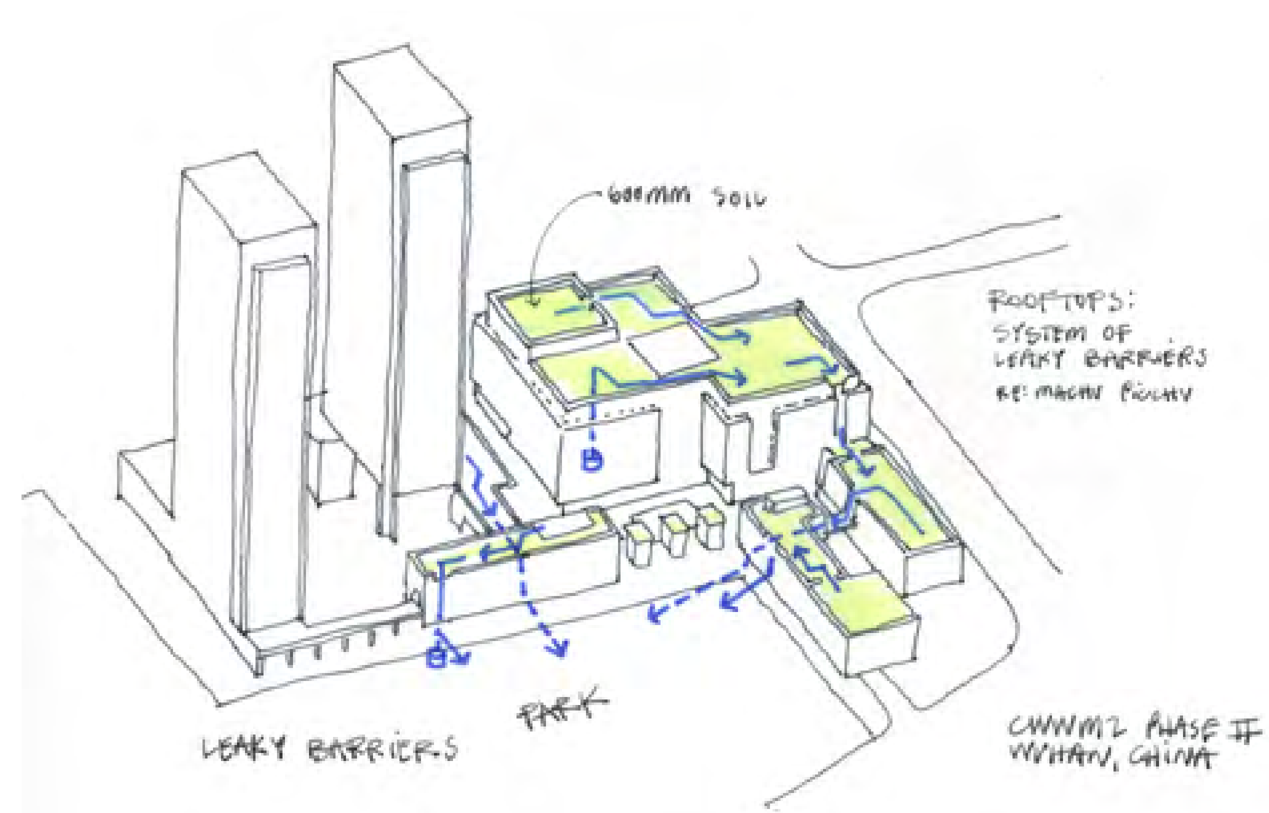
BaDT brainstorm

design ideas

Application Ideas

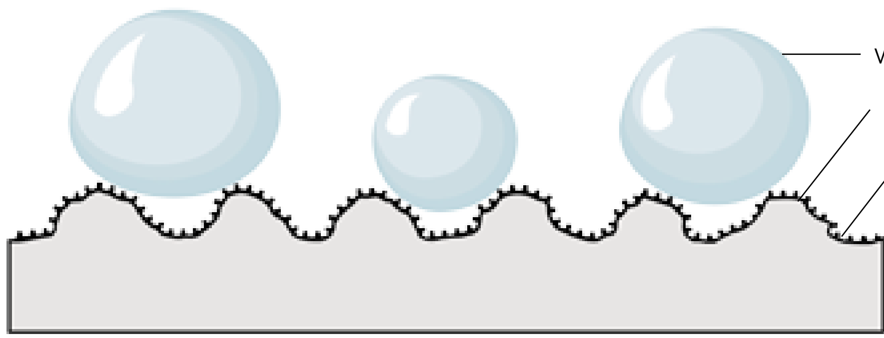
- Consider installing a series of underground or partially buried cisterns that collect rainwater and snowmelt. These cisterns should be leaky and extend away from the building, hydrating the landscape slowly and from the bottom up.
- A network of underground cisterns could connect buildings within a given development. This could serve as the basis of a water guild (see Social: Foster Social Integration • pollinators) where landscaping plants utilize the soil moisture. Humans indirectly benefit by interacting with the landscape (biophilia). A well-hydrated landscape is also important for microclimate regulation, another indirect benefit to humans. This creates myriad benefits and opportunities for a diversity of life.
- Construct water barriers as far up in a drainage area as feasible to decrease downstream effects of too much water.

LEAKY BARRIERS ROOFTOPS



lichen

A lichen that grows on tree trunks acts like a waterproof yet breathable barrier due to a rough surface and hydrophobic compounds that cause water droplets to perch while allowing airflow.



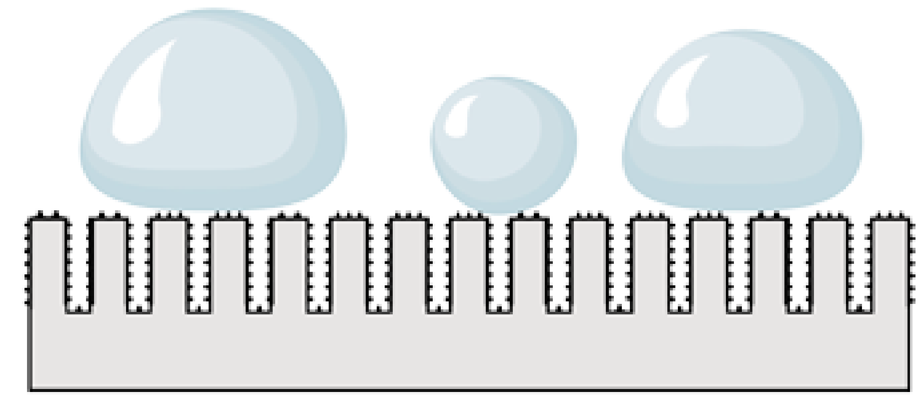
nature's design

rough surface, hydrophobic spaces create air flow

The lichen *Lecanora conizaeoides* grows on tree trunks, using the tree for support and access to light and water. It does so without harming the tree. Lichens are compound organisms, meaning they consist of symbiotic partners—algae embedded in a fungal matrix. The algae and the fungi live together as one organism, mutually supporting each other with the algae photosynthesizing sugars and the fungi providing a protective home for the algae. The rough surface of the fungus, with structures of different sizes layered on one another, keeps water droplets perched on top rather than coming in contact with the whole surface. Channels between the structures are coated with hydrophobic compounds called hydrophobins, so that the channels remain dry, allowing air to reach the algae. This combination of rough structure and hydrophobic compounds produces a biological analogue of a waterproof, breathable garment.

Lichens play an important role in ecosystems, thriving in places where plants can't grow, thus adding to the total energy-gathering, carbon-fixing ability of the ecosystem without competing with other plants. They are also a food source for insects and mites and provide shelter either directly as structures or by being incorporated onto insects' bodies as a form of camouflage.

- Lichens are compound organisms made up of symbiotic partners
- Lichens grow on trees without drawing nutrients from them or causing harm
- Lichens photosynthesize even during rain
- The fungal partner in *Lecanora* sheds water due to a rough surface combined with a hydrophobic compound
- The algae partner retains access to air for gas exchange
- Lichens are important components of the forest ecosystem.



design principle

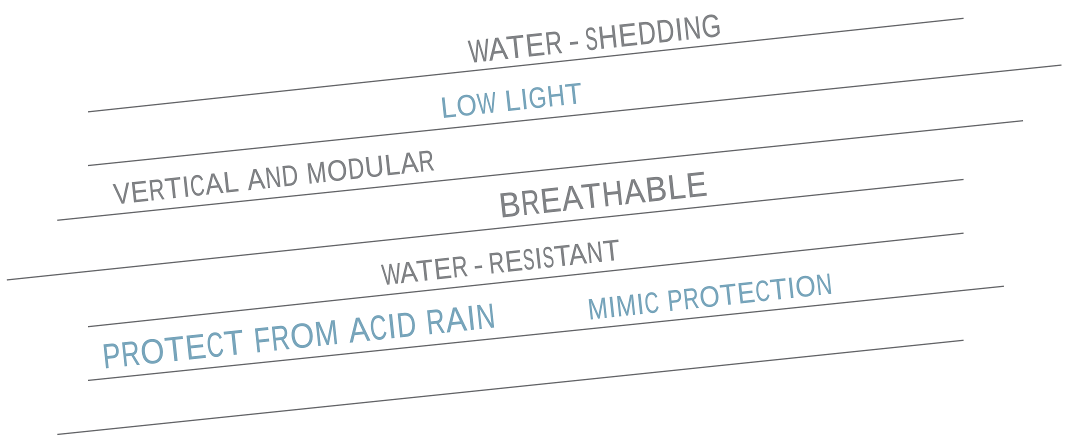
rough surface, hydrophobic spaces allow air flow

Breathable, water-shedding surface made of hydrophobic compounds combined with multi-layered roughness.

A water droplet is made up of highly polar molecules, and if put in a situation where its molecules are more attracted to each other than to a surface, it will form a sphere. A series of peaks with hydrophobic valleys will keep a sphere of water molecules perched on top, rather than seeping into the spaces between the peaks. This facilitates water rolling off a surface. At the same time, the spaces between the peaks stay dry and air can flow through them. This creates a breathable, yet waterproof surface.

Other related design principles:

- Symbiosis provides opportunities to find mutual benefits through relationships
- Symbiosis provides opportunities for one organism to gain from another without harming the host
- Empty spaces can provide sites for compatible uses
- Solar energy is captured during rain

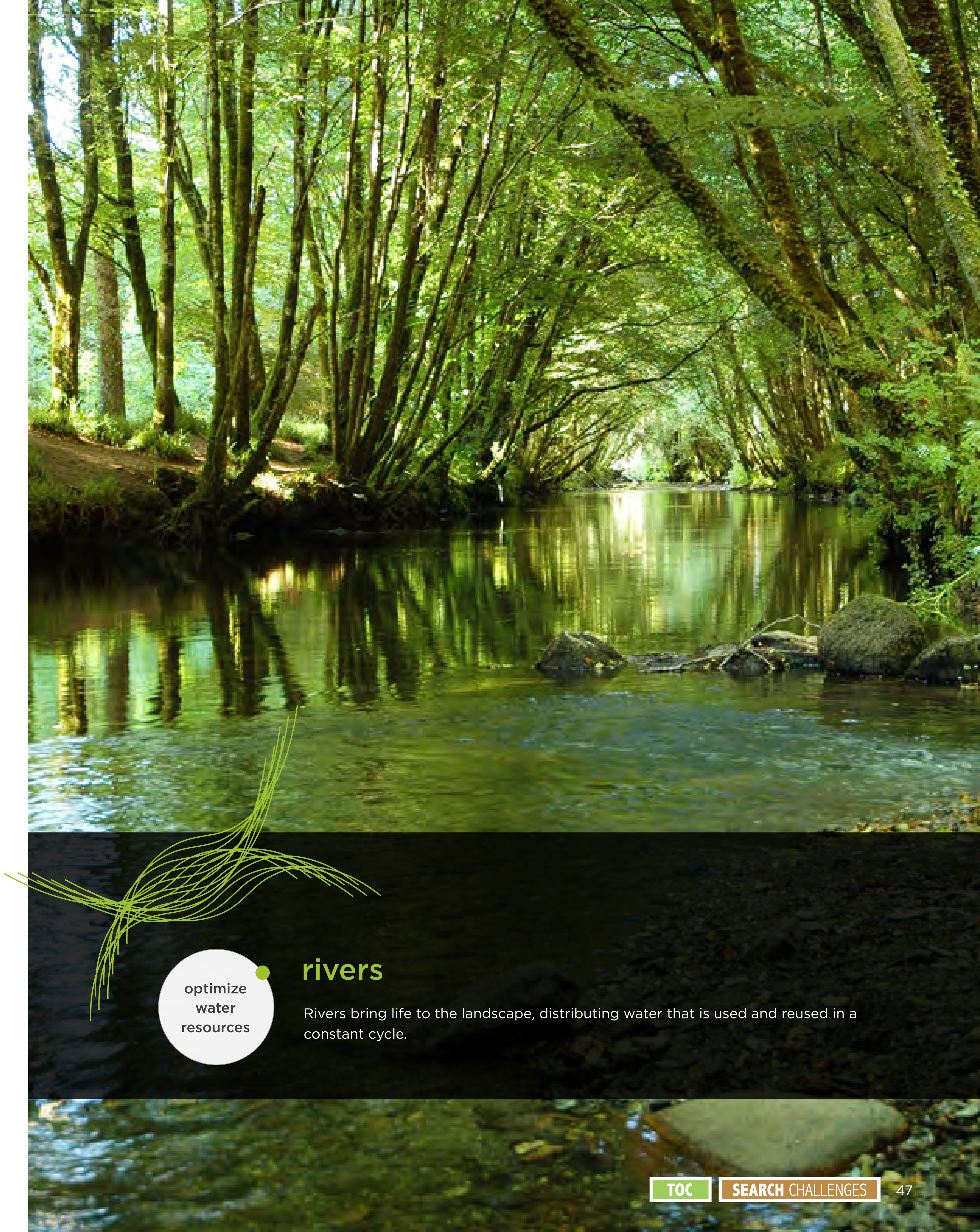


BaDT brainstorm

design ideas

Application Ideas

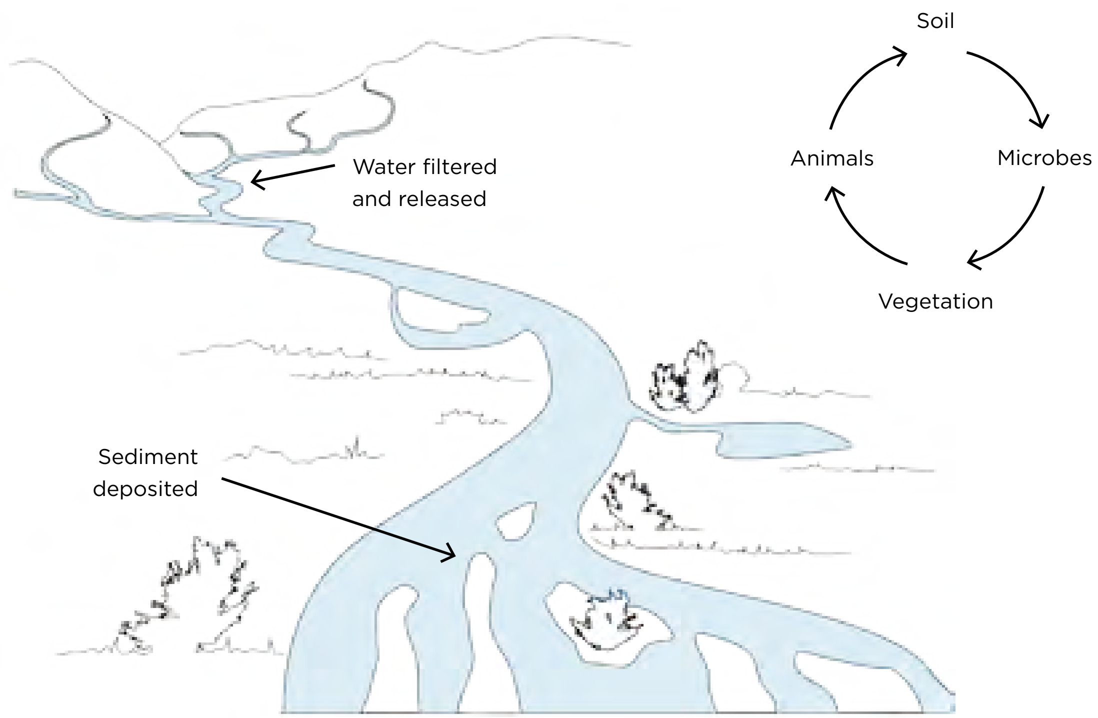
- Lichens are able to photosynthesize even during a rainstorm. Developing a water-shedding surface treatment for solar panels may allow them to be more effective during low light, stormy conditions common in the temperate broadleaf biome.
- If the building is thought of as an analogue to the tree a lichen grows on, a conceptual application could be installing a micro-solar system on the vertical surface of a building. This discrete micro-solar system could be modular and interconnected so that if one section failed, the overall system did not fail.
- Lichens work like a breathable, water-resistant fabric. In a humid climate, a building skin that is both waterproof and breathable can provide a more comfortable interior.
- Lichens shed water effectively, which protects from acid rain. A building surface or structure applied to the building surface that mimics the lichen may protect from the damages of acid rain.
- The way that lichens shed water could be incorporated into structures used to capture water, resulting in less adherence and therefore more complete capture and fewer opportunities for buildup of algae and biofilms.



optimize water resources

rivers

Rivers bring life to the landscape, distributing water that is used and reused in a constant cycle.



nature's design

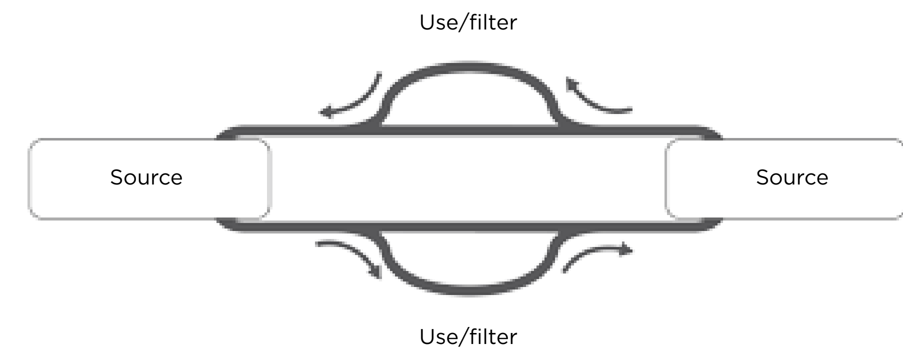
velocity, torturous path and filters purify water

The hydrological cycle involves not just the flow of water but also exchange of heat through condensation, and cooling through evapotranspiration. Climate affects the kind of vegetation that stabilizes the landscape, as well as what kind of river, channel pattern, and sediment sequences develop. Water flows through lakes, streams, rivers, ponds, wetlands, groundwater and deep aquifers. Water moves from one reservoir to another by evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow.

Rivers are complex systems that vary with their position in the landscape. Three zones, the upper, middle and lower reaches of a river course, make up a river system. The upper reach is characterized by valleys, hills or mountains, which are gradually leveled by erosion. The middle reach is largely a zone of sediment transport usually forming meandering or braided channels. The lower reach has a prolonged net sediment accumulation in a basin area.

A river contains detritus, dust particles, sediment and minerals that flow with the water through the system. Water is cleaned throughout the system by turbidity and velocity caused by moving over landscape forms, through soils, sediment, and filtered though the bodies of living organisms. There is no wastewater in nature because living organisms treat water and its constituents as food.

- In nature, water transforms into vapor, condensation, snow, ice, and rain water
- Rain water collects into bodies of water such as streams, rivers, lakes, ponds, and oceans
- River water flows in a predictable, dynamic cycle through the seasons
- Channel patterns are formed by local or regional conditions
- Water found in nature is not sterile
- Redundant food webs clean and maintain ecosystem function and health



design principle

flow, filter, and use purify water

A flow is made up of elements that aggregate into a larger mass. Flows can be managed by planning how to direct the flow. The main variables in a drainage network that control a water system are gradient, discharge and sediment.

Collected water, especially water with a high velocity, can produce strong forces against objects, causing displacement and erosion. It is costly to try to control the flow of water because of forces such as gravity and fluid dynamics. Water wants to move.

Filtering of a flow can occur through turbidity and velocity. Physical filters can pull out and consume unwanted materials.

Other related design principles:

- Water flows serve more than one purpose
- Healthy flows are not static
- Water moves materials with its flow
- Water wants to branch and channelize
- Plants and living organisms help purify water
- Sediment provides resources and a filter

PLANT FOR SEDIMENT
THREE ZONE - SYSTEM LIKE A RIVER
TREAT WATER AS FOOD
ENCOURAGE EARTH - FRIENDLY
INTEGRATE VEGETATION

BaDT brainstorm

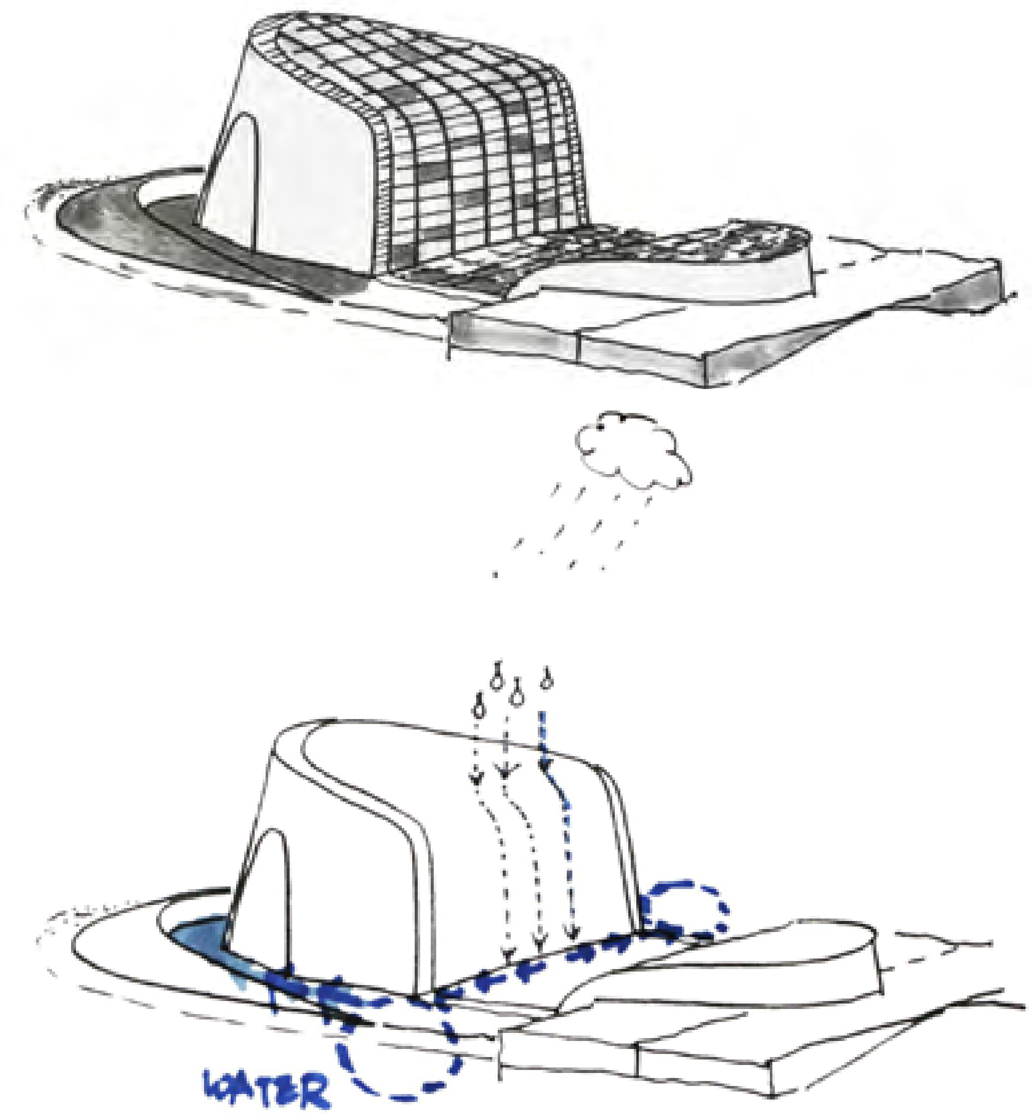
design ideas

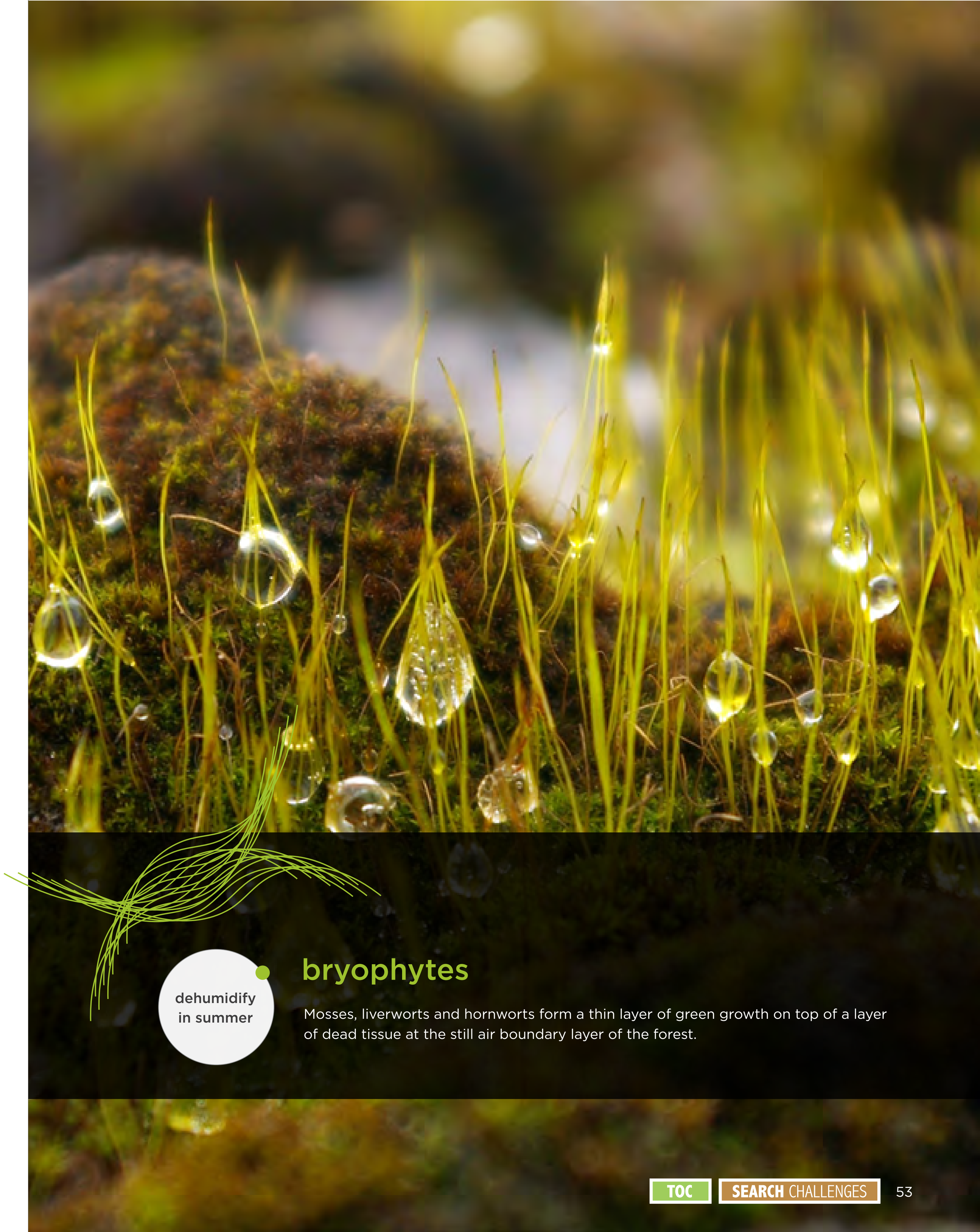
Application Ideas

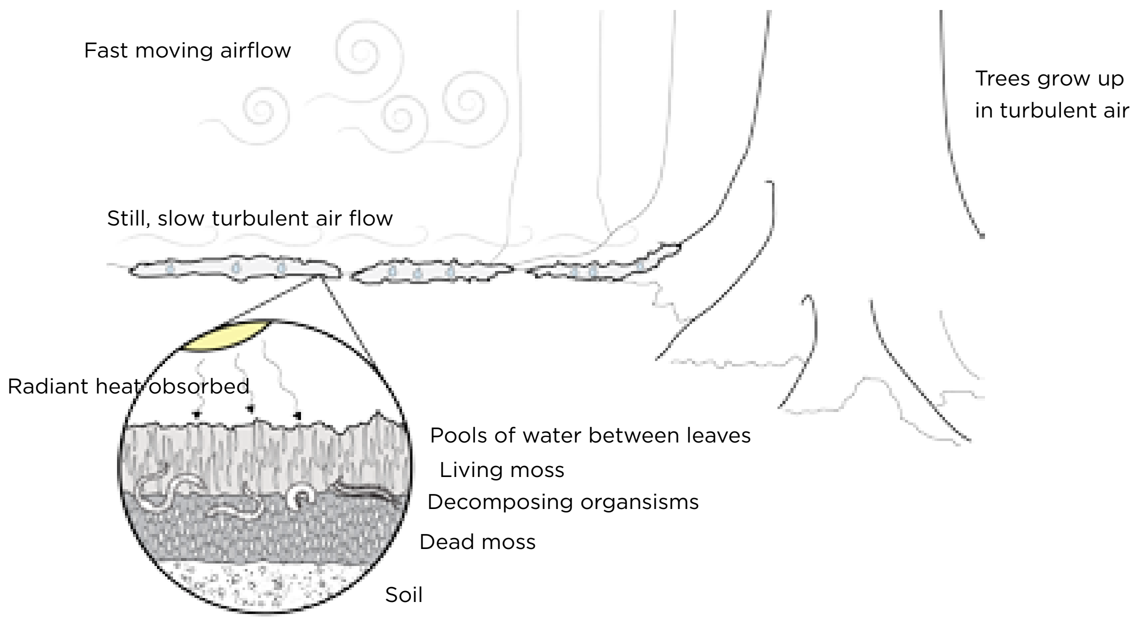
- Plan for drastic changes in water flow amount over short periods of time
- Plan for not just filtering but consumption of the gathered elements as well
- Identify where vegetation can help purify water in a water flow system
- Integrate vegetation that is best suited to help purify water
- Plan for accumulation of sediment and minerals and use water flow to flush accumulation
- Design a gray water system with three zones like a river
- Design a water system that encourages the use of non-toxic cleaning materials and proper disposal of pollutants
- Metaphorically, treat water as valuable food

WATER RETAINING FACADE

Extend time of water on site: design building, MEP system and landscape as micro-hydrological cycle for heat exchange.




dehumidify
in summer
bryophytes
Mosses, liverworts and hornworts form a thin layer of green growth on top of a layer of dead tissue at the still air boundary layer of the forest.



nature's design

absorbable, water-holding material moderates humidity

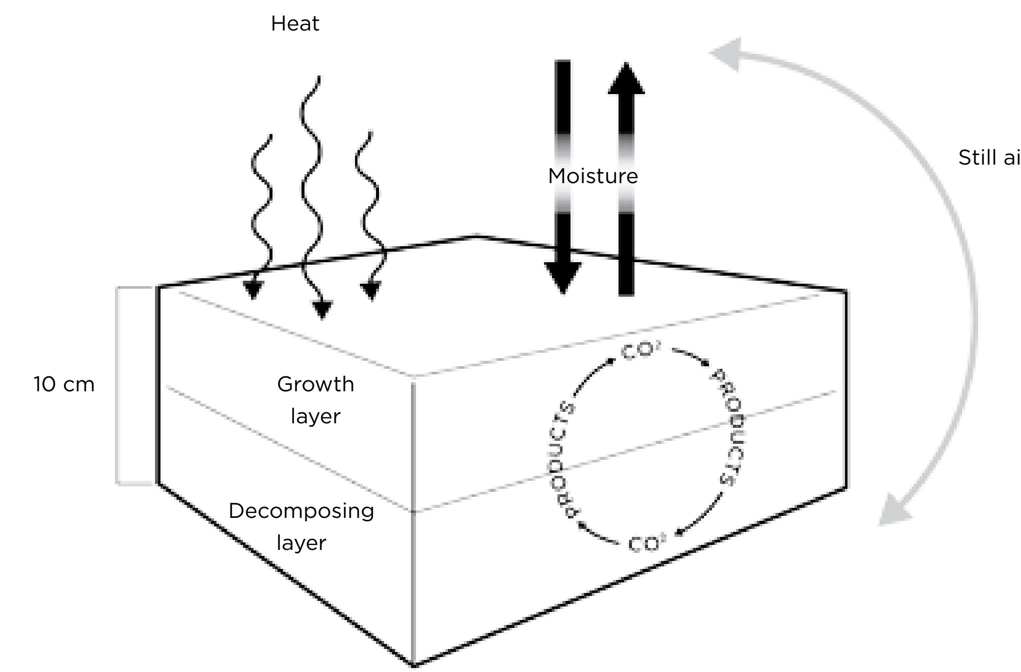
Nature responds to humidity as a resource, not as a problem to be managed. Nature allows flow of materials instead of resisting or constricting flow.

Bryophytes do not have a waxy outer cuticle, a vascular system, or roots like most other green plants. Therefore, bryophyte tissue absorbs water immediately. The bryophyte layer under the deciduous forest canopy forms a vertical structure with a living "green" zone atop a "brown" zone of dying tissue and decaying detritus. A dense, double layer structure, combined with a still air layer that protects against evaporation, allows the bryophyte layer to hold on to moisture. When evaporation does occur, bryophytes desiccate and die, adding to the underlying dead layer. Decomposing organisms living in these layers and the bryophyte plants resurrect when moisture returns, re-forming an upper living layer.

Decomposing organisms (nematodes, tardigrades, bacteria, fungi) produce carbon dioxide that supports bryophyte growth. Larger organisms such as tree seedlings, worms, insects, salamanders, and frogs thrive in the upper layer.

The bryophyte layer creates a predictable microclimate in the shade of a forest. Other bryophytes are adapted to living on rocks and trees or form peatlands in wetter, sunny areas. Bryophytes can be found in almost every ecosystem on the planet, from the tundra to the rainforest to deserts.

- Living and dead layer provides habitat for a host of diverse community of organisms (fungi, bacteria, tardigrades, nematodes, mites, springtails) and invertebrates that contribute to production of biomass and materials recycling
- Layers capture leaf canopy nutrients washed down by rain, adding to soil nitrogen
- Bryosphere regulates local temperature, soil and vegetation hydrology, soil chemistry and nutrition
- Bryosphere prevents soil erosion



design principle

absorbable, water-holding material moderates humidity

To modify humidity, small, simple structures in a dense, double layer absorb and release moisture in a still air environment.

A dense layer of small structures with tissues that can absorb moisture quickly creates conditions for interaction and cooperation with other elements, the whole of which develops into a manufacturing cycle of energy inputs, product outputs, breakdown and recycling.

Other related design principles:

- Energy produced locally decreases costs
- Layers of active and inactive material interact
- Systems occur within systems
- Recycling of waste creates a closed loop system
- An interconnected manufacturing web maintains materials within the system

WATER VAPOR - ABSORBING FACADE
MICRO - PROCESS POLLUTANTS
VERTICAL APPLICATION
TEXTURED, SHADED SURFACES
MODERATE SOURROUNDINGS

BaDT brainstorm

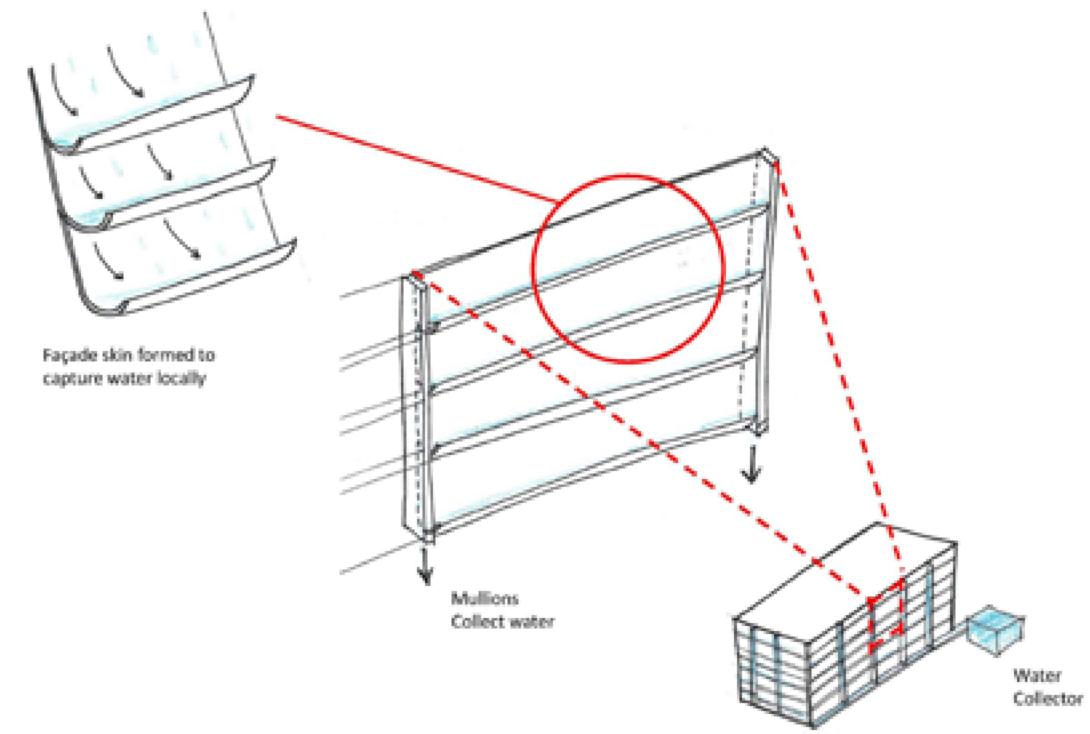
design ideas

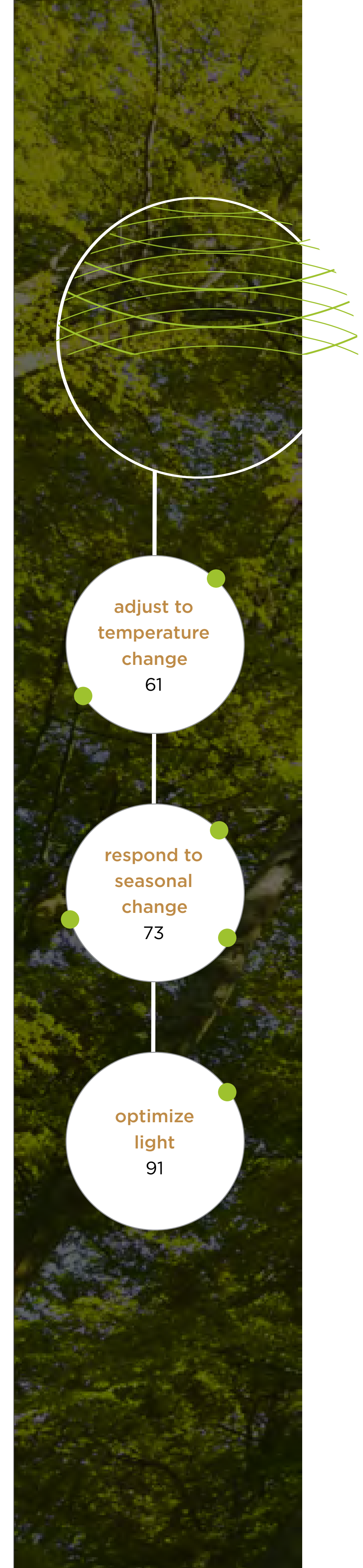
Application Ideas

- Develop or find a building façade material that can absorb water from the air and either hold it for later use or drain it into a reservoir. Use in combination with a water-impermeable layer to prevent deeper saturation into more sensitive building materials/layers.
- This water-absorbing/holding/draining material could also conduct micro-processing of environmental wastes, either physical (e.g., debris) or chemical (e.g., pollutants). The Biolytix® technology is an example of how this works in a horizontal system; could a similar system be designed for vertical applications?
- A literal application would be to design textured, shaded surfaces adjacent to walkways, parking lots, and buildings to encourage moss and bryophyte growth that will absorb rainwater and help moderate micro-climate conditions in the immediate surroundings.

DEW FACADE

Harvesting available water





ENERGY

Life has had 3.8 billion years to test out ideas for capturing, storing, and efficiently using energy. One energy challenge in this biome is the seasonality of energy availability and usage.

A common condition during summer in the temperate broadleaf forest is high heat combined with high humidity. Plants have an elegant system for staying cool that is coupled to production of energy and the passive processes of evaporation, water adhesion, and cohesion. The resulting design also uses something else in prominent supply in this biome—water. Humidity is a resource that is used to help cool every leaf, and in turn, the whole forest. This is an example of two patterns repeatedly seen in nature. One is that nature rarely spends energy on resistance and also makes use of locally available resources. The other pattern is what can be described as the principle of "lots of littles." That is, many small, seemingly weak elements added together result in a powerful, problem-solving process.

Another pattern in this biome related to energy is a diversity of designs. In order to adapt to the seasonal change of winter, living organisms must adapt to long months of cold temperatures and a drastic change in available nutrients. Trees drop their leaves, move nutrients to their roots, and store them while reducing their metabolism in the long wait for spring and warmer weather. Animals reduce their energy expenditure, hibernate, find cover, and store energy as fat or store food in caches. The many designs evidenced in these adaptations suggest that nature doesn't rely on any single solution. Solutions vary because nature thrives on diversity and novel ideas.

- cool structures
- move moisture passively
- reduce energy expenditure
- create thermal cover
- store energy
- optimize energy sources

ENERGY

LIFE'S PRINCIPLES

REFERENCE THE DEFINITIONS

EVOLVE TO SURVIVE
Replicate strategies that work
Replicate successful methods to meet similar functions

INTEGRATE DEVELOPMENT WITH GROWTH
Invest in strategies that promote both development and growth in relationship to life conditions

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT:
Use multi-functional design
Use one design to perform more than one function

BE LOCALLY ATTUNED AND RESPONSIVE
Design heating and cooling systems to be responsive to ambient conditions and needs of people within a space

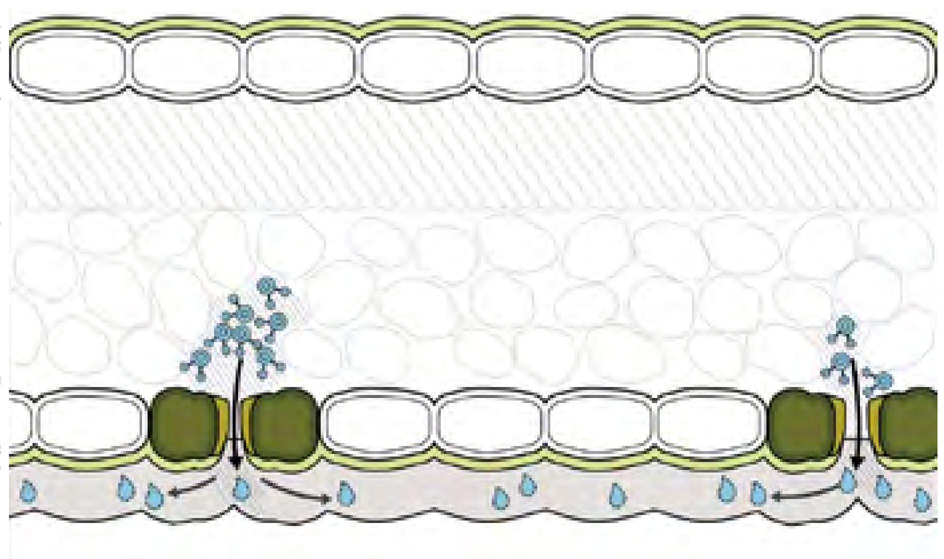
ADAPT TO CHANGING CONDITIONS
Embody resilience through variation, redundancy, and decentralization
Decentralize solar collectors and vary their design, placement, and type based on exposure to light and shade

USE LIFE-FRIENDLY CHEMISTRY
Transport water to cool without using polluting energies

adjust to temperature change

leaves

Leaves are cooled by drawing soil moisture up through the tree and into leaf stomata that release water vapor to the surrounding leaf and to the atmosphere.



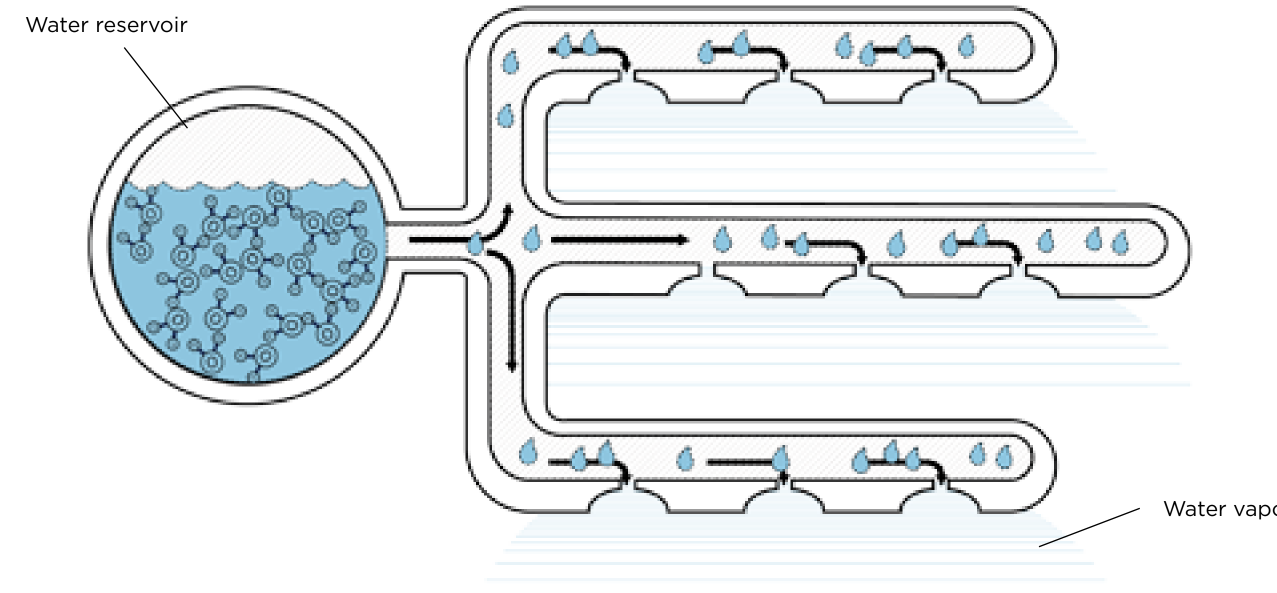
nature's design

passive valve cools with moisture

A leaf's primary job is to conduct photosynthesis, capturing the energy provided by the sun to convert carbon dioxide into organic compounds. Enzymes play an important role in this conversion, but they can't work at high temperatures. So, a leaf cools itself through transpiration in which soil moisture is drawn upward from the roots of the tree through stems, branches, and veins to leaf stomata. Leaf surfaces can cool by as much as 20-30° F (11.1 to 16.7° C). Special cells, called guard cells, regulate the opening and closing of the stomata.

All trees transpire and thus cool the temperature in the forest. Within the temperate broadleaf and mixed forest biome, urban areas average 14° F (8° C) warmer in the summer than the dense, tall forested vegetation surrounding them. This cooling effect comes from evaporation of moisture from the soil and transpiration of moisture from millions of leaf surfaces. At the ecosystem scale, this results in a cooling of temperatures throughout the ecosystem.

- Transpiration pulls a string of water molecules from the roots up through the plant via cohesion and adhesion forces
- Water is drawn to the guard cells of the stomata by osmosis (potassium pump system)
- Guard cells swell by inflow of water and contract by loss of water; this opens and closes the pore
- Stoma closed → water uptake → increased pressure → stoma open
- The outer surface of the top of the leaf is tightly sealed by wax-coated, interlocking pavement cells
- Stomata are found in greater numbers on the underside of the leaf



design principle

passive energy pump with valve transports water

Design an evaporative cooling system that draws moisture from a source and delivers to a sink site where valve-like pores are triggered to open and close based on humidity and heat levels.

A passive energy pump draws water from a lower source through a structure to the outside of that structure to create a water vapor layer that cools the whole structure. Several systems, including sensory valves, are coupled and triggered in response to changes in temperature and humidity. Many units of evaporation produce an additive effect to create a greater result.

Other related design principles:

- Moisture flow responds to varying requirements
- Repeated structures create an additive effect
- Systems are coupled to reinforce effect
- Valve opens and closes in response to humidity and heat fluctuations
- Different forms of water (vapor and liquid) allow cooling effect
- Valve positioned away from heat source to protect from desiccation

EVAPORATIVE COOLING
50 DEGREEES
USE THE COOL EARTH
VALVES
PASSIVE PUMP
WATER VAPOR
MOSS GARDEN

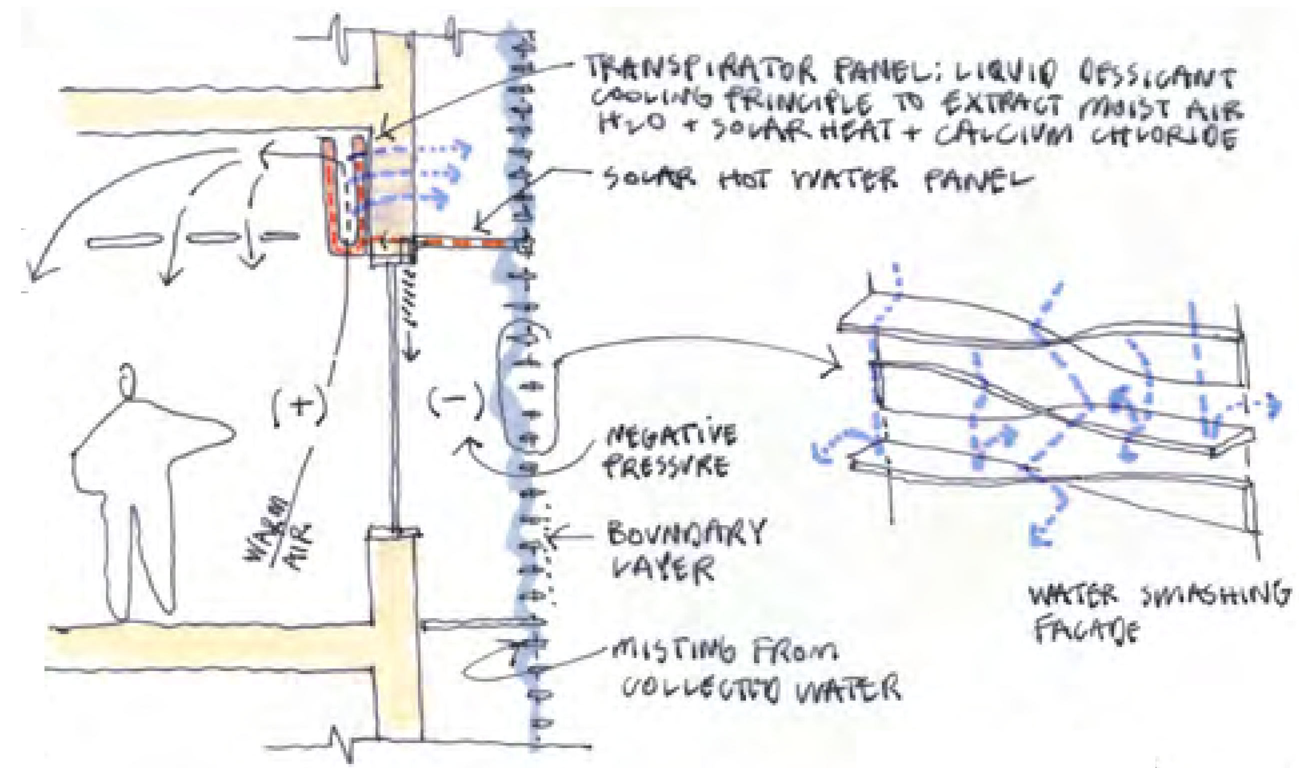
BaDT brainstorm

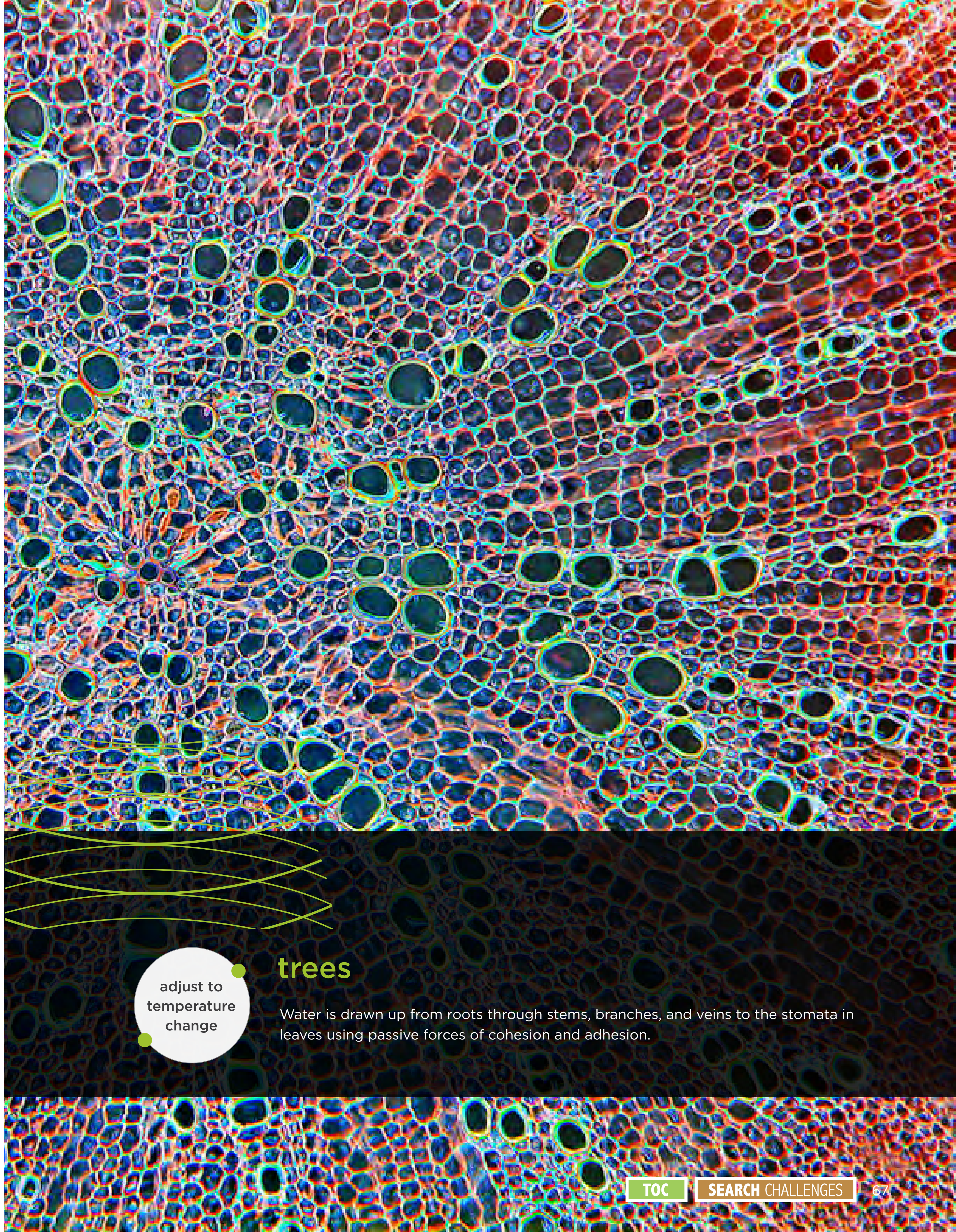
design ideas

Application Ideas

- Evaporative cooling technology (e.g., swamp cooler) is not considered effective in humid climates like the temperate broadleaf biome. However, it's the cooling method of choice for all vegetation in this habitat and it has important implications for macroscale climate patterns.
- The water moving through the plant is cool—the earth keeps it around 50 degrees. Is there a way to use the earth rather than an electrical refrigerant system to cool the water that runs through the evaporation system? Perhaps this strategy can be combined with the beaver dam strategy (Water: beaver dam barriers slow water) of underground cisterns.
- Valves that control the rate of this artificial transpiration could be tuned to respond to ambient temperature and humidity levels. The pump would move cool water when the room was too warm and/or dry and would shut off when the room had cooled or reached a maximum humidity level.
- A literal application could involve water vapor being released onto a bed surface for a moss garden. This method could be used in an indoor or outdoor garden area.

BIO - ADAPTIVE FACADE

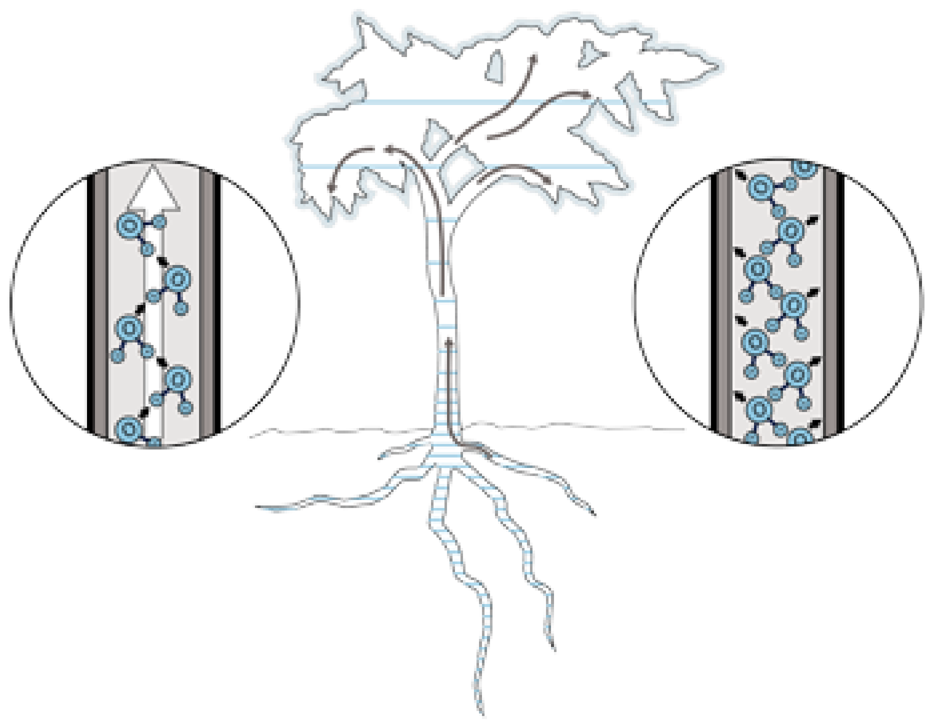




adjust to temperature change

trees

Water is drawn up from roots through stems, branches, and veins to the stomata in leaves using passive forces of cohesion and adhesion.



nature's design

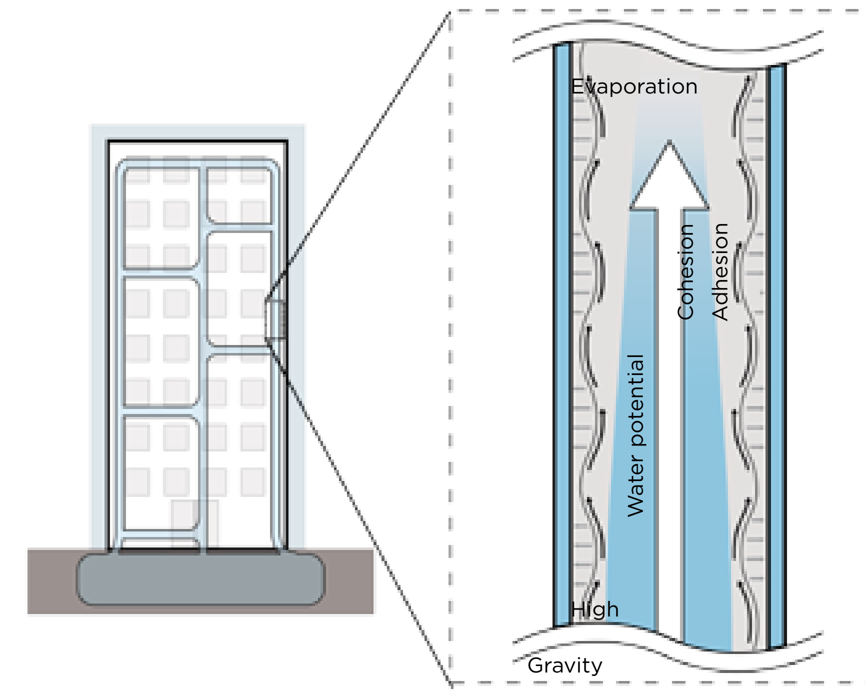
transpiration moves water

Trees are protected from hot temperatures and water loss by pulling soil moisture from the soil through the roots and then up the vasculature of the trunk, branches, and veins to the leaves. There, the moisture is released as water vapor through leaf stomata and into the surrounding atmosphere. Wind causes evaporation and a cooling effect around the tree canopy.

Moisture is pulled up through the vasculature of the tree by two chemical forces acting on the water molecules—cohesion and adhesion. Water movement is additionally driven by a pressure gradient created by the pulling force of evaporation. Evaporation of water from the leaves of a tree causes water in the conduits to move from the soil, a source of moisture that has higher water potential, up a conduit with decreasing water potential along its length, to the sink (leaf evaporation).

Scaling: At the tree scale, moisture is brought to leaves to produce cooling evaporation to protect the leaves. At the forest scale, all trees transpire together and cool the temperature of the forest. At the ecosystem scale, soil moisture also evaporates, contributing water vapor to the surrounding atmosphere and resulting in a cooling of temperatures throughout the ecosystem.

- Cohesion is formed between the hydrogen bonds in water molecules
- Adhesion causes water molecules to be attracted to the tree vessel walls and to overcome gravity
- Transpiration pulls a string of water molecules from the roots up through the trunk and into the leaves
- Water provides structural support for the architecture of young branches, stems, and leaves.



design principle

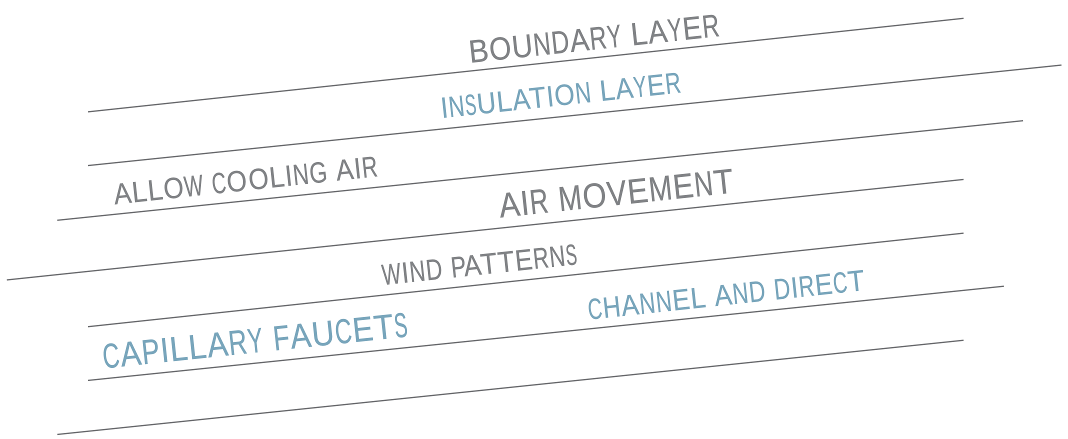
water pulled against gravity by adhesion and cohesion

Moisture is drawn upward from a lower source through a series of vertical tubes inside a structure. The moisture is released to the outer surface to create a water vapor layer that cools the whole structure. The process pulls water from a lower source with higher water potential up to a higher sink with lower water potential.

A passive energy pump is created that pulls water against the force of gravity by the combined forces of evaporation and the attraction of water to the sides of a series of vertical, microscopic tubes via cohesion and adhesion.

Other related design principles:

- Cohesion-tension theory of intermolecular attraction of water moves water upward, against the force of gravity
- When one water molecule is lost to evaporation or transpiration, another is pulled along by the processes of cohesion and adhesion
- Source and sink move water
- Suction moves water



BaDT brainstorm

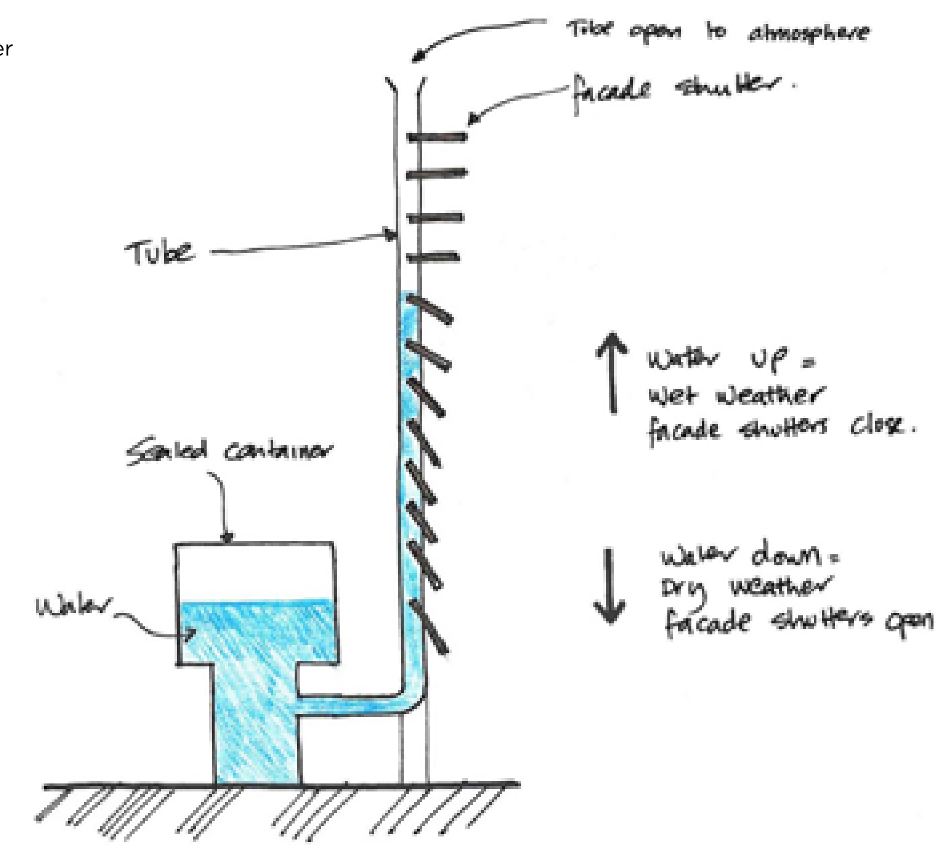
design ideas

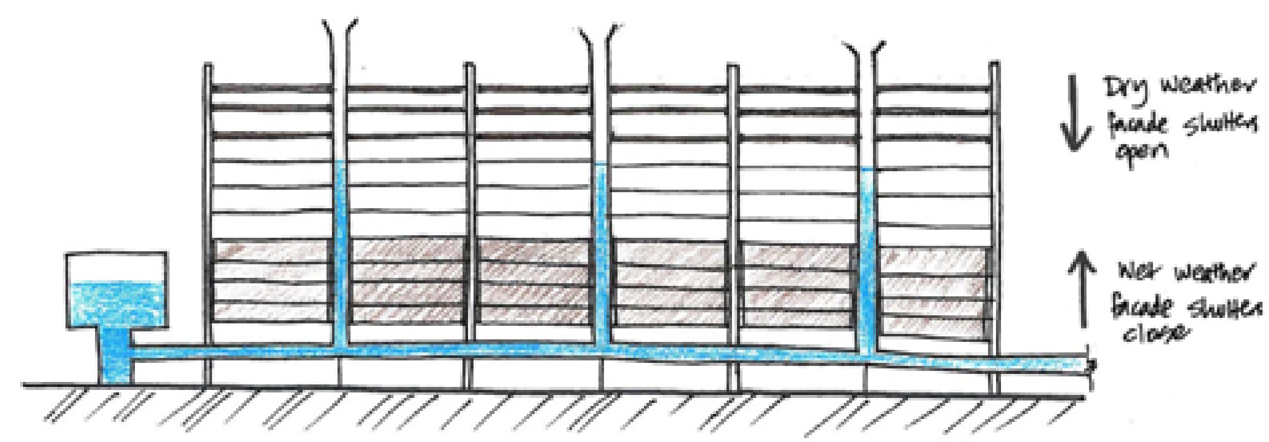
Application Ideas

- Create a boundary layer on roof surfaces that can be opened and closed to create an additional layer of insulation in the winter or allow cooling air to move over the surface of the building in the summer. This boundary layer can be especially useful to moderate the temperature near functional/mechanical components on exposed surfaces.
- Utilize air movement on the site to increase evaporative cooling. That can involve taking advantage of prevailing wind patterns, or it could be contrived by arranging buildings and/or landscaping in a way that channels and directs small air movements across building surfaces.
- Design capillary faucets to pull water up through a building (cooling as it goes), then as the water flows down use that movement to generate energy (see Energy Machine on AskNature).
- Literal: Water from reservoir is drawn up through conduits using cohesion and adhesion forces into a garden that is evaporating.

DEW FACADE

Harvesting available water





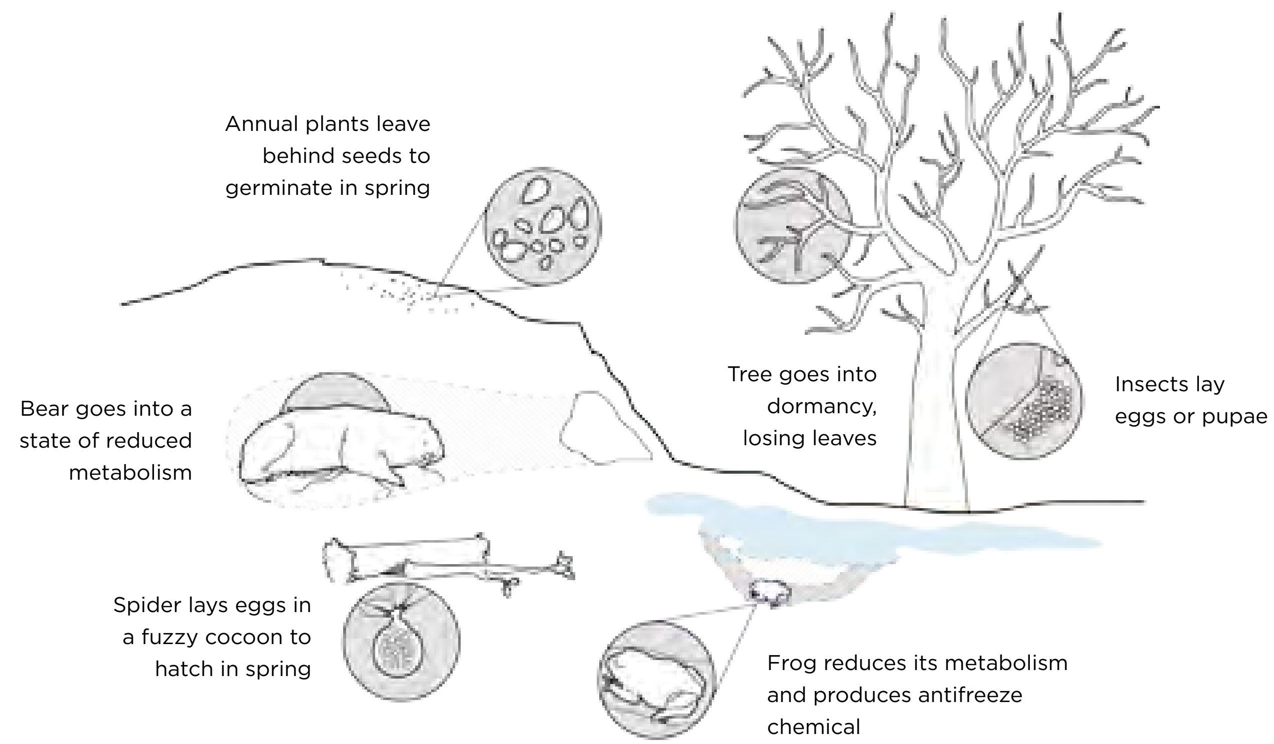
PASSIVE COOLING

Passive downdraft evaporative cooling

respond to seasonal change

plants and animals I

Organisms survive winter's challenges by reducing activity to minimize required activity input.



nature's design

energy saving methods reduces energy expenditure

In winter, there is less energy input to the system due to less photosynthesis. Staying warm and fed during cold temperatures and searching for food is costly. One strategy for coping with this energy challenge is to reduce the energy expended.

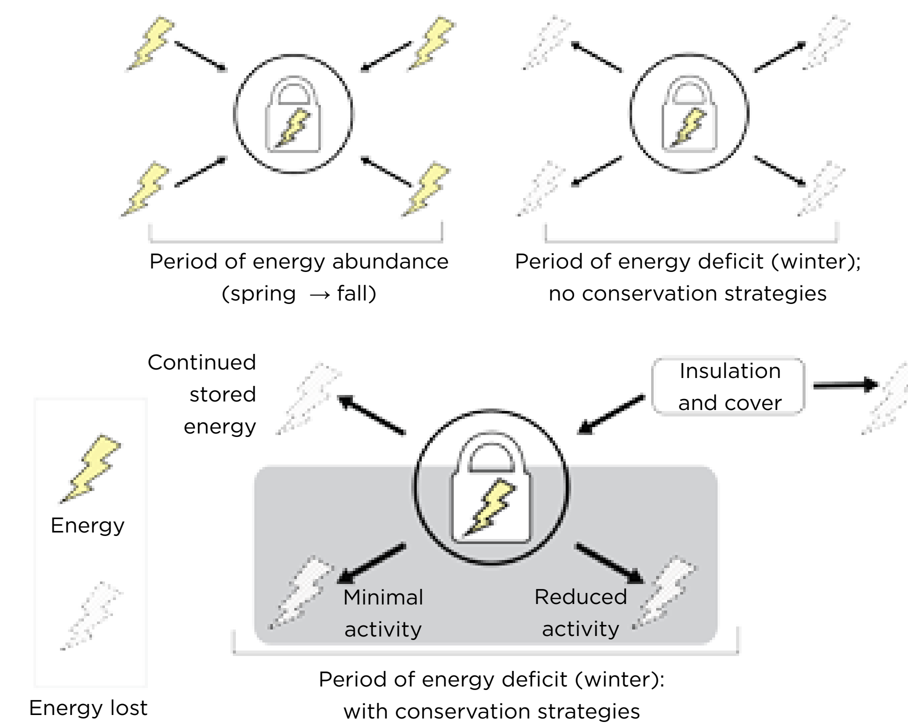
Some animals reduce their metabolism during extremely cold periods. For example, bats, European hedgehogs, and some ground squirrels drastically reduce their metabolism during the winter, expending stored fat slowly. Breathing and heart rate slows and body temperatures are reduced. Trees and shrubs lose their leaves and become dormant.

Frogs and insects use a combination of lowered metabolism and production of antifreeze chemicals to survive the winter. Antifreeze chemicals prevent formation of ice crystals, which can damage sensitive cell membranes.

An extreme form of reducing metabolism is dying while concurrently leaving offspring behind in a protected state. While this is not beneficial for the individual, it ensures the continuation of the population and species. Examples include insects that leave their young in the form of eggs or pupae, annual plants that leave behind seeds, and spiders that leave eggs in fuzzy casings.

Deep snow creates problems for deer, causing them to expend extra energy to move around and avoid predators. Deer winter in sheltered areas of lower snow depth.

- Winter is a time of reduced energy availability
- Excessive energy expenditure is a challenge in winter
- Seasonal adaptation of activity levels saves energy
- Multiple strategies for coping with winter's challenges increase survival



design principle

behavior adjustments reduce energy usage

Reducing the amount of energy used helps reduce energy costs. Where energy requirements change on a seasonal or daily basis, adjusting activity levels can reduce or even out usage. One option is to decrease the rate of energy usage throughout the system. Another is to stop entirely the use of energy by some users on a seasonal or daily basis. Where the costs of obtaining energy change on a seasonal or daily basis, finding ways to reduce usage during those peak periods can reduce costs.

Other related design principles:

- Chemicals protect from damage due to cold
- Combine strategies such as storing energy and reducing usage to increase effectiveness
- Sacrifice unneeded energy usages to focus on those most needed to decrease costs

INCORPORATE SOCIAL NETWORK
PROMOTE ENERGY EFFICIENCY
EXPLOIT COLD TEMPERATURES
COLD CONVECTION
WINTER ENERGY BUDGET
TARGET AMOUNT
TARGET RATE

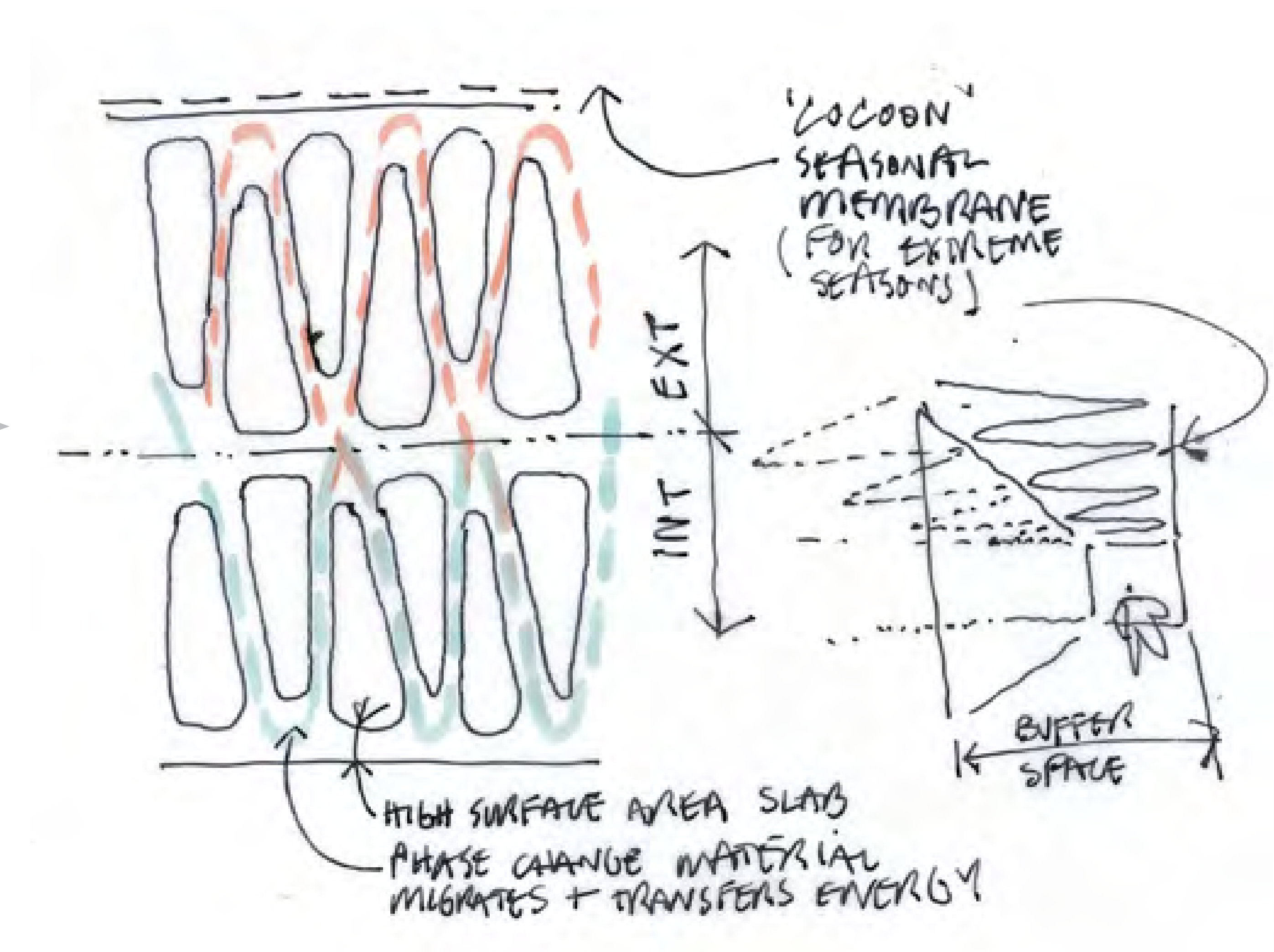
BaDT brainstorm

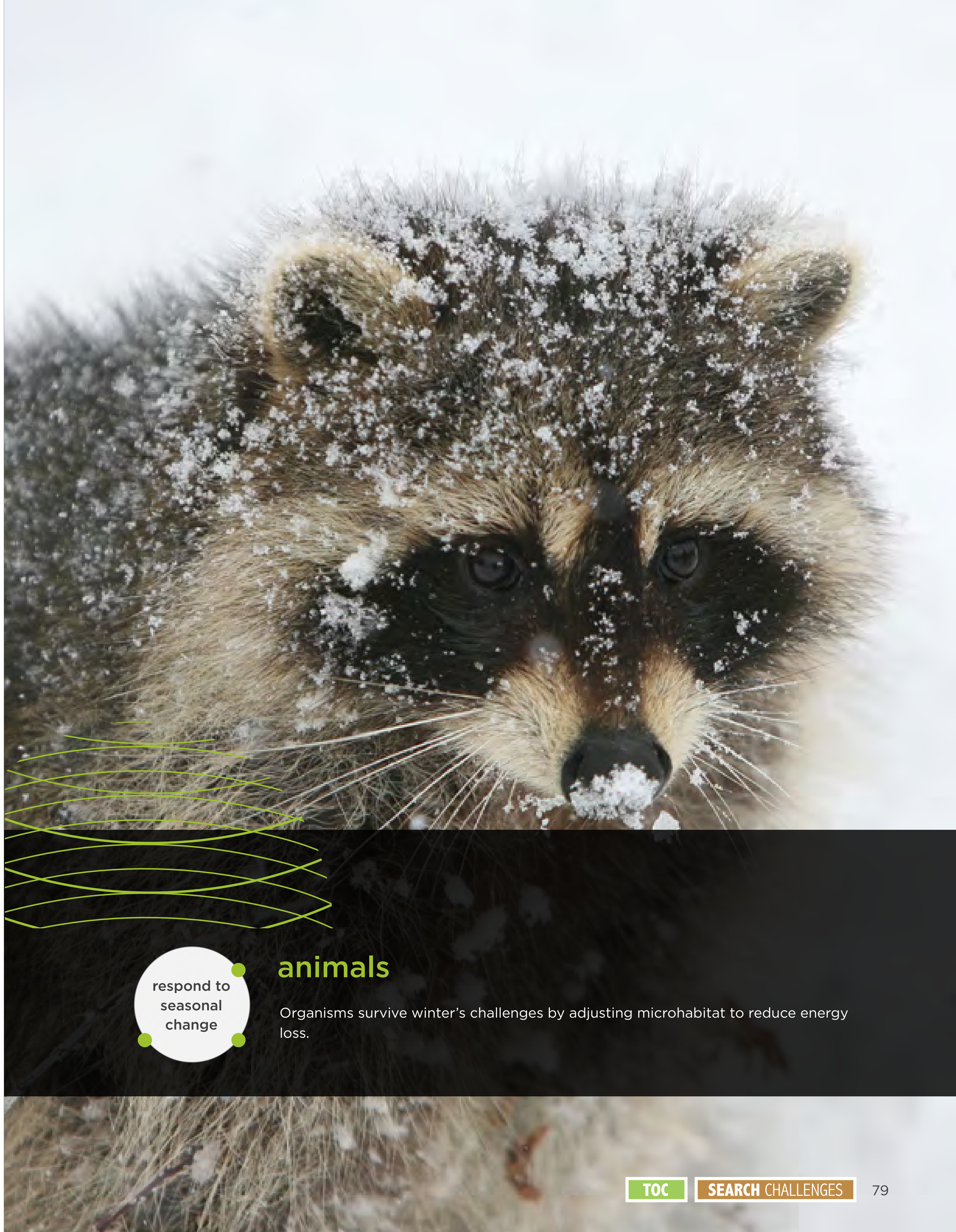
design ideas

Application Ideas

- Incorporate a social network-type system that promotes building energy efficiency through behavioral nudges that track individual usage and compare with other users.
- Rather than using energy to create refrigeration in the winter, exploit external cold temperatures to lower energy consumption; use cold convection through metal rods to produce refrigeration.
- Develop a summer energy budget and a winter energy budget for a building. This reflects seasonal variations in available energy (based on daylight and sun strength) and gives users a target amount and rate to function within.
- Implement a system that anticipates future power usage by collecting usage data from “buzz” social networks, weather and news reports.

ACTIVE THERMAL BRIDGING SYSTEM

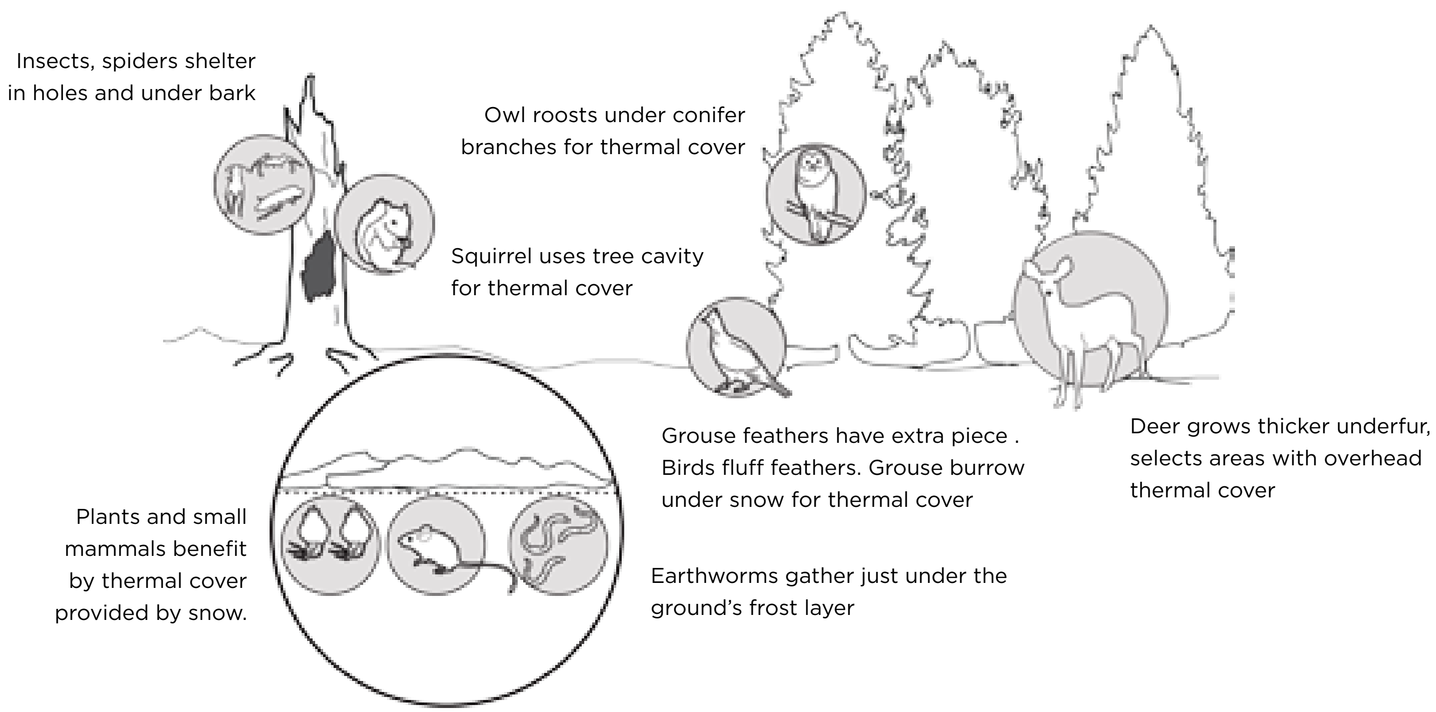




respond to seasonal change

animals

Organisms survive winter's challenges by adjusting microhabitat to reduce energy loss.



nature's design

thermal cover protects from cold

Winter is a period of combined challenges: cold temperatures, deep snow, and less food. Organisms employ a variety of methods to reduce the amount of energy lost to heat.

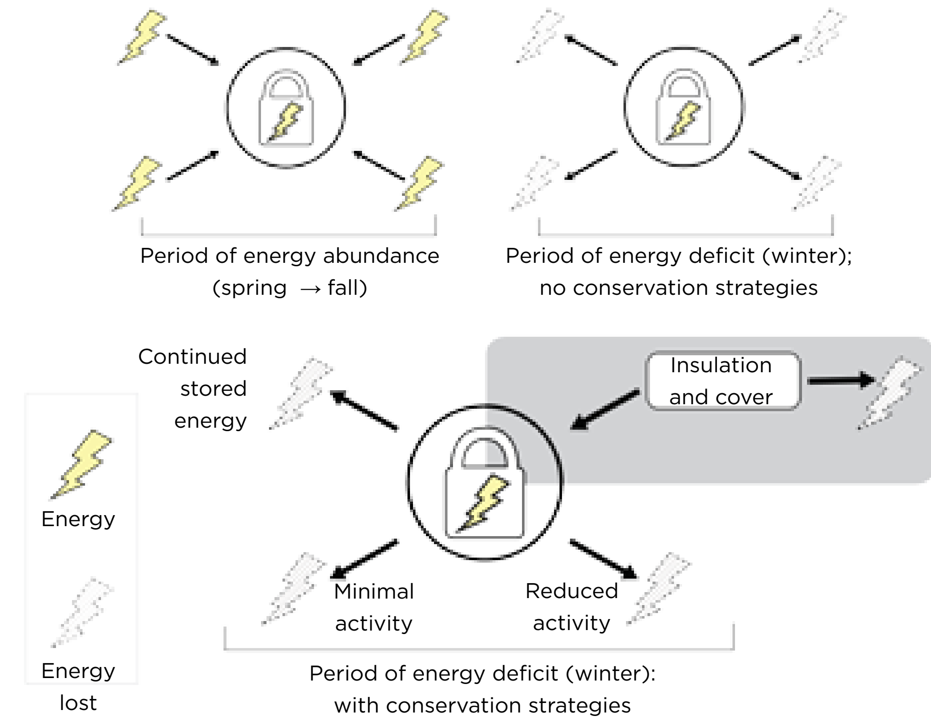
Some seek thermal cover above ground. Deer move to deeryards, areas of less snow with overhead cover to reduce heat loss. Hedgehogs build thick nests of leaves. Owls and grouse spend cold winter periods among branches of dense conifers to reduce heat loss from above. Squirrels and nuthatches use tree cavities as thermal cover. Some insects spend the winter tucked under pieces of bark, in logs, or under leaf litter.

Other organisms seek thermal cover underground. Earthworms move deep into the ground into the frost-free layer. Snakes gather in underground dens in rocky areas. Bears winter in underground dens.

Deep snow also offers thermal cover. Small mammals burrow under snow for thermal cover, access to food, and protection from predators. Perennial plants, grouse, and voles also rely on snow cover for thermal insulation.

Another way to reduce heat loss is to increase the insulation value of fur or feathers. Mammals grow thicker underfur in the winter, covered by waterproof guard hairs. Birds adjust to cold temperatures by fluffing their feathers, capturing warm air within the structures.

- Major challenges are food availability, cold temperatures, and snow cover
- Waterfowl and upland game birds have special feathers that add insulation
- Combining heat by communal roosting decreases heat loss
- Timing of activities for warmer periods prevents excess heat loss



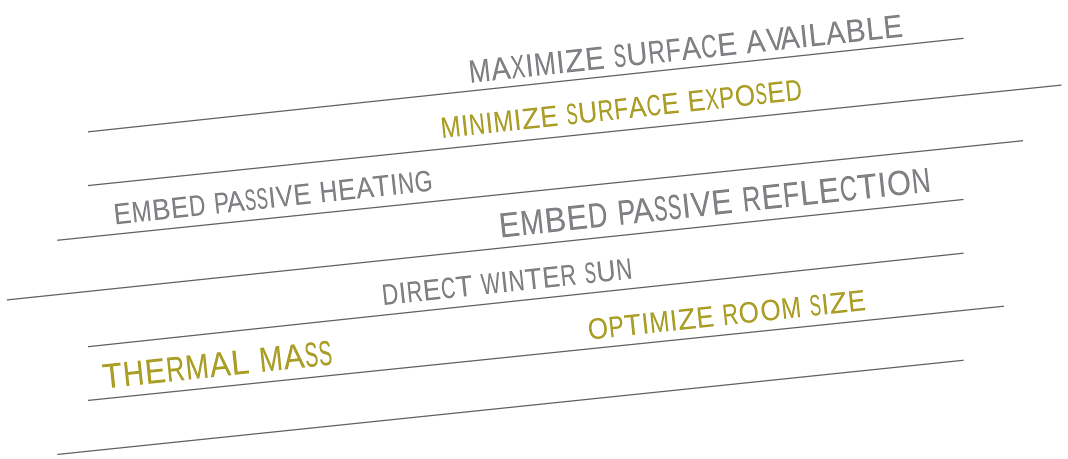
design principle

insulation changes adjust to seasonal changes in temperature

Thermal loss is a major source of energy usage in the winter. Heat rises, so protecting heat loss from overhead is a key technique for saving energy. Insulating structures trap warm air within a closed space, capturing lost body heat or other released heat and using it to maintain a comfortable temperature. Insulating structures can adjust to temperature and humidity by opening to create more air space and thus insulation, and closing to decrease insulation. This provides the ability to adjust to daily and seasonal changes in temperatures. Wind moving across a surface increases thermal heat loss, so protecting the insulating structures from air movement increases heat retention. The structure of the insulation itself is also key to heat retention and breathability.

Other related design principles:

- Capture group heat to increase value of thermal cover
- Capture waste heat to reuse as an energy source
- Time activities to avoid excessive waste of energy through heat loss

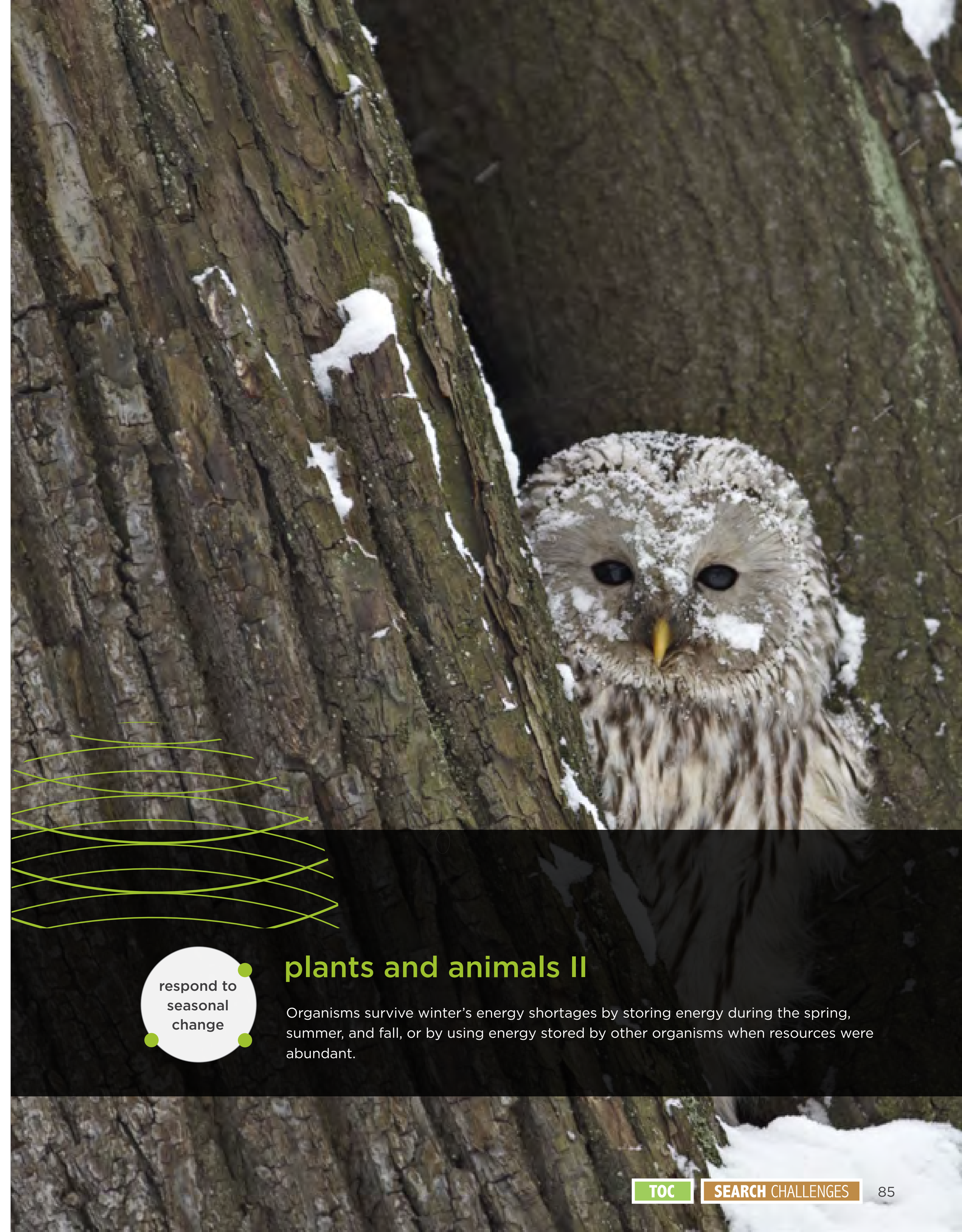


BaDT brainstorm

design ideas

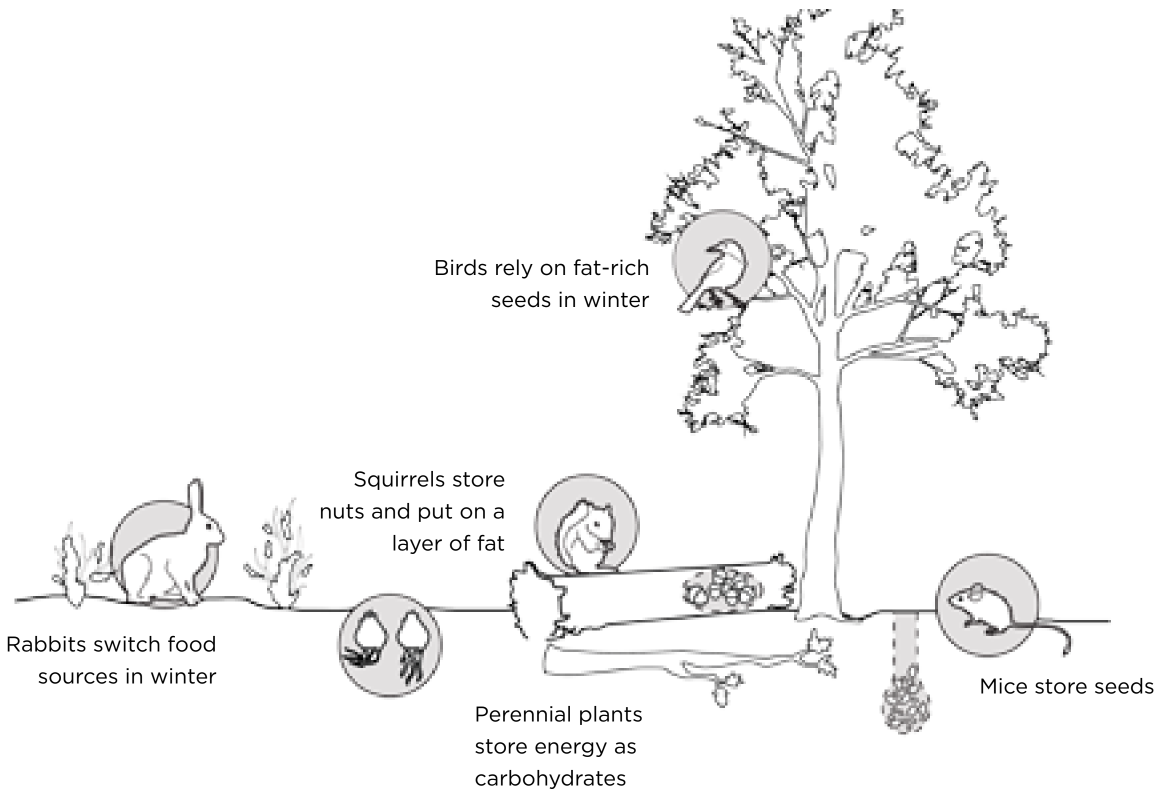
Application Ideas

- Maximize the surface available for energy production but minimize the surface area exposed to desiccating wind. The right balance will result in optimization.
- Embed passive or reflective heating elements in the building façade to prevent snow accumulation or direct winter sunlight to create warm air.
- Look for sources of waste heat that could be recovered and reused. This could be from friction, vibration, radiation (via thermal mass, hot water from boilers and/or plumbing), etc.
- Optimize room sizes to capture and maybe store heat from its occupants—this will be most effective where more people consistently gather.



plants and animals II

Organisms survive winter's energy shortages by storing energy during the spring, summer, and fall, or by using energy stored by other organisms when resources were abundant.



nature's design

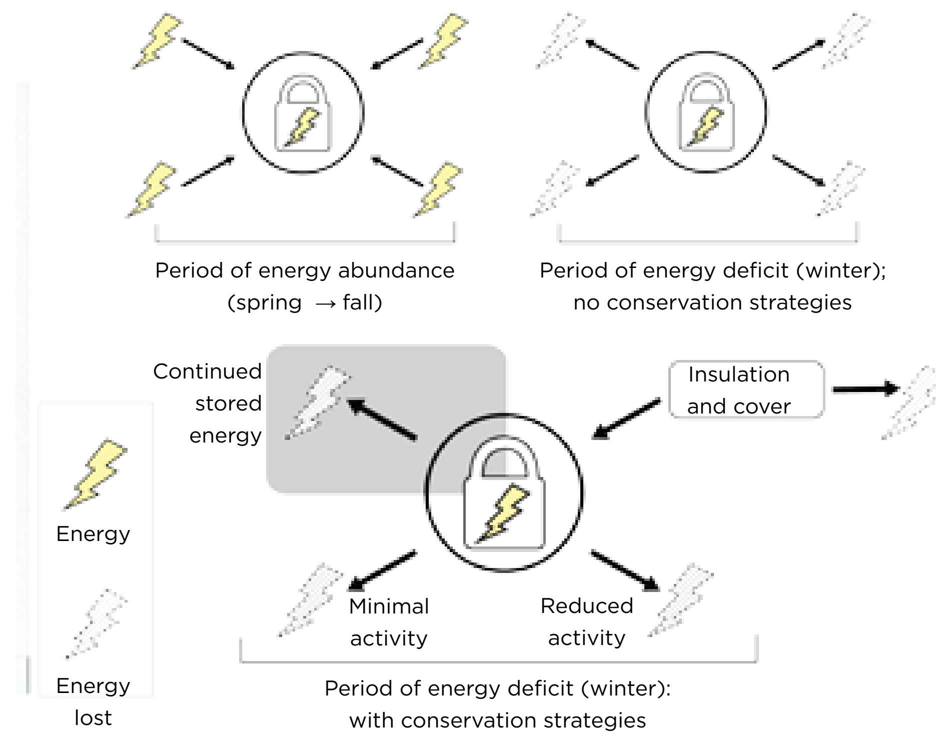
energy storage and alternative sources

Spring through fall is a time of energy input in the temperate broadleaf forest biome, ultimately due to photosynthesis. This is the period when food is plentiful, young are produced, and energy from the sun is stored as carbohydrates and fats. Winter is a time of lower energy inputs.

Some animals store food items for consumption in the winter. These include squirrels, mice, beaver, and some species of birds. Some, such as bears, deer, and birds, store energy as fat. Perennial plants, those that grow every year rather than from seed, store energy for the next year's growth in the form of carbohydrates in underground bulbs or tubers.

A different way of dealing with decreased food resources is to change the types of food consumed. For example, deer and rabbits forage for three seasons on soft foods like leaves and flowers. However, in the winter, they change to browse, chewing woody branches and bark that are all that's left of deciduous trees and shrubs after they lose their leaves. Sometimes, switching food types requires a change in intestinal microflora, the bacteria that help digest complex molecules like cellulose. Birds that stay around for the winter switch from a nutrient-rich diet of insects and fruit to an energy-rich diet of seeds.

- A major challenge in winter is food availability
- Coping mechanisms include leaving the area entirely (migrating), staying active and exposed, and reducing metabolism
- Organisms still require energy for each of those coping mechanisms
- Combinations of coping mechanisms are employed, so that no one organism uses just one mechanism
- Seeds and nuts "want" to be stored by squirrels and other animals, because this is how they get dispersed and planted



design principle

energy storage and variety of sources adapt to seasonal changes

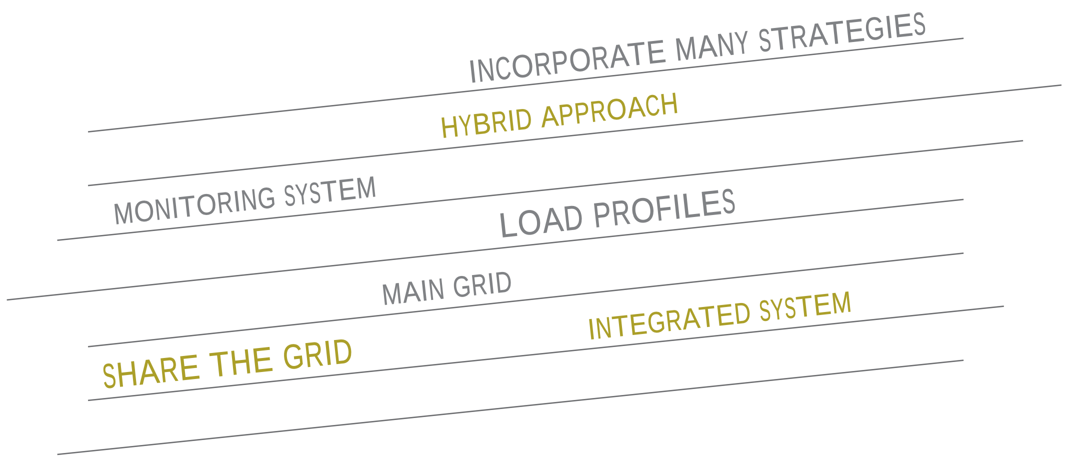
During periods of abundance, energy or resources can be stored for times of scarcity. This is easier to plan for in a predictable environment than one that is unpredictable. Scarcity can be the result of lowered energy input into a system, such as lower amounts of sunlight or lower food production due to cold weather. Both of these are predictable. Scarcity can also be caused by access to energy or other resources being cut off due to disruption of delivery such as transportation difficulties due to storms or damage to power sources. Another unpredictable cause of scarcity would be the length of time or the severity of the period of low energy input, such as an extremely cold or long winter.

Having a variety of mechanisms to cope with energy or resource abundance and scarcity increases the chances of surviving them. Relying on just one mechanism may work in predictable cycles, but could be disastrous when faced with shortages or disruptions that weren't expected.

Ensuring that energy or resources are sufficient to last throughout the season, by planning for both predictable and unpredictable scarcity, maintains functions in a system throughout the year.

Other related design principles:

- Take advantage of existing distribution networks to move other resources
- Have ability to change types energy sources to increase resilience to disruption



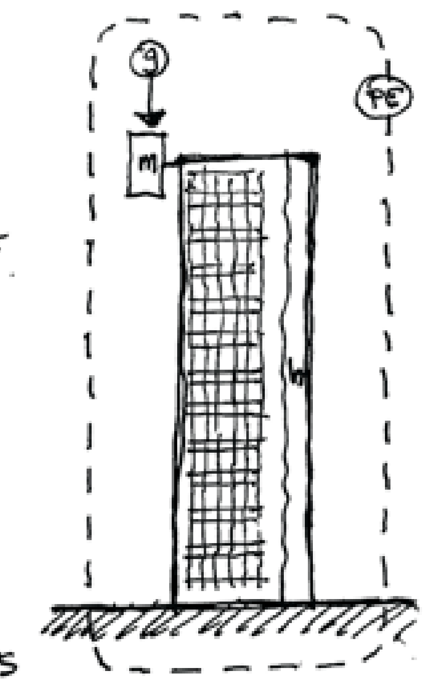
BaDT brainstorm

design ideas

Application Ideas

- Rather than focusing on just one "alternative energy" source, incorporate as many strategies as possible in combinations that reduce the need for energy and supply renewable energy when it is needed. A hybrid approach of passive solar, geo-thermal, geo-cooling, solar, wind, micro-hydro, and heat recovery mechanisms creates modularity and redundancy. In a robust integrated system like this, it would probably be appropriate to use small amounts of coal and/or gas energy in some applications.
- Incorporate a monitoring system that suggests best energy usage behaviors based on load profiles of building users/occupants and supply condition of the grid.
- Feed extra energy gained from individual buildings into the main grid and/or feed extra energy to a neighboring building.

GRAVITATIONAL POTENTIAL ENERGY (GPE) STORAGE SYSTEM



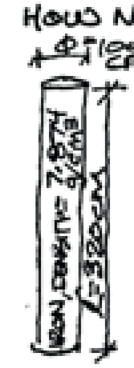
A MASS (M) SUSPENDED AT A HEIGHT (h) HAS A STORED ENERGY POTENTIAL (PE) DUE TO THE ABILITY OF GRAVITY (g) TO DO WORK ON THE MASS

SUCH THAT,

PE = m g h

EXAMPLE:
- 150 M TALL BLDG
- 2X6 ARRANGEMENT OF 9M X 9M BAYS
- CYLINDRICAL IRON WEIGHTS SUSPENDED AROUND PERIMETER
  ϕ = 100 cm, l = 320 cm
  6 per bay

HOW MUCH ENERGY CAN BE STORED?



Mass, m per weight:

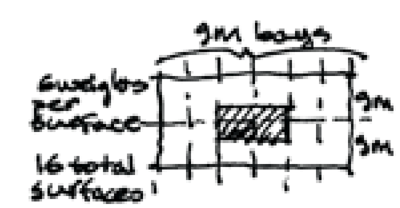
$M = \pi \left(\frac{100}{2}\right)^2 cm^2 (320 cm)(7.87) g/cm^3$

≈ 20000 kg/weight

TOTAL SYSTEM MASS:

20000 kg/weight (100) weights

≈ 2000000 kg



6(16) = 96 ≈ 100 weights

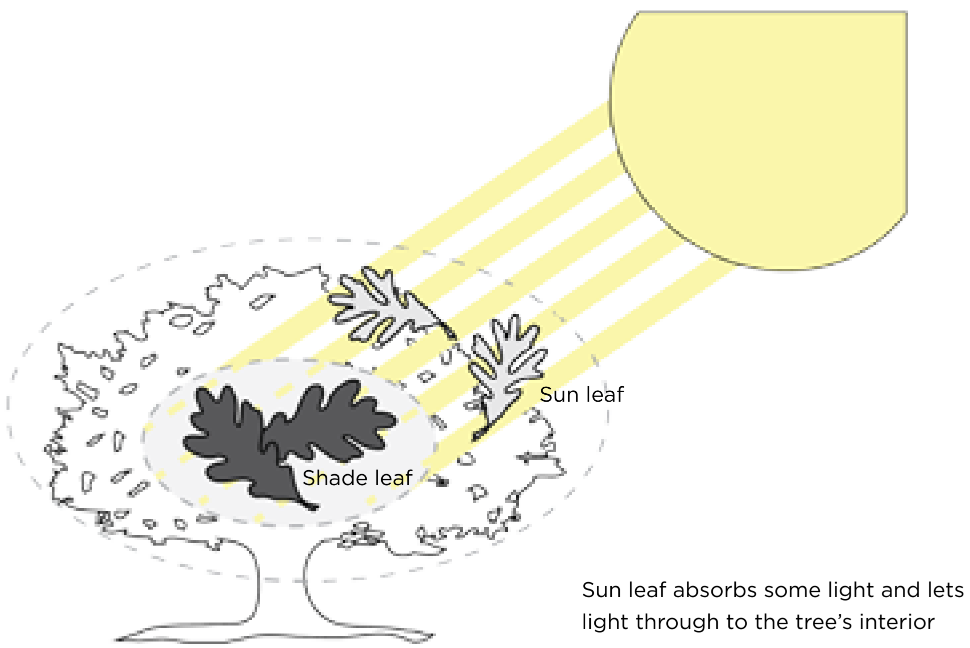
PE = mgh
(M) = 2000000 kg
(g) = 9.81 m/s²
(h) = 150 m

$PE = 2000000 kg (9.81 m/s^2)(150 m)$
$= 2943000000$ J
$= 2.94$ GJ (gigajoules)
$2943 MJ \left(\frac{1 kwh}{3.6 MJ}\right) \approx \boxed{800 kwh}$

optimize light

trees

Trees have varying leaf shapes and sizes depending on the sunlight exposure levels, allowing even shaded leaves to contribute to photosynthesis for the tree.



nature's design

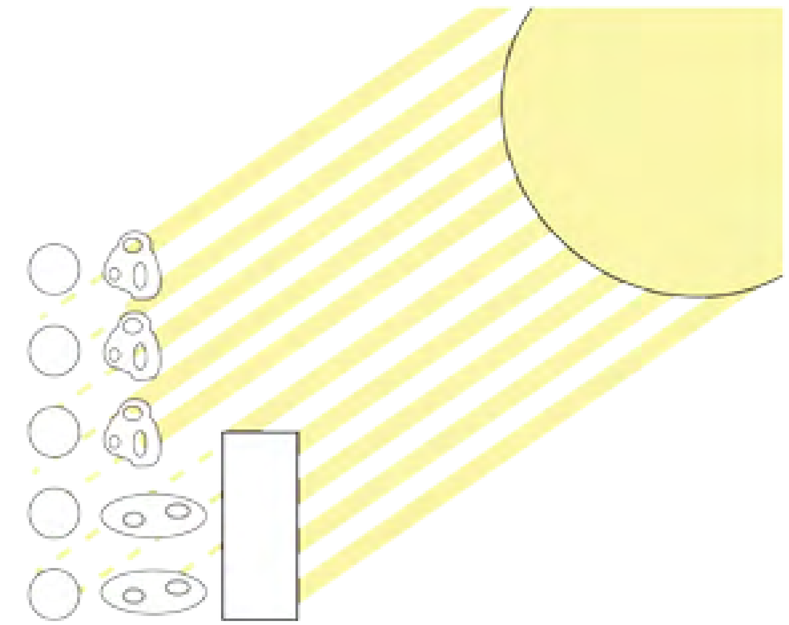
sun and shade leaves optimize energy source

Trees have adapted over millions of years to optimize light collection. Leaves display a range of sizes and shapes in response to the light levels present within a tree. This is called intracanopy plasticity.

Trees in the temperate deciduous forest have sun and shade leaves. In oaks, sun leaves grow near the top and on the more sun-exposed sides of trees, while shade leaves grow within the crown and on the shady sides of the trees. Sun leaves are smaller, thicker, have deeper sinuses between narrower lobes, and have more stomata per unit area. Shade leaves are the opposite in each respect. The shade leaf spreads its mass more thinly over a wider area to capture more diffuse irradiance and it is rich in photosynthetic cells, which scatter irradiance internally. The shape of sun leaves allows light to enter the canopy and reach the shade leaves.

Irradiance-driven plasticity may arise from both internal cues and environmental responses. The differences among leaves begin at the time the leaf is in the bud, and the leaves are even more sensitive to irradiance quantity and quality as they emerge and expand. This plasticity means that as conditions change, the tree can respond.

- In one study of the temperate forest, at canopy tops, the area of individual leaves was on average 0.5–0.6 times that at basal-interior, and leaf mass per area was 1.5–2.2 times higher.
- The shape of the tree crown varies depending on the amount of light and the angle at which it strikes.
- Overstory trees tend to be tall and have wide crowns to capture sunlight while understory species tend to have round crowns to capture more diffuse light.

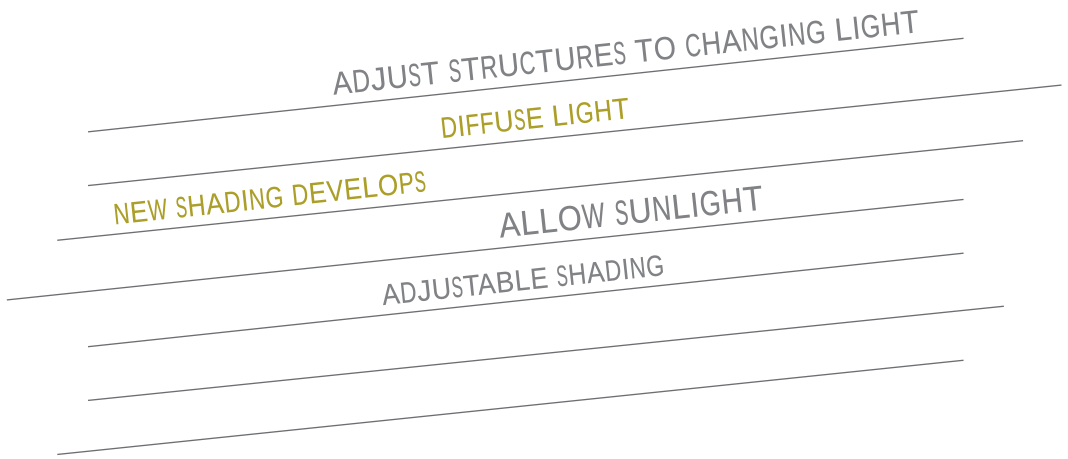


design principle

flexibility optimizes light availability

Availability of light and shade changes over the course of the season, from season to season, and over the course of years as the local conditions change. Maintaining flexibility over space and time allows for adjustments to changing light availability and intensity. Wide thin structures absorb more light than narrow, thin structures. Narrow, thin structures allow more light through to areas below. Structures in the shade take advantage of more diffuse light than those in direct sunlight.

Other related design principles:
- Shape influences ability to absorb light.
- Internal structures scatter light.



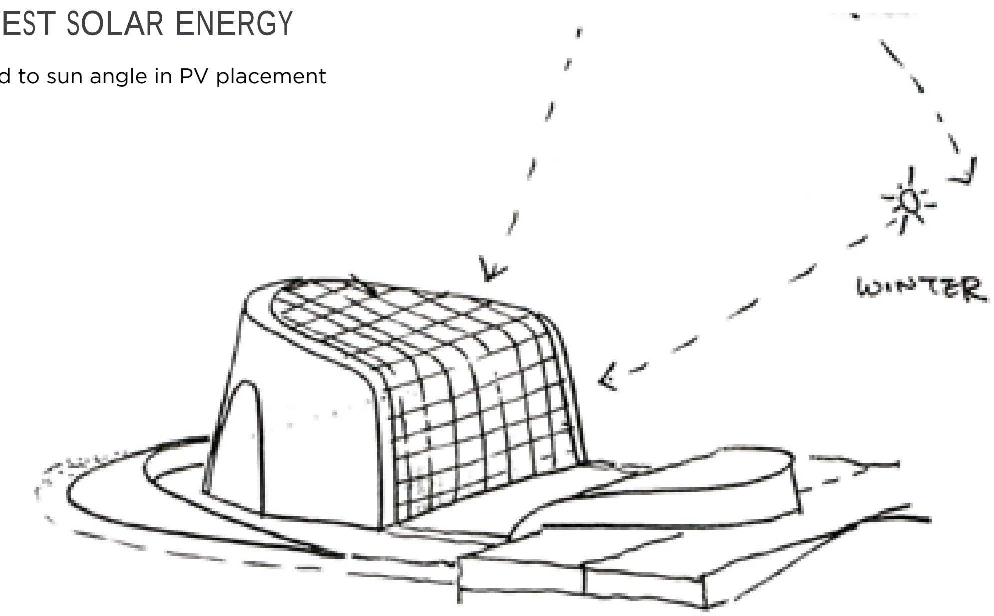
BaDT brainstorm

design ideas

Application Ideas
- Maintain flexibility by adjusting structures and groups of structures to changing light availability and light intensity.
- Utilize optimized solar cell systems in areas receiving diffuse sunlight.
- Allow for adjustment of solar systems, windows, and window shades to respond to new shading from growing trees and new buildings.
- Allow sunlight to enter buildings by designing adjustable shading structures.

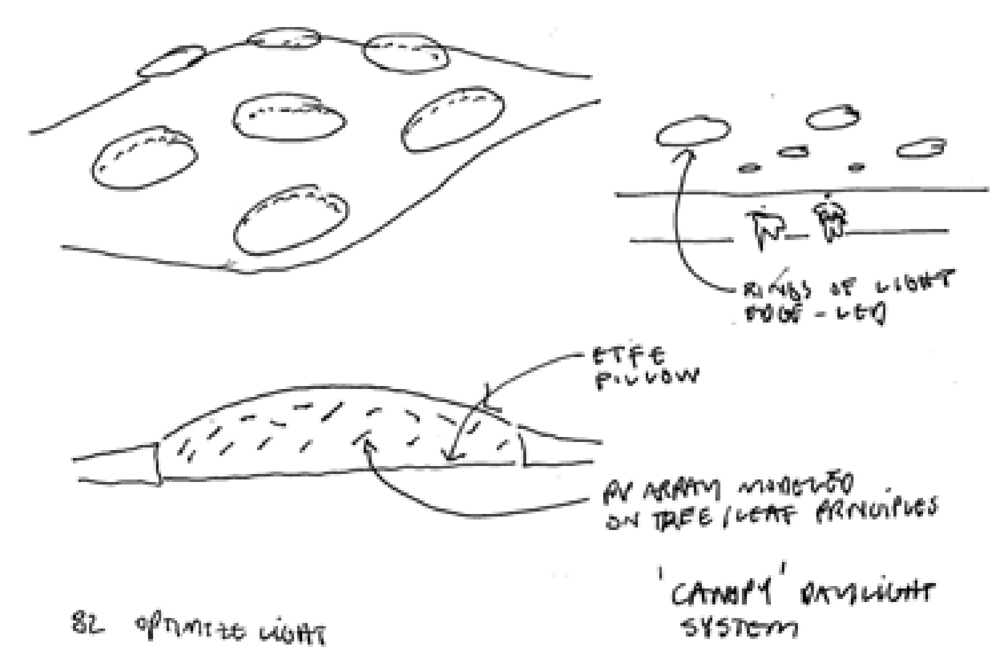
HARVEST SOLAR ENERGY

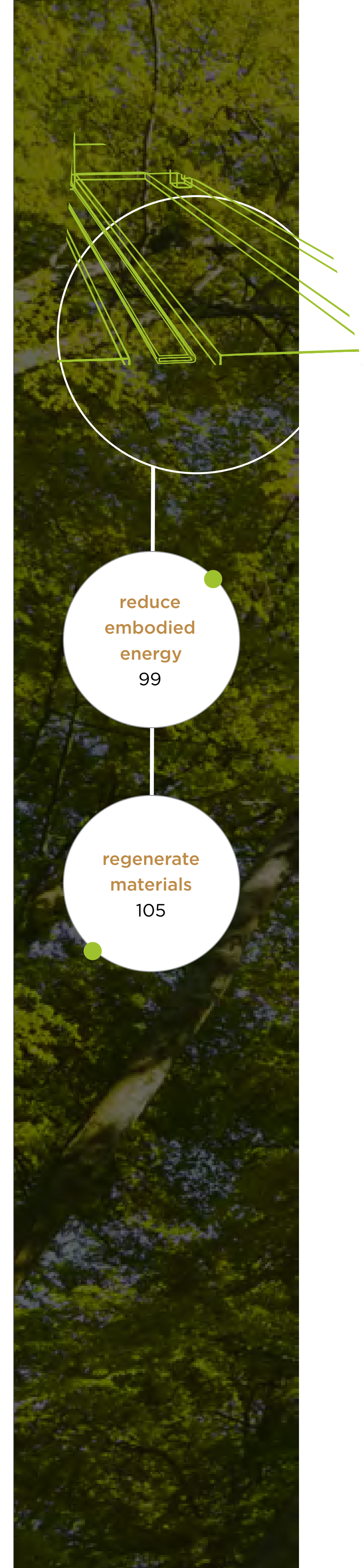
Respond to sun angle in PV placement



OPTIMIZE LIGHT

“Canopy” Daylight System





MATERIALS

The temperate broadleaf forest biome is one of the most human populated biomes on the planet. Hundreds and thousands of years of exploitation have left this biome bereft of its former richness. Another pattern in this biome is the use of locally available materials. Organisms don't spend valuable energy searching far from home. Paper wasps, for example, use locally available wood and chew it, mixing in their own saliva to form a paste that they then use to build a nest. This material is both water-repellent and easy to manipulate into a multichambered structure that fits their needs. Abandoned nests eventually degrade into material broken down by other local organisms—forming a closed loop system.

The harbinger of the end of winter is the brief flowering of herbs that take advantage of a leafless tree canopy, finding a niche in the seasonal cycle to capture as much sunlight power as possible. Braving the cold and sending up shoots in melting snow, these millions of plants capture nutrients that would otherwise wash away before the trees can awaken. Again, we see the principle of “lots of littles” at work.

Expending the least amount of energy to procure materials, forming closed loop systems, and capturing materials at an opportune time are three patterns worth noting. The ability to interact with one's neighbors cooperatively along with the configuration of the complexity of life is what governs the stability and structure of an ecological network. Networks in nature tend to be modular and nested. This may be why they are both complex and stable.

The metabolic cost to produce materials might be better viewed by comparing the relationships among consumers and resources across networks in an ecosystem. This is precisely the reason why materials design today emphasizes a focus on systems thinking.

- use local materials
- capture and release nutrients

MATERIALS

LIFE'S PRINCIPLES

REFERENCE THE DEFINITIONS

EVOLVE TO SURVIVE
Time capture of resources to local climate and human productivity

INTEGRATE DEVELOPMENT WITH GROWTH
Combine modular and nested components
Use modular designs to add structures as funding, materials, and needs grow

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT:
Recycle all materials
Maintain a closed loop by capturing and intercepting intermittent resources to survive for long periods of few resources

BE LOCALLY ATTUNED AND RESPONSIVE
Leverage cyclic processes
Time projects to take advantage of the most opportune conditions and availability of needed resources

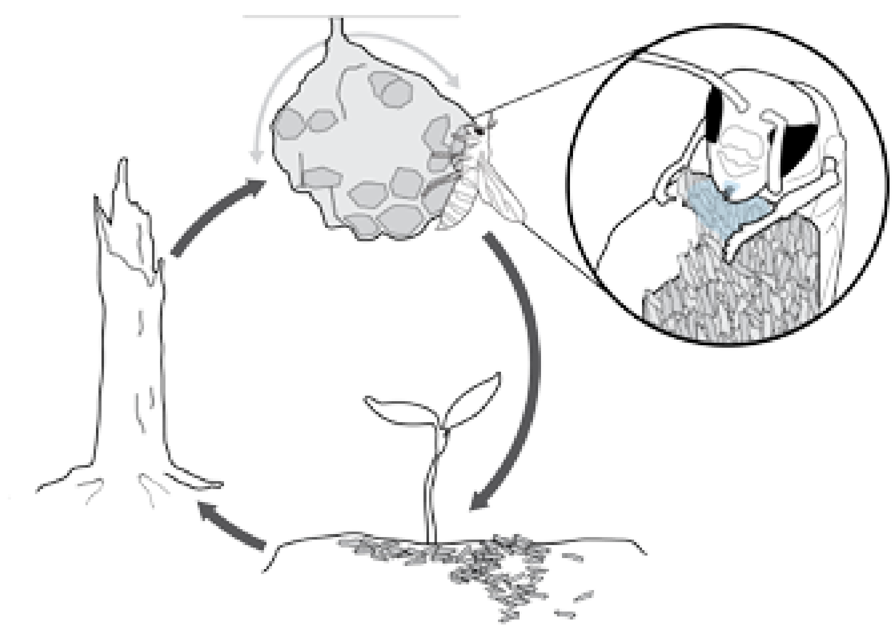
ADAPT TO CHANGING CONDITIONS
Customize the amount of materials and chemicals needed depending on local conditions

USE LIFE-FRIENDLY CHEMISTRY
Use life-friendly chemistry to capture and store resources

reduce embodied energy

paper wasps

Paper wasps make nests combining their protein-based oral fluid and wood fibers.



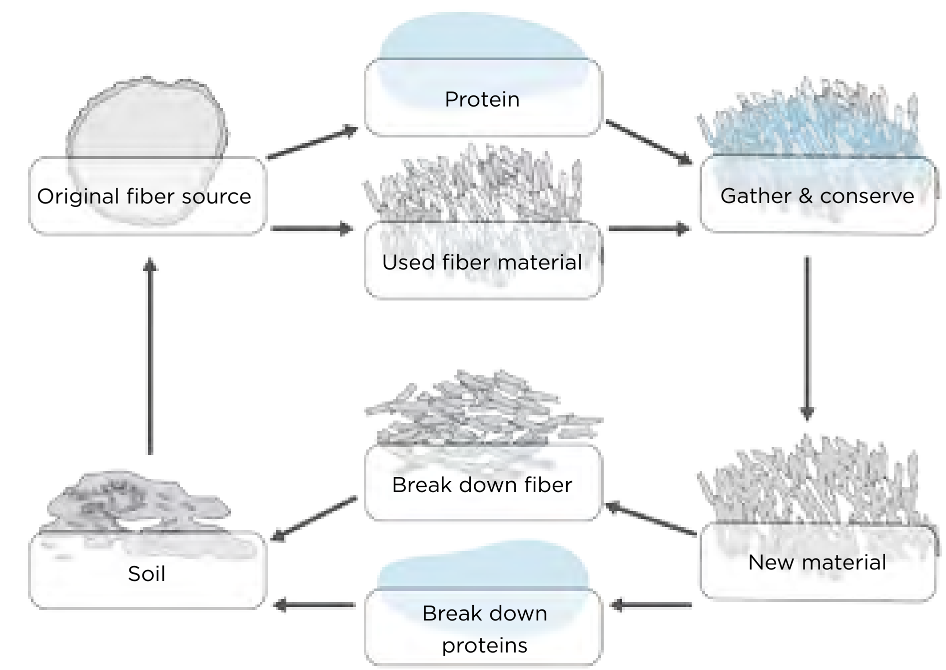
nature's design

locally available materials optimize resources

Paper wasps scrape wood fibers from dead wood, then chew the material and add saliva to make an adhesive to construct a dome-shaped comb of up to several hundred cells suspended from a central stalk. This composite material dries into a strong, water insoluble and water-repellant structure. The wasps maintain the water-repellant properties of the nest by continuing to add saliva, but only where it is most needed, such as on top of the comb. Once helpers are born, they start adding cells to the nest. This modular approach to construction matches size and effort to the available work force and resources.

Paper wasp nests make efficient use of limited resources by having each cell wall shared with another. All materials are gathered locally. All materials eventually decompose back into their constituent parts, becoming part of the food web with fungal breakdown of the tougher molecules—cellulose and lignin—to return nature's building blocks to the soil.

- Paper wasps use wood fiber and protein-rich saliva to create nests
- Saliva acts as an adhesive, strengthening agent, and water-repellant coating
- Domed shape sheds water
- Nests are built in a modular fashion as resources become available
- Shared walls reduce material usage
- Materials come from waste and decompose back into the soil



design principle

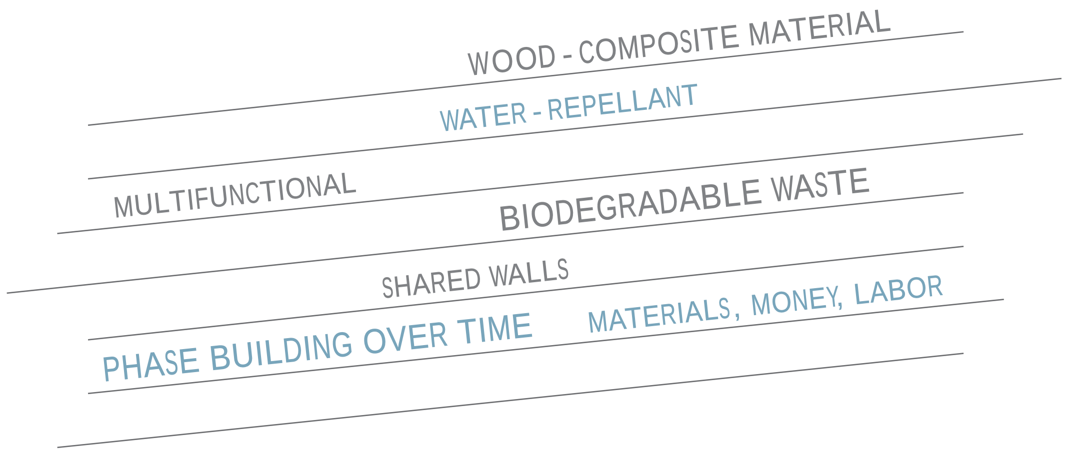
mixing local materials reduces embodied energy

Value-added materials are produced by combining locally obtained fibers with a protein-rich fluid to make an adhesive that is used to construct a structure.

Protein-rich fluid can serve three functions when combined with wood fibers—adhesiveness, strength, and water-repellency. In this example, both fibers and natural chemicals are obtained locally, balancing the cost of effort expended with the benefits provided by the materials. If selected carefully, the chemicals used should decompose into their harmless constituents and be easily taken up by organisms or reused for another purpose.

Other related design principles:

- Domed shape sheds water
- Targeted use and shared walls reduces materials
- Modular construction allows growth
- Matching size and effort with available resources minimizes waste
- Minimizing travel distance to materials conserves energy
- Collective intelligence coordinates activities
- The structure causes work behavior to occur



BaDT brainstorm

design ideas

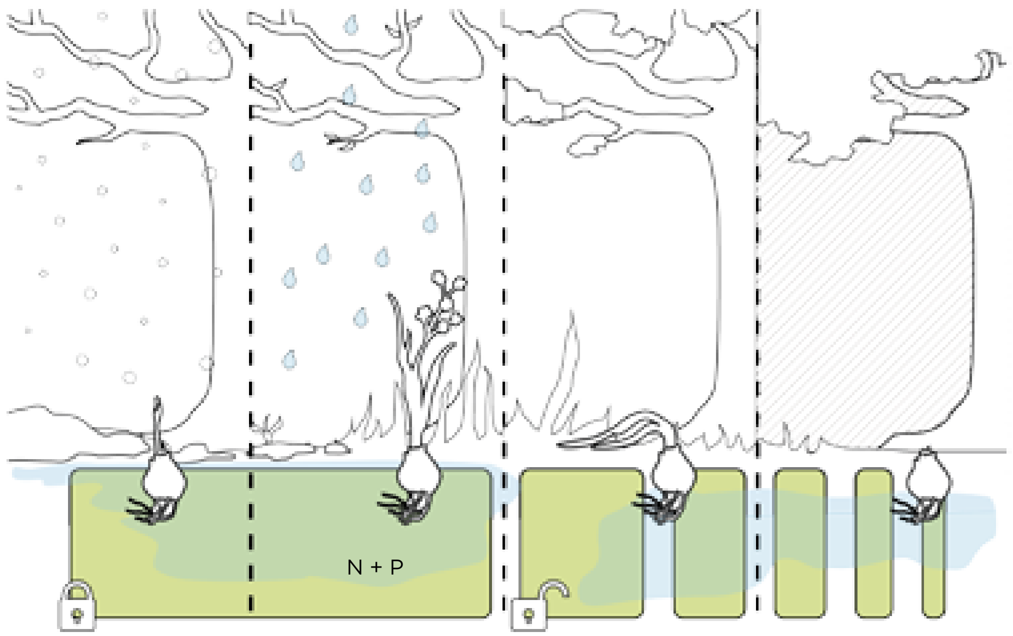
Application Ideas

- Develop a wood-composite material that incorporates water-repellent multi-functional proteins (wasp saliva is particularly high in the amino acid proline). Source the wood locally, perhaps combining it with other local biodegradable "waste" materials. Reclaim and reprocess these materials locally at the end of their life cycle.
- Optimize material use by capitalizing on shared walls.
- As a project phasing strategy, design a multi-level building to be built a few floors at a time, as materials, money, and labor are available. This may be a particularly useful approach in times of economic uncertainty and/or recession, labor strikes, or material shortages.

regenerate materials

ephemeral herbs

Ephemeral spring-flowering herbs capture nutrients early in the season, providing a temporary “dam” that slowly releases nutrients back into the soil, making them available at a later date for the forest community.



Bulbs (herbs) trap nitrogen (N) and phosphorus (P), and store until dying back, and then releases slowly back to the soil

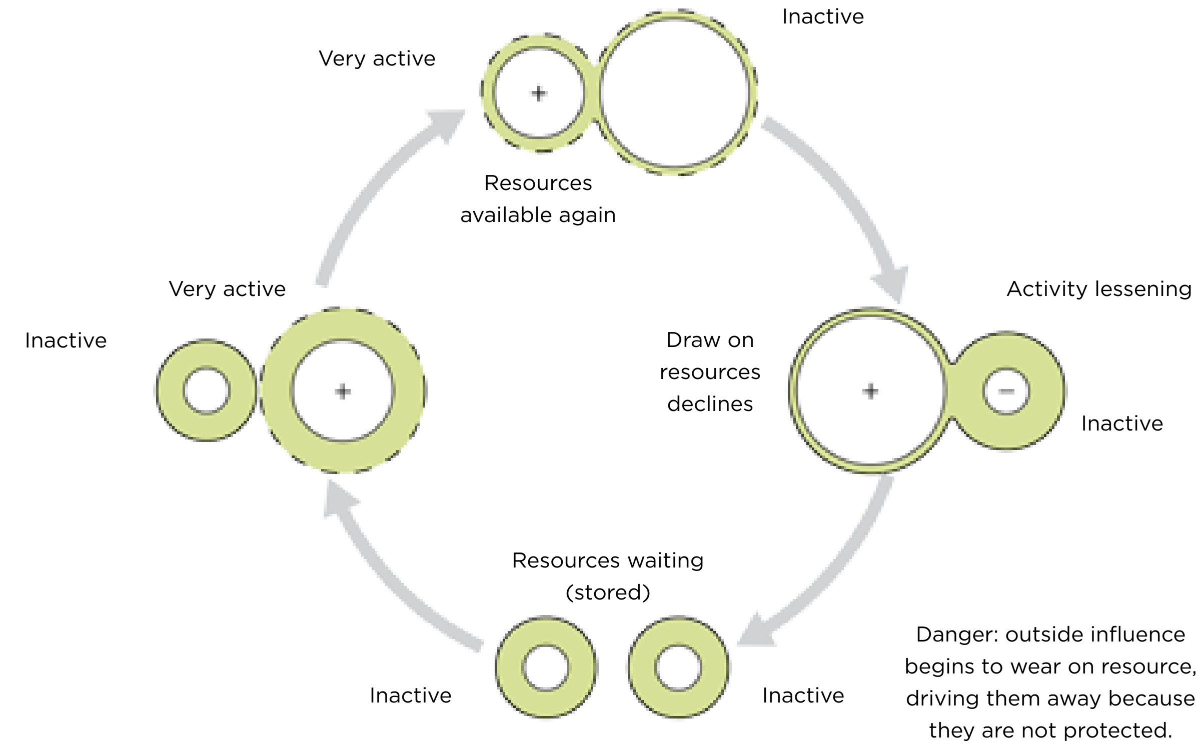
nature's design

temporary dam cycles nutrients

Hundreds and thousands of ephemeral herbs in the understory of the forest canopy are the first to flower in the early spring, capturing available sunlight as well as soil nutrients that would otherwise wash away with snowmelt and rain. These early-flowering herbs complete their reproductive cycle in a matter of weeks. As the leaf canopy emerges and sunlight is reduced, these herbs go to seed, die back, and become inactive until the following spring. The nutrients these herbs capture in their above-ground material degrades and is re-released into the soil at a time when trees and other plants need access to these nutrients.

Scaling: The principle of "lots of littles" adds up to perform a large service to the forest community.

- Lower forest layer of spring flowers take advantage of the high sunlight conditions for brief period
- Spring flowers absorb nutrients and use them to produce leaves, flowers and seeds
- Spring flowers are acclimated to low light availability
- Spring flower lifespan occurs under high illumination conditions early in the season to capture nutrients
- Maximizing carbon gain and storage during high to low light transitions is achieved by producing new leaves physiologically suited for spring conditions



design principle

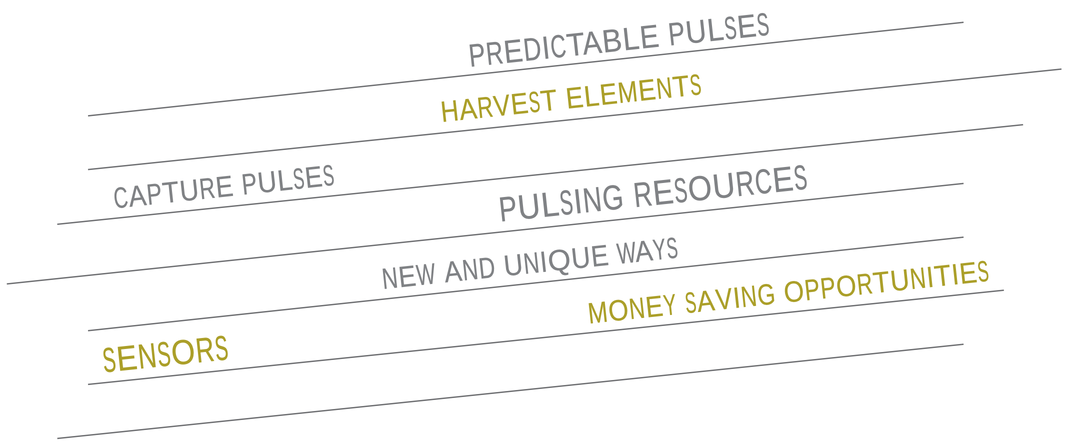
materials in danger of being lost are held within the system, then released

Certain elements become very active once conditions are conducive and before conditions deteriorate. These elements are temporary, low cost, and briefly collect a resource that is ephemeral in nature and at risk of vanishing. The elements take up unprotected resources and use them for growth and replication. Receding at the end of the growth period, the elements release the captured resources slowly, allowing these resources to become available to other elements now ready to use them.

Local systems are attuned and adapted to resource flows, capturing resources at opportune times, using a variety of methods, some short-term damming of resources.

Other related design principles:

- Elements respond to local resource availability
- Systems are linked to capitalize on temporal opportunities
- Systems are attuned to respond to pulse and cycling of resources
- Systems integrate short-lived elements
- Systems synchronize production to resource availability
- Elements intercept resources at opportune times to prevent resource waste
- Systems capture resources and store for later use to maximize and reduce resource waste

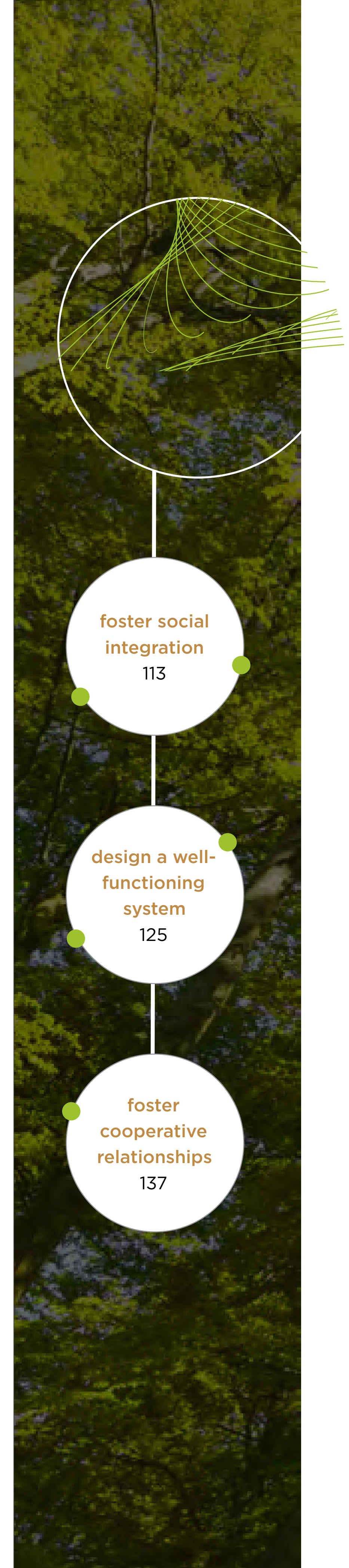


BaDT brainstorm

design ideas

Application Ideas

- Evaluate what resources, energies, and/or flows (water, energy, occupants, attitudes/moods, traffic patterns, etc.) occur in predictable pulses. Are any of these elements that you want to harvest? Channel? Redirect? Block? Develop infrastructure or programmatic elements that can capture these pulses in ways that create long-term benefits for the system.
- Which of these pulsing resources, energies, and/or flows represent a lost opportunity to capture valuable reserves for later use? Capturing and storing these flows helps slow the movement of resources through a system, creating more potential for them to be used in new and unique ways.
- Install sensors in buildings that transmit information about inefficiencies, problems, and risks. This information can be used to cut off problems before they get bad and also highlight money saving opportunities



SOCIAL

Working together, communicating, sharing resources—these are not uniquely human needs. All living organisms must figure out how to engage with each other in ways that create short- and long-term benefits so they can survive and thrive.

Our language and our “civilization” tend to separate humans from living systems in nature, but in fact human society is a living system in nature. Many of the emergent properties of society and social interaction have risen out of seemingly random interactions. Structure is an important factor that determines what kind of interactions, and thus what kind of behaviors, emerge. Structure, which can include physical structures, rules, or goals, determines behavior by creating context. This is the same for all living, dynamic systems, whether human or non-human. The way we design these structures determines what kinds of behaviors will result.

Although human social systems and ways of communicating are different from those of other species, there are high-level patterns expressed by other species that we can examine. These patterns can show us unique nuances that may help us design the structures that foster social interaction among diverse groups, encourage cooperation, and promote efficient and fair use of shared resources. Taken together, this can create a well-functioning, resilient system.

- integrate unlike elements
- share resources
- create redundant functional groups

SOCIAL

LIFE'S PRINCIPLES

REFERENCE THE DEFINITIONS

EVOLVE TO SURVIVE
Integrate the unexpected
Maintain flexibility in use of common resources such as meeting rooms, so that if one user alters its use patterns, there is a seamless transition to a new user

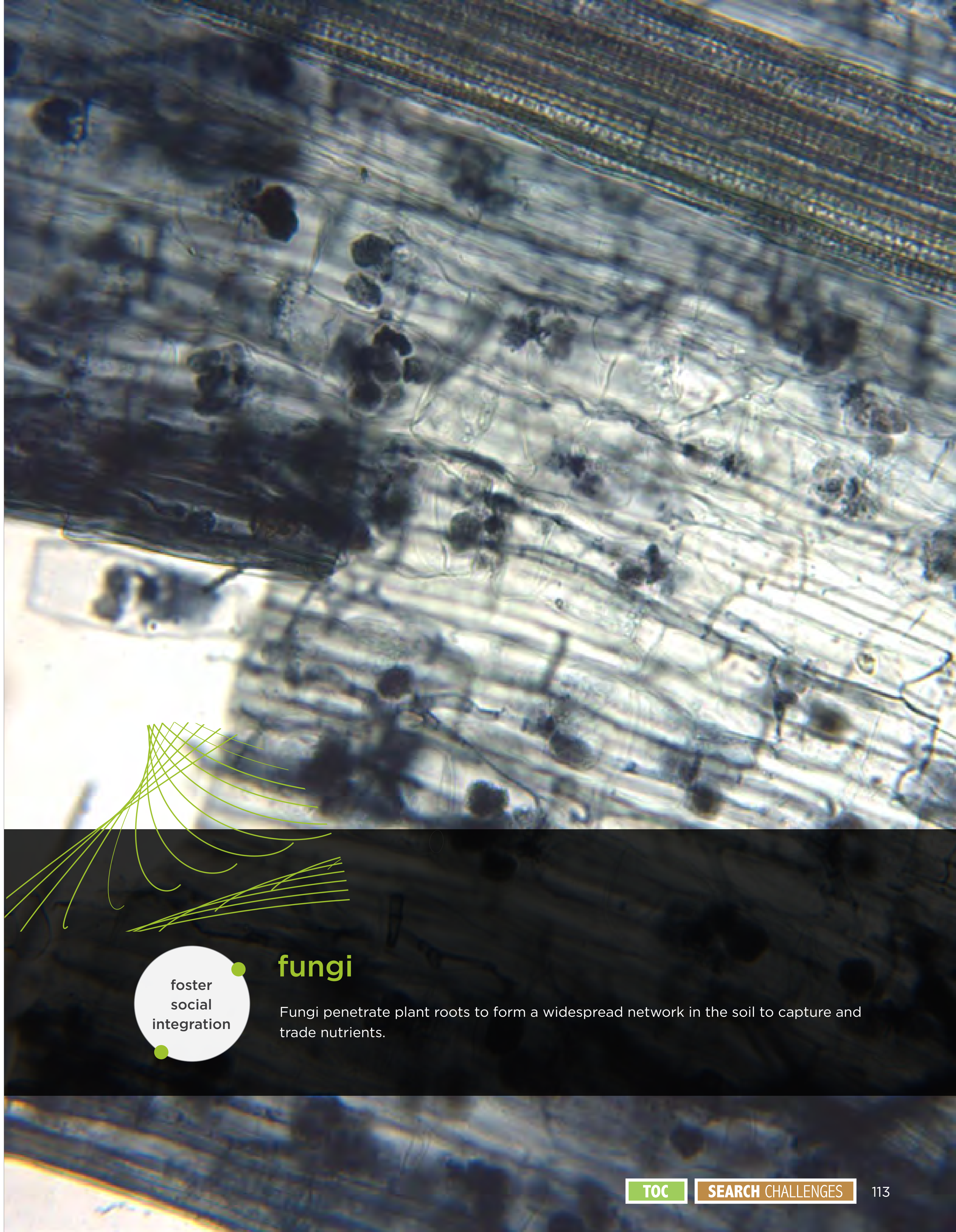
INTEGRATE DEVELOPMENT WITH GROWTH
Self-organize
Create conditions that support self-organization of social systems, rather than try to force them from a top-down approach

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT:
Fit form to function
Design transition zones between types of use or types of structures to enhance interactions and sharing of information

BE LOCALLY ATTUNED AND RESPONSIVE
Cultivate cooperative relationships
Seek opportunities to create, encourage, and support mutual relationships to increase interactions among individuals and groups in a community

ADAPT TO CHANGING CONDITIONS
Embody resilience through variation, redundancy, and decentralization
Plan for disturbance or disruption of social systems by maintaining adequate representation of people and organizations that serve similar functions

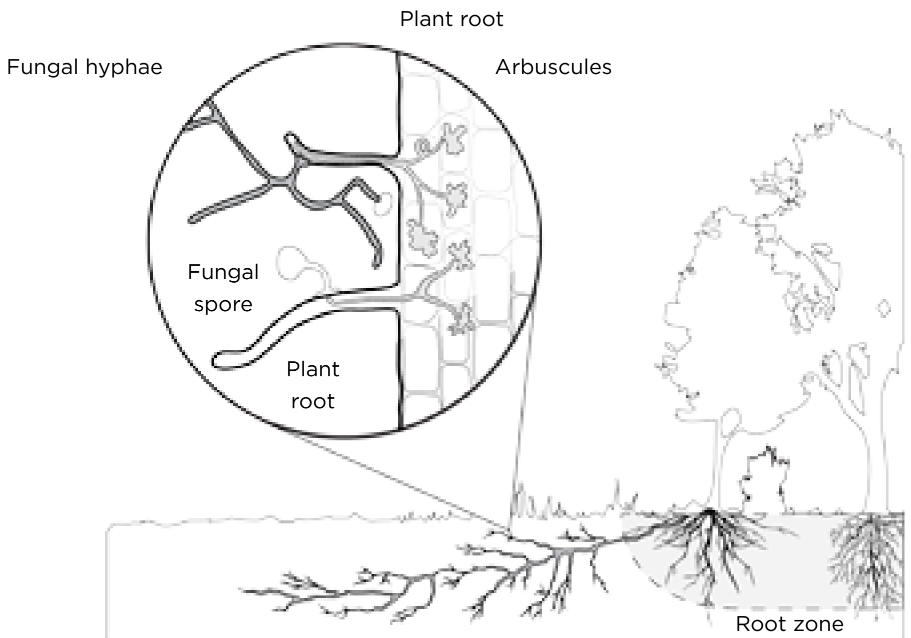
USE LIFE-FRIENDLY CHEMISTRY
Build selectively with a small subset of elements
Maintain a healthy community by selecting construction and maintenance materials that minimize use of harmful chemicals



foster social integration

fungi

Fungi penetrate plant roots to form a widespread network in the soil to capture and trade nutrients.



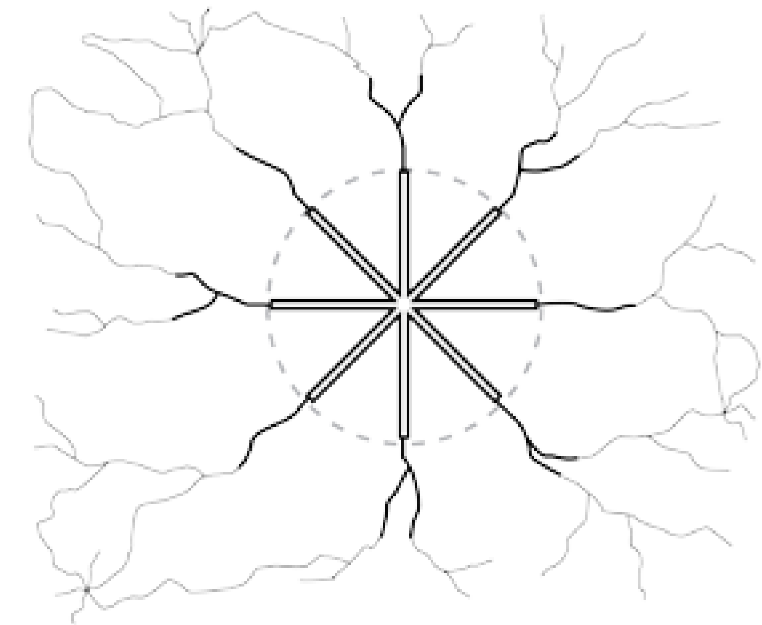
nature's design

fungi penetrate plant roots to form a widespread network in the soil to capture and trade nutrients

Arbuscular mycorrhizae (AM) are fungi that penetrate cells in plant roots using arbuscules, a unique structure to trade phosphates and nitrogen for plant sugars. Probably 90% of plants use this symbiotic and mutualistic trading system in which the fungus must "pay in advance," making it difficult for the fungus to cheat the plant. The AM fungi form widespread networks of mycelia and hyphae in the soil to travel beyond the plant roots into areas rich in resources and to transport these nutrients back to the plant. AM fungi penetrate plant root hairs and use them to travel into the roots and form a "glove-like" arbuscule inside of plant cells. No real cell penetration occurs because the fungal arbuscules remain in a compartment of the plant cell, surrounded by an interfacial matrix and a peri-arbuscular membrane that protrudes into the plant cell. The fungus absorbs sugars from the host root and the plant saves the expense of growing roots to gain access to far-away resources by forming this mutual arrangement.

Scaling: The presence of microscopic structures connected to a widespread network of multi-branched hyphae at the local scale of one plant root is multiplied by the tens of millions of connections in all plants in an area to deliver nutrients and some protection in return for sugar.

- AM fungi colonize roots
- Roots respond by allowing the penetration by the fungi and proliferate more roots and root hairs
- AM fungi transfers phosphates and nitrogen across arbuscule membranes
- Plants allow sugars to transfer to the fungi in response.

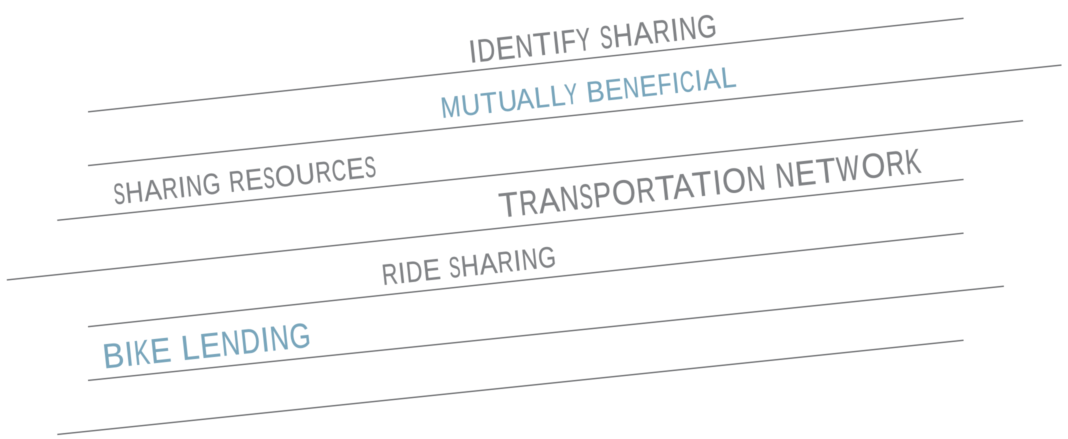


design principle

cooperation among partners increases resources

Resources far away are not cost effective to capture by building more infrastructure. Instead, such resources can be gained through a mutual association with partners. Trading extra resources in exchange for hard to access resources also helps to lessen the cost. Multiple elements delivering small amounts of resources add up when multiplied into a large, complex network. Many duplicate connections allow for a stable economy.

Other related design principles:
- Easy exchange across borders facilitates sharing of resources
- Use of empty space within communities provides room to share resources
- Colonization with permission enhances mutually beneficial relationships
- Resources beyond a border encourage working together
- Reciprocal recognition and regulation facilitates sharing of resources
- Sharing of resources helps others to tolerate stress conditions
- Interdependence benefits all partners
- Networking supports community health



BaDT brainstorm

design ideas

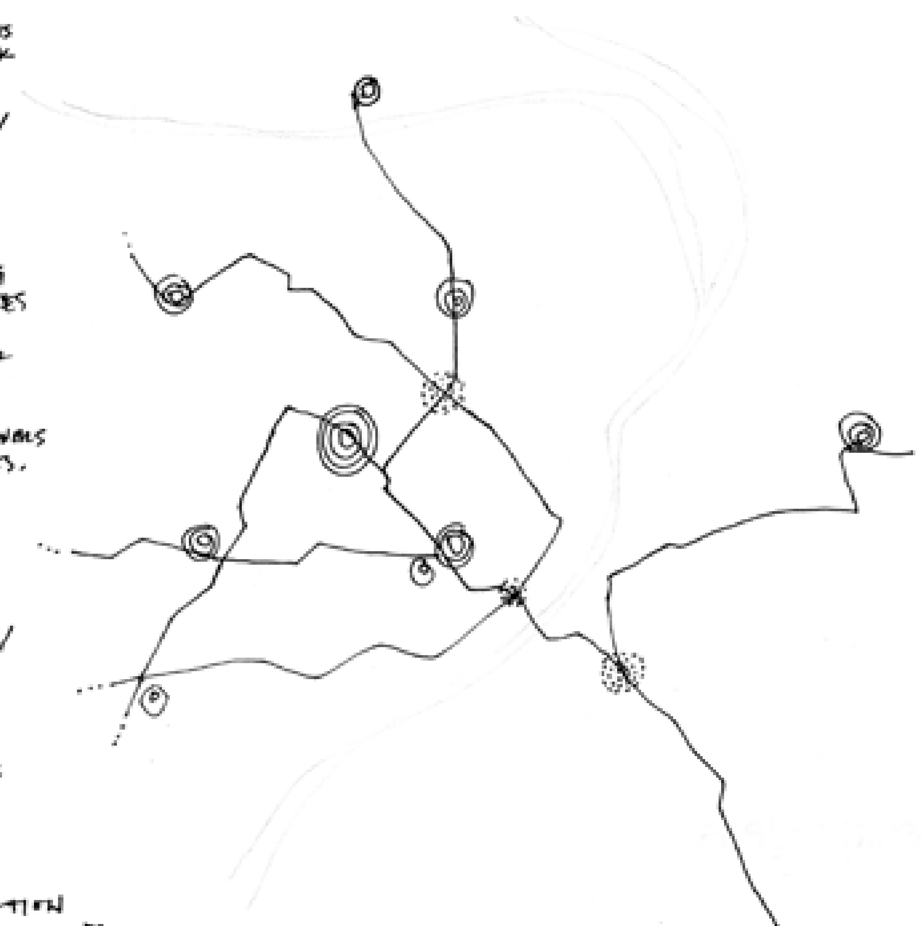
Application Ideas

- Identify other buildings or nearby industrial operations that could share mutually beneficial resources (the resources shared will likely be different).
- Encourage a transportation network among building users/occupants for ride sharing, car lending, bike lending, etc.

UNIVERSITY NETWORK

Mutual association with partner universities conserves resources

- COOPERATION OF UNIVERSITIES ALONG METRO NETWORK
- POTENTIAL NEW COLLABS ALONG UNDERDEVELOPED/ UNDERSERVED AREAS WHERE SYSTEMS COME TOGETHER
- ROUTING NEW LINES TO CONNECT TO EXISTING UNIVERSITIES. RESOURCES
- ALSO COULD WORK FOR FOOD . .
- MUTUAL ASSOCIATION/PARTNERS
- TRADING EXTRA RESOURCES. LESSENS COST



EXISTING UNIVERSITIES/ INSTITUTIONS

PROPOSED

LIGHT RAIL LINE

MUTUAL ASSOCIATION WITH PARTNER UNIVERSITIES CONSERVE RESOURCES

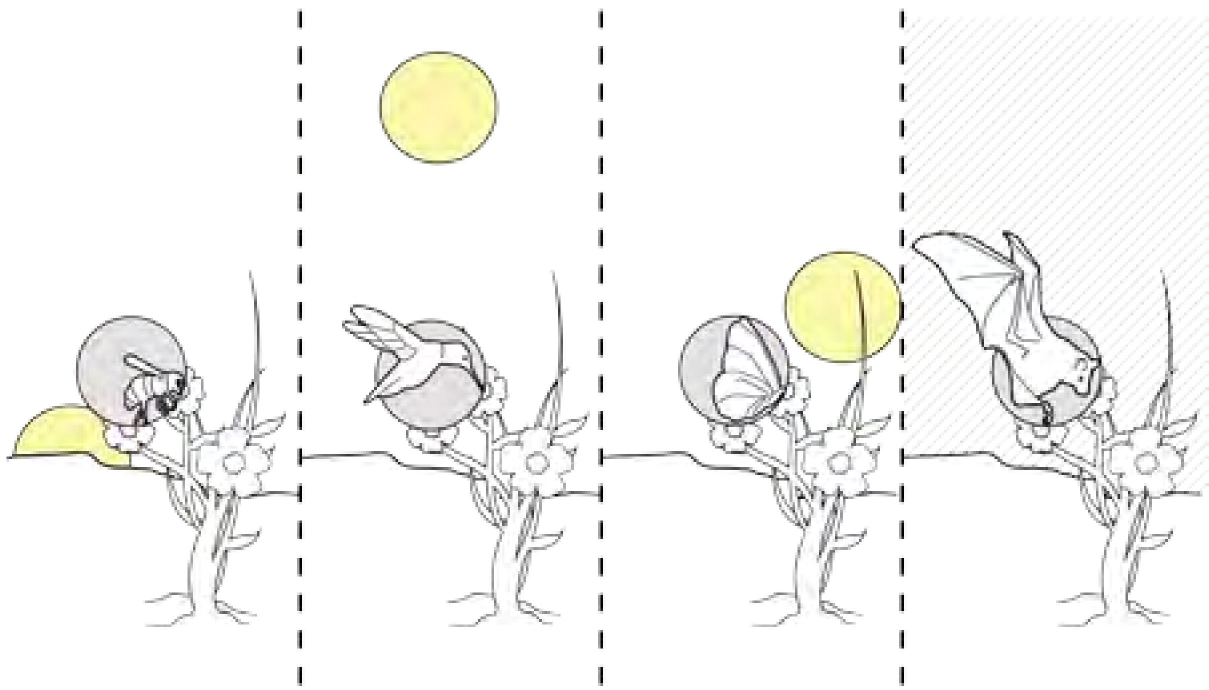
NETWORK OF UNIVERSITIES AS A LARGE/COMPLEX SYSTEM MADE UP OF SMALLER, UNITS DELIVERING FEWER, SPECIFIC RESOURCES

RECIPROCAL ... SHARING OF UNIVERSITY RESORCES

foster social integration

pollinators

Resource sharing guilds allow multiple species to use the same resources without competing.



nature's design

resource sharing guilds allow multiple species to use the same resources without competing

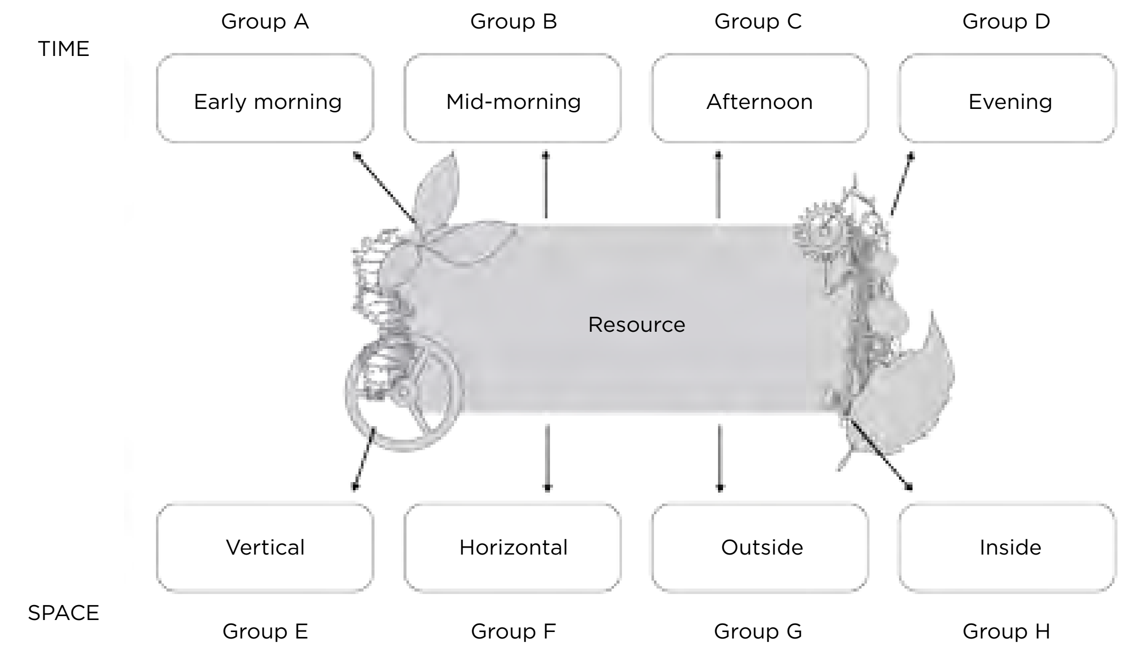
In ecology, guilds represent a basic framework of social structure. A guild is an assembly of species clustered around a central resource that act in relation to this resource in ways that assist its health, avoid competition with each other, and buffer adverse environmental effects.

A resource-partitioning guild consists of species that use the same resource in the same community in a similar way. For example, nectar-feeding animals like bees, birds, some bats, and other insects all depend on flowers for food. These organisms avoid competing with each other for a limited resource by feeding at different times, foraging at different locations, eating faster or slower than others, and/or migrating through the area. This results in effective partitioning of the resource.

Because the flowers are also benefiting from the many nectar feeders, they have co-evolved to flower at different times of the year and even different times of the day, in order to help support the diversity of animals dependent on them.

If one species of the guild were to drop out, others could expand their activities or range to fill the gap. This confers stability and resilience because of redundancies in community function and overall flexibility.

- Resource-partitioning guilds are the mechanism organisms use to share a given resource while avoiding competition with each other
- Organisms share a resource, but vary how the resource is used and when it is used
- The resource, if it is also a living organism, will respond favorably if it is also benefiting from the exchange



design principle

partitioning of resources in time and space discourage competition and encourage resource sharing

Sharing a valuable resource is accomplished by partitioning its use in space and time. If the partitioning is designed effectively, the resource will be consumed at an optimum rate, and, ideally will also be regenerated. If one user group left the guild or changed priorities, the resource would simply be re-partitioned.

Other related design principles:

- Cooperation fosters social interaction
- Avoidance of competition fosters social collaboration
- Multiple consumers of same resource can create resource resilience
- Maintain resources for long-term use

DESIGN GUILDS
RESOURCE BUDGET
ENCOURAGE CREATIVITY
REINFORCE APPROPRIATE USE
ACCOUNTABILITY AMONG PEERS

BaDT brainstorm

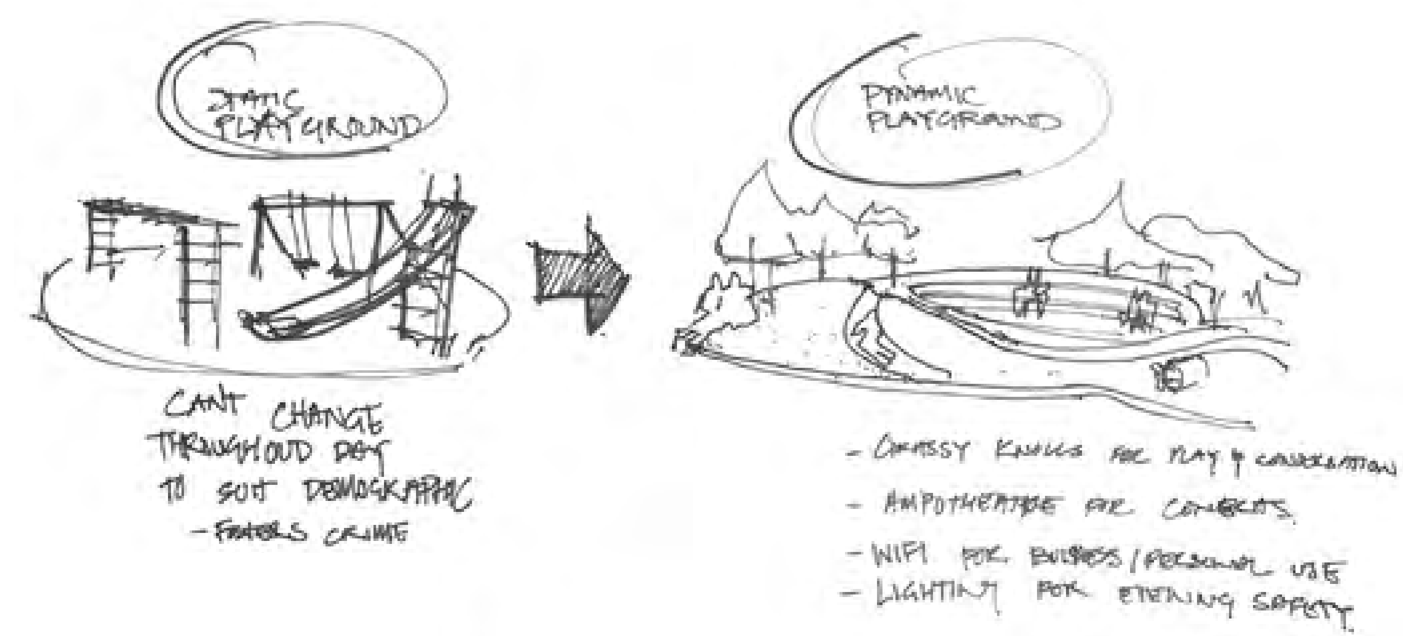
design ideas

Application Ideas

- Use common resources shared by building users to purposely design guilds. This could include water, energy, material flows, and/or food. Determine the different ways individuals or businesses use the resource and co-develop a shared usage policy/procedure. Create “resource budgets” for any given resource so that people can see and respond to what’s available at what times.
- Create opportunity for users/occupants to find unique ways to access and use the resource—encourage creativity.
- Use the design of programmatic elements to reinforce appropriate use of the resource. Often, making the resource highly visible helps people see the impacts of their behavior and also creates accountability among peers.

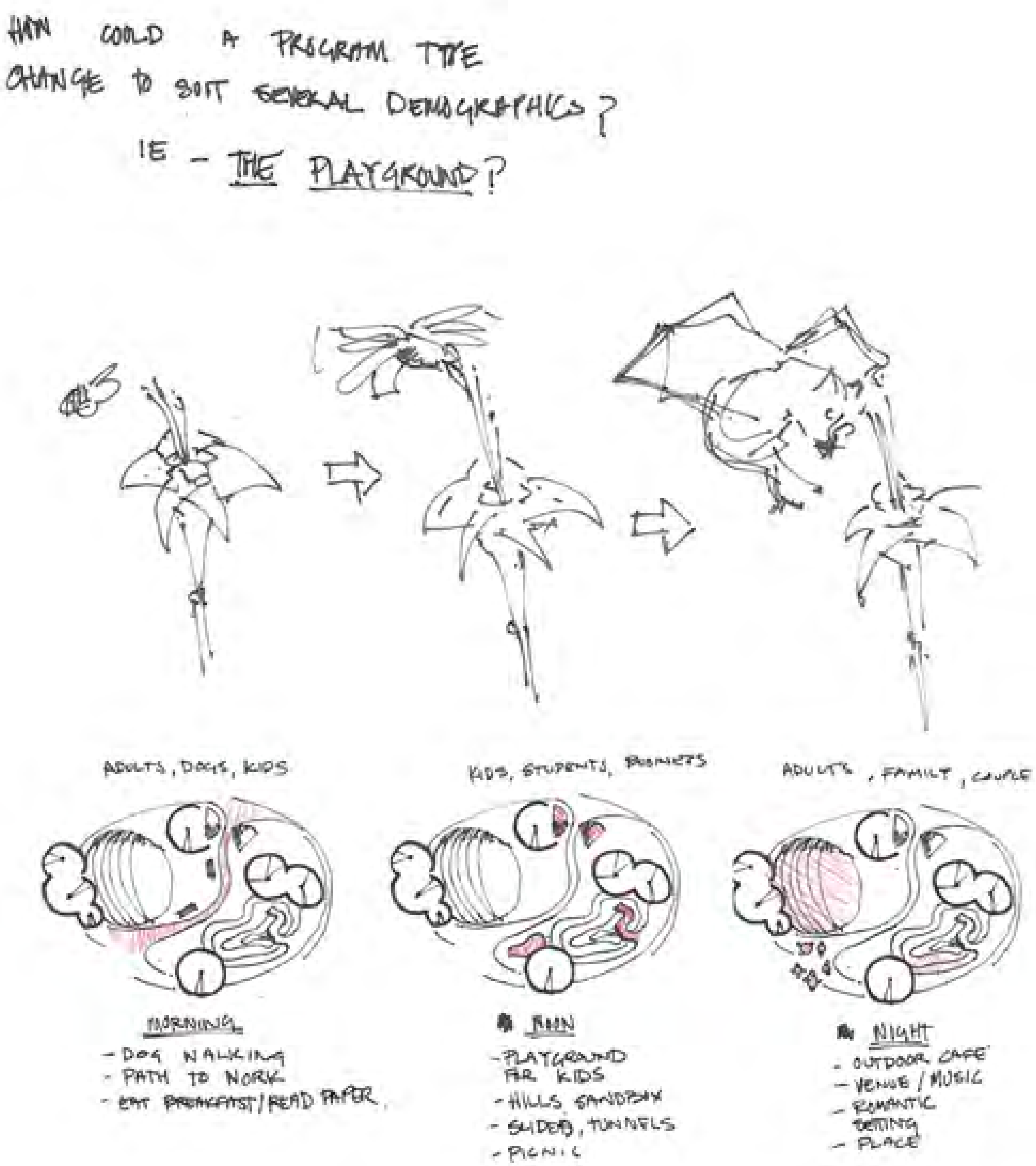
DYNAMIC PLAYGROUND

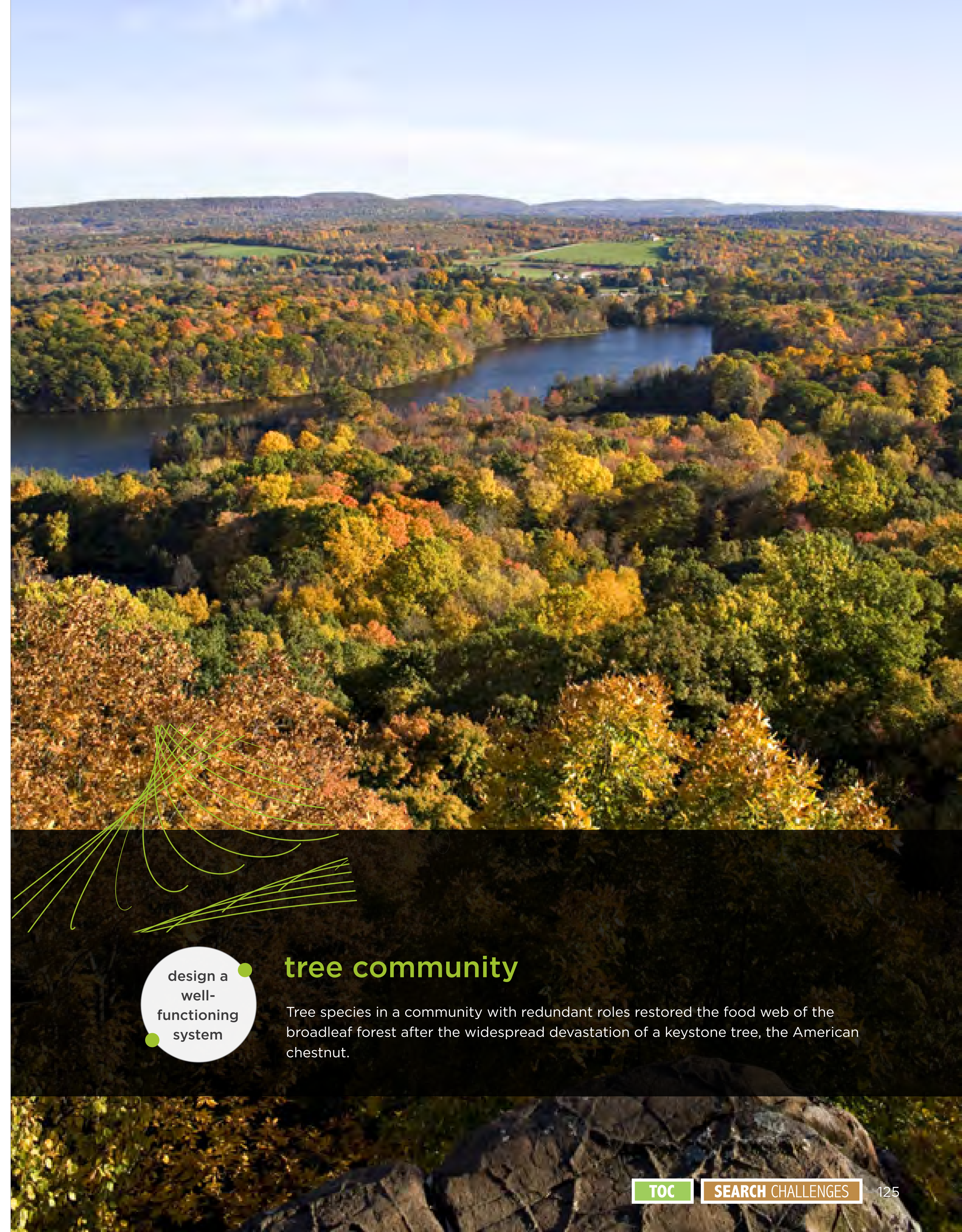
Dynamic vs. static playground, multi-functional, for all ages, year-round



DYNAMIC PLAYGROUND

Dynamic vs. static playground, multi-functional, for all ages, year-round

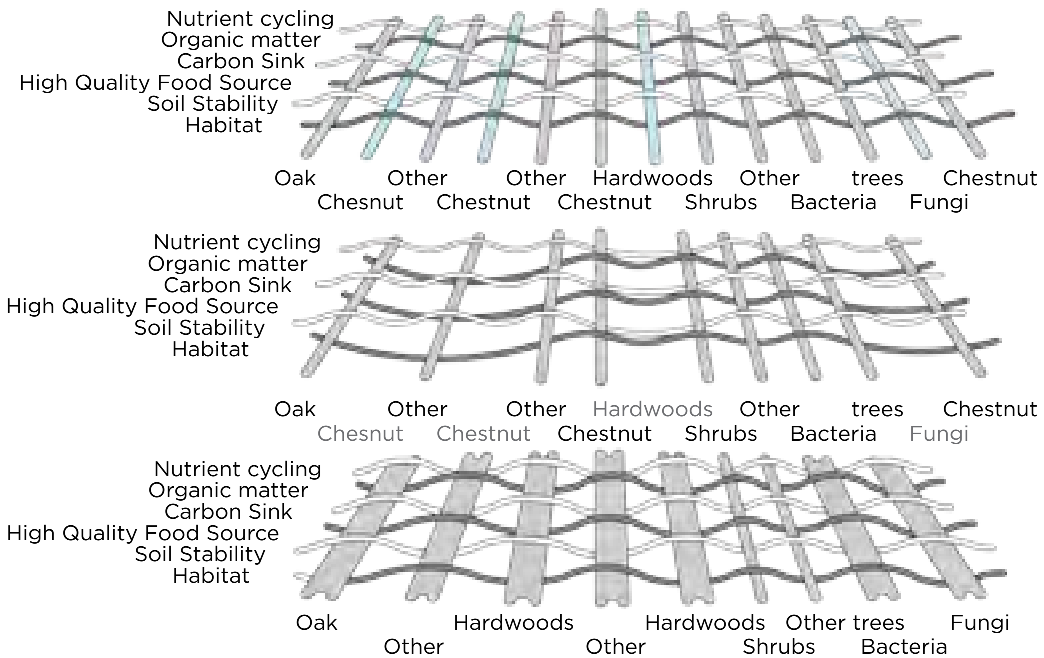


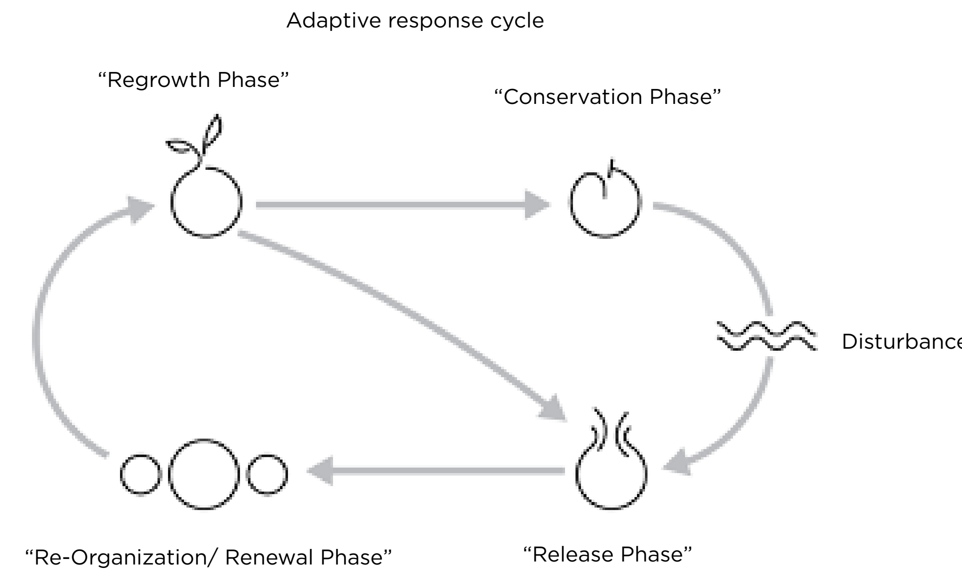


design a well-functioning system

tree community

Tree species in a community with redundant roles restored the food web of the broadleaf forest after the widespread devastation of a keystone tree, the American chestnut.





nature's design

redundant functional groups create resilience

Prior to the early 1900s, the American chestnut dominated 25-50% of the canopy of the northeastern US forests. This important keystone species provided an abundant supply of high quality food for a great many creatures. Secondarily, it stabilized soil, provided habitat, and sunk a tremendous quantity of carbon in its large, long-lived structure.

However, the accidental introduction of a pathogenic fungus to which the trees had no resistance killed all the trees within 40 years. Now, all that remains are sprouts from the original rootstock unable to reach sexual maturity before again being attacked and stunted by the fungus.

When the chestnut trees died, the forest canopy opened up, the food web deteriorated and soil erosion ensued. However, over the last 70-80 years, tree species that were not susceptible to the fungus but were in the same functional group (i.e., abundant food producers and soil stabilizers) began to fill in the canopy and are now dominant. Oak trees, sugar maples, serviceberry, and black cherry have replaced the American chestnut and now serve as primary food sources for forest creatures, and a dense understory took over, assisting in soil stability. A catastrophic biological event was resolved because of the redundant functional roles existing in the community of species in this ecosystem.

- The American chestnut is a native keystone species of the US temperate broadleaf forest
- The chestnut performs multiple functions for the ecosystem
- A blight affecting the American chestnut has radically altered the structural and functional relationships in the northeastern US forests
- Functional diversity and response diversity allowed the forest to recover and persist as a temperate broadleaf ecosystem

design principle

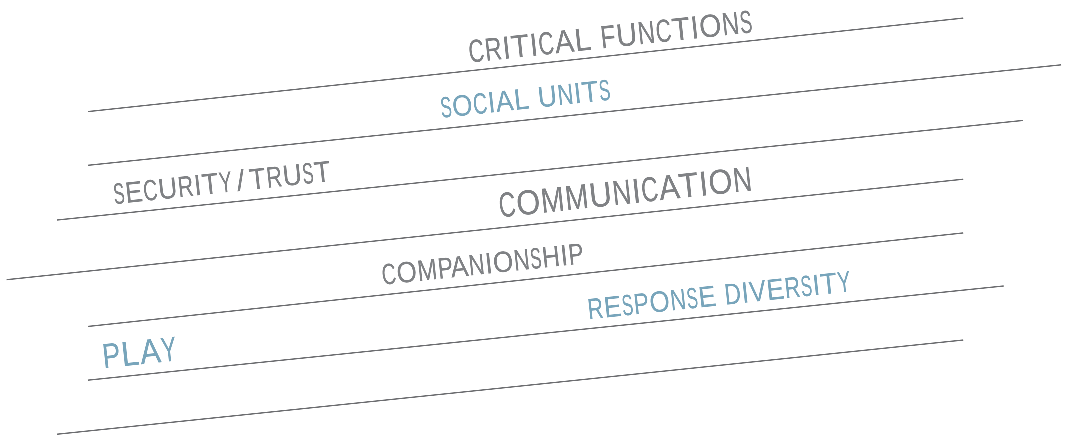
redundant performers of key functions foster resilience

Critical functions within a system are supported by multiple elements. These elements are grouped according to the primary functions they perform, called functional groups. Elements within the same functional group that respond differently to the same disturbance foster resilience. For example, if one element in a functional group fails, others can fill the gap and the overall performance of that function can continue.

Major disturbance often causes instability, but disturbances can also create the opportunity for innovation during the reorganization process.

Other related design principles:

- Redundant functional roles secure resilience
- Critical functions are highly supported by redundant elements
- Functional diversity + response diversity foster resilience
- Adaptive response cycle fosters resilience



BaDT brainstorm

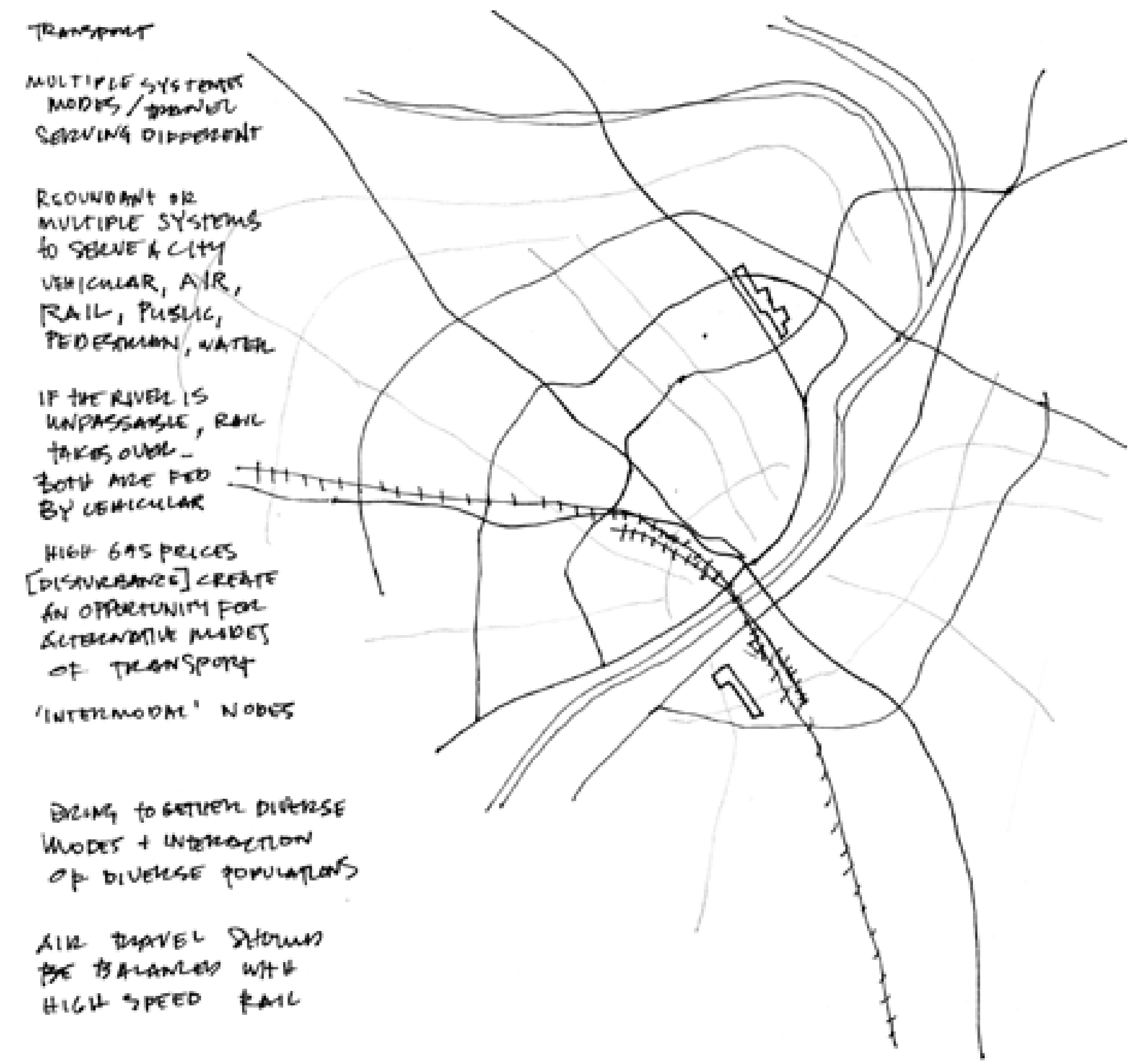
design ideas

Application Ideas

- From a social perspective, evaluate the critical functions that make a social unit strong. These functional groups could include security/trust, communication, companionship, play, support in times of need, etc. Are there structural, programmatic, or planning elements that can support and foster these functions (critical elements well supported), and are there MULTIPLE ways of supporting each one (functional diversity)?
- Bringing together groups of people with different skill sets, socio-economic backgrounds, interests, and personalities within each functional group will help build response diversity.

CITY SERVICES

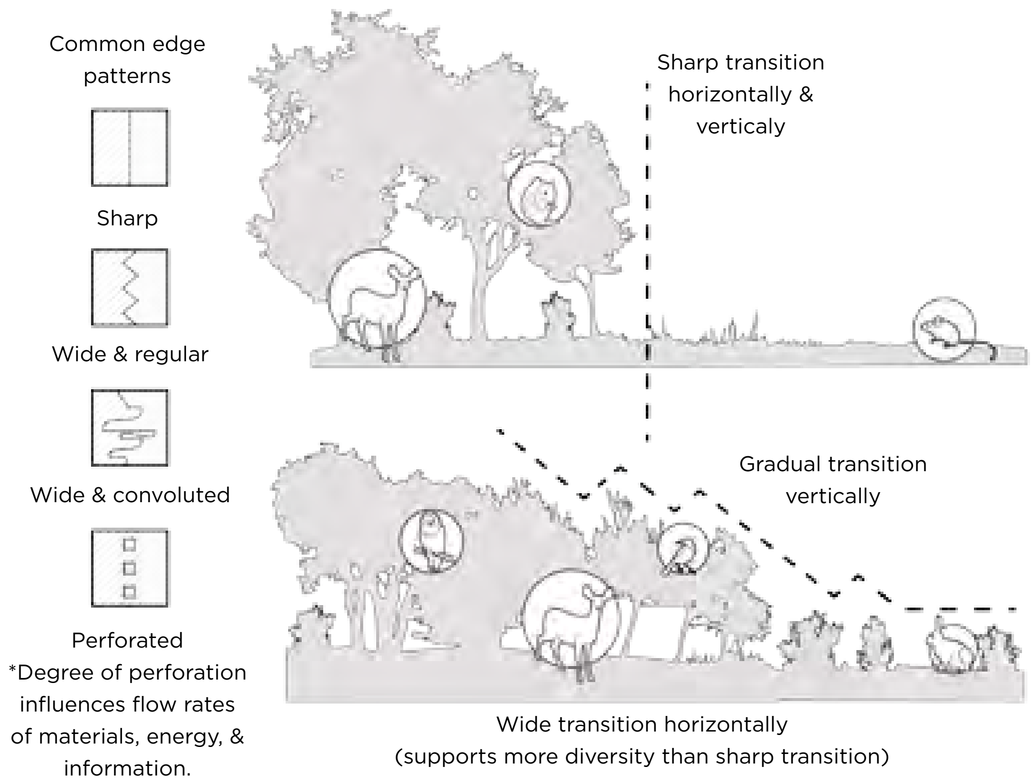
Redundant or multiple systems service a city



design a well-functioning system

ecotones

Ecotones support tremendous diversity and species interaction, and create robust systems capable of buffering disturbance.



nature’s design

ecotone fosters social diversity

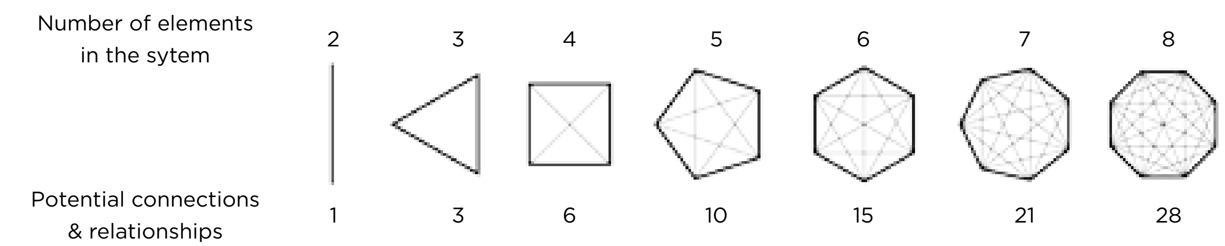
An example of an ecotone, or edge, is the transition between a wet meadow system and a drier upland wooded system. Such meadow-forest edges are rich, diverse habitats where species interact. The complexity and interdependency of relationships in ecotones, as well as the physical structure of the transition zone, result in an accumulation of energy, materials, and information, providing food, mates, communication, and shelter.

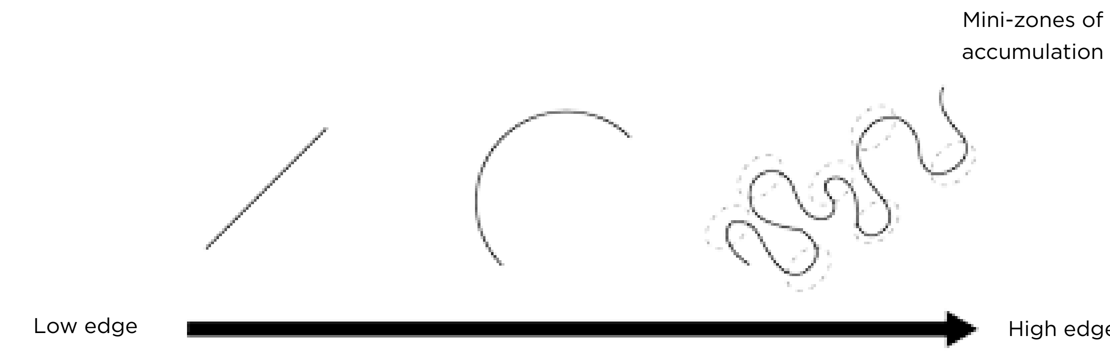
Horizontally, the ecotone transition can be narrow (a sharp change, as in a forest abutting an agricultural field), or it can be wide (gradual change, as in natural meadow to forest transition). Vertically, ecotones show transitions in vegetation height from grasses and herbaceous ground cover in the wet meadow to woody shrubs and herbs with variable soil moisture, to dry upland canopy species in the forest.

The degree of “perforation” in an ecotone inhibits or enhances dispersal of energy, materials, and information across the edge. For example, an expansive patch of brambles inhibits dispersal, whereas a large tree fall or flowing stream create space and enhance dispersal; a wet meadow to upland forest can buffer flood damage or resource depletion resulting from prolonged drought.

The greater the contrast between transitions, the more robust and diverse is the ecotone. The wider the transition, the greater the capacity to support diversity and buffer disturbances.

- Ecotones are “hot spots” where organisms interact to get food, find mates, communicate, rest, and take shelter
- Ecotones are diverse, robust systems
- Perforation in an ecotone inhibits or enhances the flow of material, energy, and information
- Ecotones help the ecosystem buffer disturbances





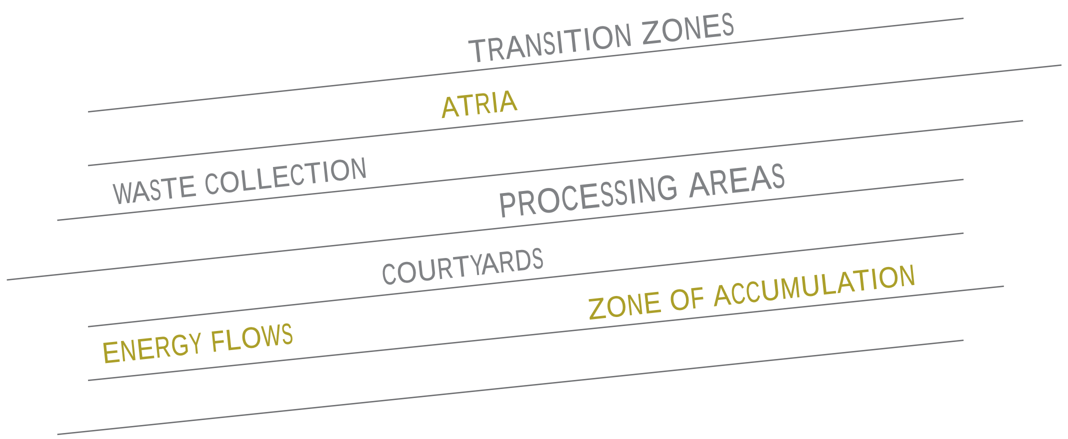
design principle

transition areas within a community foster social diversity

Transition zones represent opportunities to leverage and optimize diversity and interconnectedness. The two main elements that contribute to a robust and resilient edge system are its physical structure and highly interconnected, interdependent relationships among its users. Edge systems with wide transitions between different environments support higher diversity and have a higher capacity to absorb disturbance. The greater the differences between transitioning environments, the higher the potential for a rich edge system. Adjusting the degree of open areas within the transition zone will influence the rate and ease with which energy, materials, and information will flow.

Other related design principles:

- Edges are zones where materials, energy, and information accumulate
- Edges support diversity because it is easy to find resources that meet needs for survival and wellbeing
- Wide transition zones are more robust and resilient than sharp transition zones
- Adjusting “perforations” in a transition zone influences rates of material, energy, and information transfer
- Highly interconnected relationships result in robust transition zones



BaDT brainstorm

design ideas

Application Ideas

- Identify transition zones within a building and/or group of buildings. Examples may include entry ways or atria, waste collection/processing areas, laundry areas, elevator/stair corridors, plazas, courtyards, parking zones, shipping and receiving areas, etc. Each of these represent an opportunity to direct the flows of energy, materials and information in ways that increase interactions and connections among building users.
- Integrate the "back building" activities (waste, laundry, shipping/receiving) with "front building" activities to create opportunities for users to interact in new ways, and have access to new information (which may change behaviors and consumption patterns).
- Create a seamless transition between inside and outside of a building, and between buildings. This can involve transitions within the structures themselves, but can also integrate a landscaping component to help connect different "environments."
- Use concept of increasing edge to create "zones of accumulation" where material, energy, and information can accumulate in ways that give people greater capacity to meet their needs (food, water, rest, communication, etc.) in non-traditional ways.

TRANSITION ZONES

Park open space as transition zone increases interactions + connects

PARK / OPEN SPACE
AS TRANSITION
ZONES THAT INCREASE
INTERACTIONS + CONNECTIONS

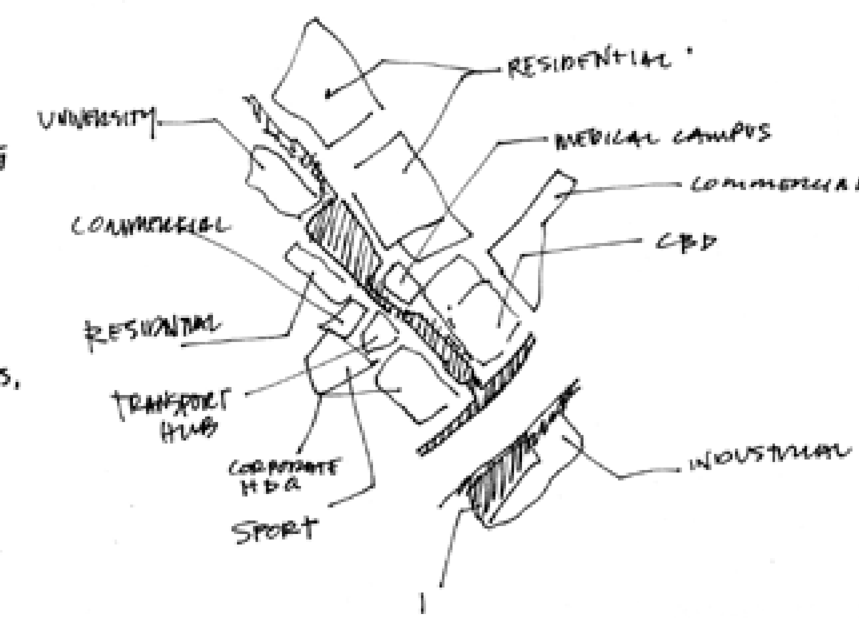
SEAMLESS TRANSITION

ZONE OF TRANSITION
BETWEEN DIVERSE
PROGRAMS _ LINKS
THEM BY ADDRESSING
THEIR NEEDS ALONG
ITS EDGE

PARK AS 'HOT SPOT'
OF ACTIVITY WHERE
PEOPLE 'INTERACT'
TO GET FOOD, FIND MATES,
COMMUNICATE, REST, ..'

HIGHLY PROGRAMMED
OPEN SPACE

ECOTONE PARK



BUFFERS DISTURBANCES
SUCH AS FIRE

REGENERATION OR OPENNESS

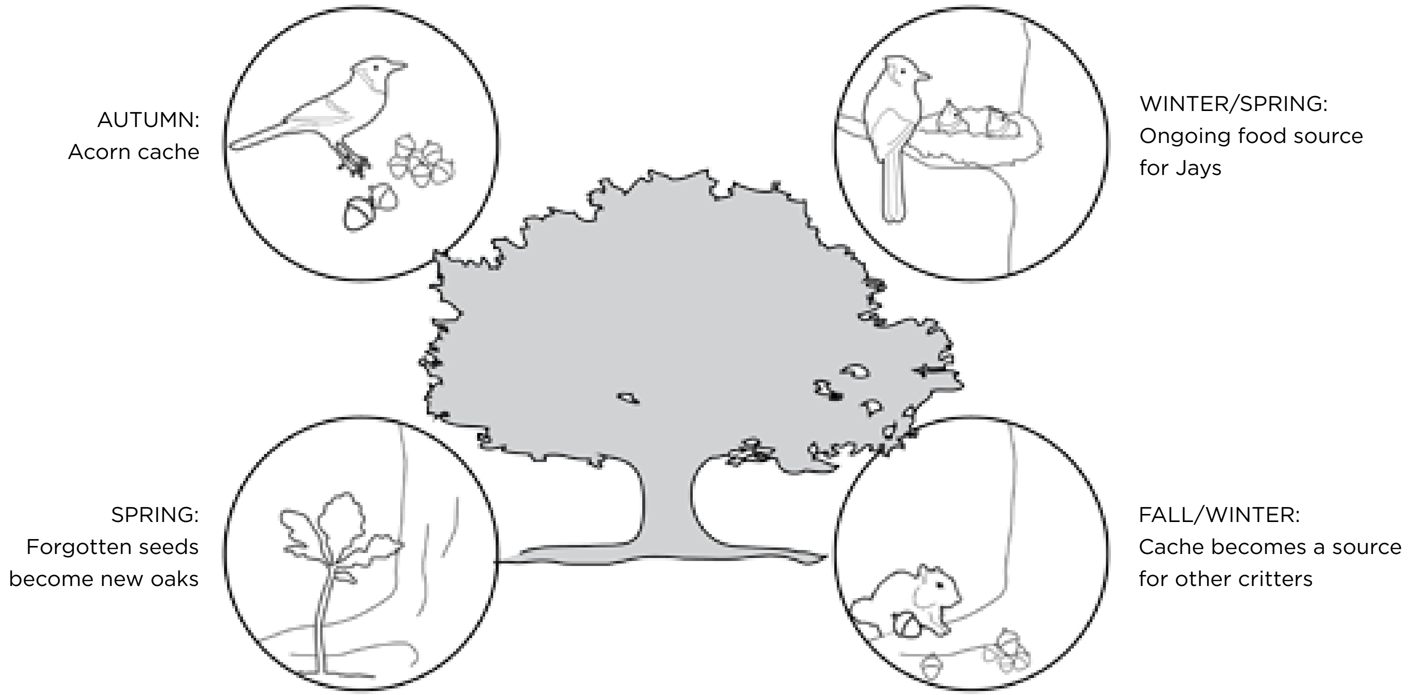
BRINGS DIVERSE SYSTEMS
TOGETHER

INTERDEPENDENT RELATIONSHIP
FOR DIVERSE USERS.

foster cooperative relationships

jay and oak

Blue jays and pin oaks have a cooperative relationship that not only enhances the survival of each but also provides increased opportunity and benefits to the ecosystem as a whole.



nature's design

cooperative arrangement enhances social networks

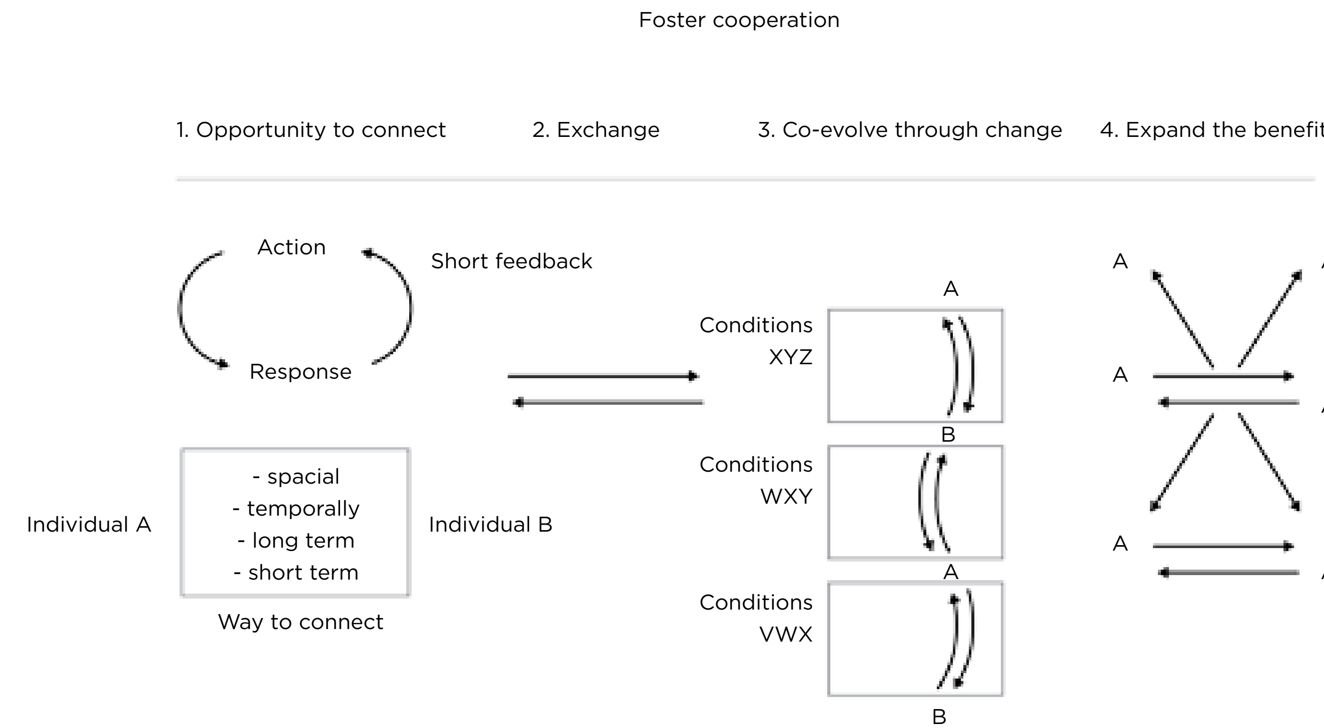
The jay is a common inhabitant of the temperate forest that benefits from its association with oak trees. The jay collects acorns and caches them underground near its nest for consumption through the winter and spring. Caches are often along gap edges (mini-ecotones) because they are easy to rediscover.

Jays are efficient seed collectors. In one study, 50 jays were estimated to transport and cache 150,000 acorns from 11 oak trees over 28 days, carrying the seeds up to 22 km away from the parent tree. Because jays can be forgetful, some acorn caches are left undisturbed and the seeds germinate into new oak trees.

This relationship benefits the oak not only because its seeds are being widely distributed, but also because the jays are masters at selecting the best acorns (the highest nutrition for themselves and their young), which means the most fit seeds have the greatest chance of carrying on their genes.

Mutualistic relationships play a critical role in moving energy and nutrients across ecosystem borders and thus have a large impact on the structure and function of those systems. Likewise, this relationship benefits many other species, such as increased habitat and a food source for creatures such as rodents that raid jay caches.

- Mutualistic interactions benefit both organisms
- Blue jays and oaks both derive direct benefits from being in association
- The relationship results in increased fitness for both species
- Additional benefits from the alliance are realized by myriad other species
- The cooperative relationship influences the overall structures and functions of the ecosystem



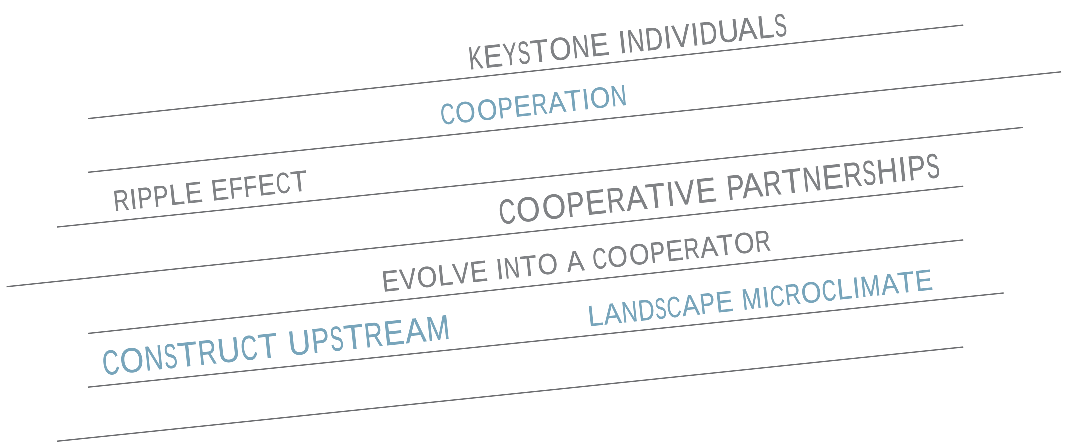
design principle

mutualistic relationships enhance social networks

Cooperation works because both individuals in the relationship experience enhanced chances of survival, which means that there is double the incentive to support the behaviors and actions that result in that benefit. At some level, both parties must be cognizant of the benefits of working together. Interestingly, the benefits gained are generally different for both parties. In order to foster cooperation, the following conditions must be met: 1) potential cooperators must be able to connect—this is accomplished through increasing the number of ways they can connect and keeping short feedback loops (i.e., information flows), 2) the benefits must be exchanged and realized, 3) the relationship co-evolves over time while adapting to changing conditions, and 4) the higher the multi-functionality of the relationship—the more benefits it creates for the greatest number of other individuals—the higher the likelihood that relationship will persist over time. Highly successful cooperative relationships between keystone individuals define the structure and function of a system and also how resources and energy move through it.

Other related design principles:

- Foster interaction between different groups to increase survival and success
- Avoid competition (expensive and lose-lose for both parties) to conserve resources and relationships
- Enhance system dynamics to foster cooperation
- Cooperation enhances adaptation to changing conditions over time



BaDT brainstorm

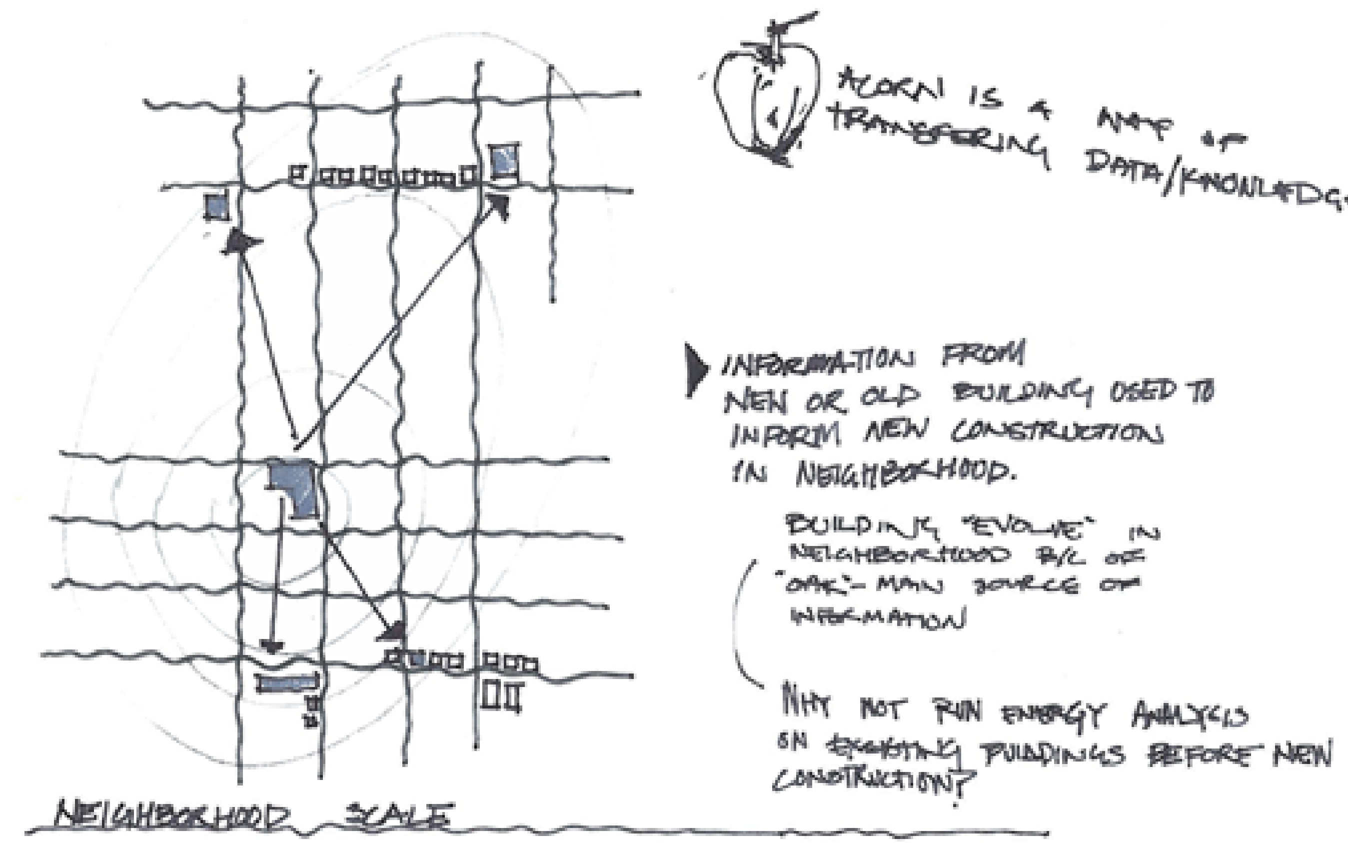
design ideas

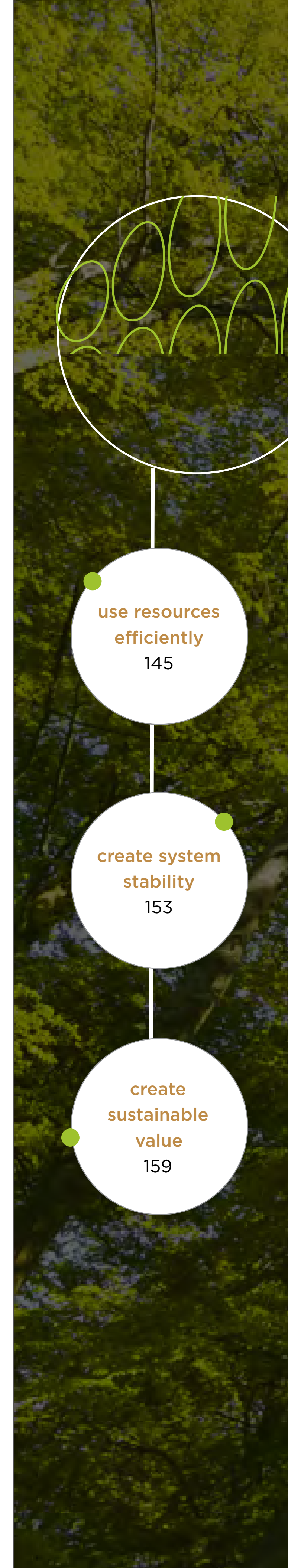
Application Ideas

- Identify "keystone" individuals, businesses, and/or industries operating within a building or within a development and encourage their cooperation (reference the four mechanisms of cooperation in this entry's Design Principle text). The exchanges of these entities will likely have beneficial ripple effects for the whole community.
- Similarly, HOK can identify other keystone entities in the architecture industry and consider what kind of cooperative partnerships could emerge; this could be especially powerful if an entity viewed as a competitor could evolve into a cooperator.

NEIGHBORHOOD EVOLUTION

Information from old building used to inform neighborhood





ECONOMIC

Economics describes the flow of goods and services that create the potential for people to meet their needs. Humans use monetary capital to facilitate these transactions. Nature uses relationship capital. This is an interesting juxtaposition to consider when it comes to evaluating “the bottom line,” and what the non-negotiable break-point is. What would our economic transactions look like if relationships, not money, were the bottom line? How can relationships be leveraged to meet needs without a requisite transaction of money?

Organisms’ relationships to each other and to the resources they need to survive determine their success. Competition and rapid use of resources can be effective ways for a species to get established, especially after a disturbance, but in the long term this is a very expensive and wasteful mode of action. The rate of resource use has the greatest implications for maintaining that resource and for cultivating its long-term value. Cooperation and interdependence are the least expensive means of transacting.

Project management is connected to economics, and represents how materials, capital, time, and individuals are utilized during the period of transition from one system state to another. In nature, this process is called succession. This section includes one entry that describes the mechanisms of succession as a model for project phasing and arriving at some desirable future state. Succession in nature can help us plan for potential disturbances in projects, and appreciating limitations as opportunities for creative abundance through cooperative relationships. More explanation about the various succession models are given in the notes in the appendices.

- incorporate succession
- create diverse structures
- sustain value with limits

ECONOMIC

LIFE'S PRINCIPLES

REFERENCE THE DEFINITIONS

EVOLVE TO SURVIVE
Integrate the unexpected
Learn from unexpected disturbance events and take advantage of resources that result from the disturbance

INTEGRATE DEVELOPMENT WITH GROWTH
Self-organize
Be responsive to levels of resource availability to concentrate on development as well as growth

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT:
Find the limiting resource and tailor projects to prevent overconsumption of that resource

BE LOCALLY ATTUNED AND RESPONSIVE
Use readily available materials and energy
Start slowly and set the stage for efficient use of resources by developing cooperative relationships

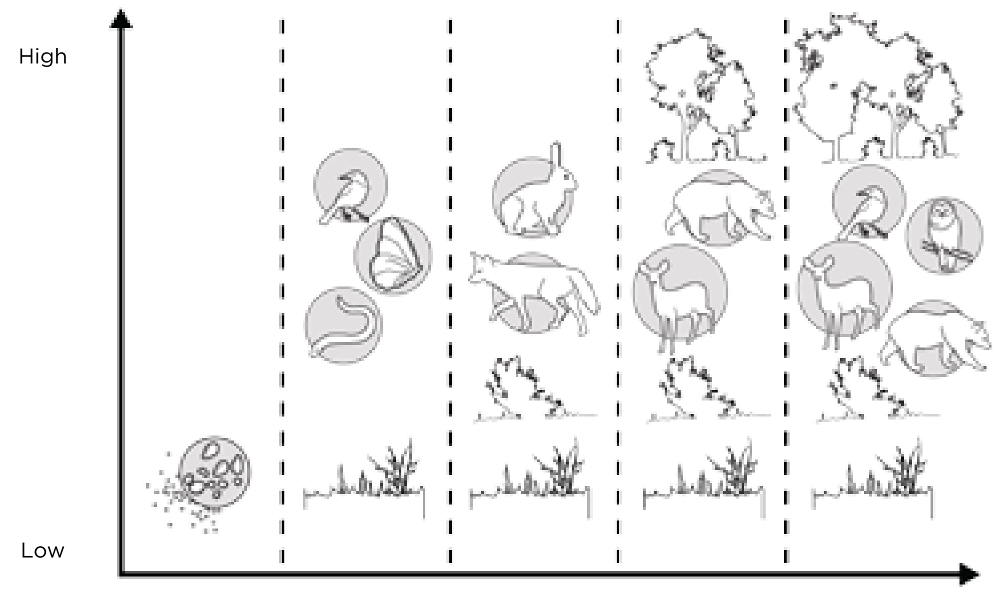
ADAPT TO CHANGING CONDITIONS
Embody resilience through variation, redundancy, and decentralization
Incorporate variation to lessen chances of future disruption in services

USE LIFE-FRIENDLY CHEMISTRY
Break down products into benign constituents
During development and growth, capture waste material and use it as a resource for future stages

use resources efficiently

ecosystems

Ecological succession moves ecosystems through phases of development, including pioneering bare soil and responding to resource availability and changing conditions over time.r



nature's design

succession phases development

Ecological disturbances disrupt ecosystem, community, or population structure, and change resources available. After disturbance, ecosystems respond following one or more models of succession.

In the classic linear model of succession, pioneer species colonize bare soils, producing nutrients and habitat suitable for the next stage of succession. In turn, these species produce organic matter and are colonized by mutualistic, nitrogen-fixing mycorrhizae. Soil nutrients and seeds accumulate in the soil, acting as biological legacies available to restart succession after future disturbances. Succession arrives at a climax of highly adapted species that replace themselves.

The relay floristics model suggests that pioneer species modify the environment of bare ground and create conditions for the next group of species, which in turn modify the environment. The initial floristics model occurs following minor disturbances; nearly all species that will ever be present in the soil seed bank already exist there (biological legacies), but only grow when the conditions are right.

The adaptive characteristic model describes three strategic adaptations of plants. Short-lived species colonize environments with plentiful resources and allocate most of their energy and resources to reproduction, not growth. Competitor species devote themselves to resource gathering, storing just enough energy and resources to flourish the next year and then aggressively consuming as much space as possible, exhausting resources. Stress-tolerant species are adapted to limited resources and invest in self-maintenance and cooperative relationships. They can absorb and store nutrients when not growing, and eventually replace competitors. For more information, see Notes.

Factors influencing the extent and severity of disturbance events are:

- Location of biomass reserves (above or below ground) at time of disturbance
- Resource base
- Niche strategies of species (how they respond to disturbance)
- Relative competitive abilities
- Landscape characteristics
- Scale

Linear succession model

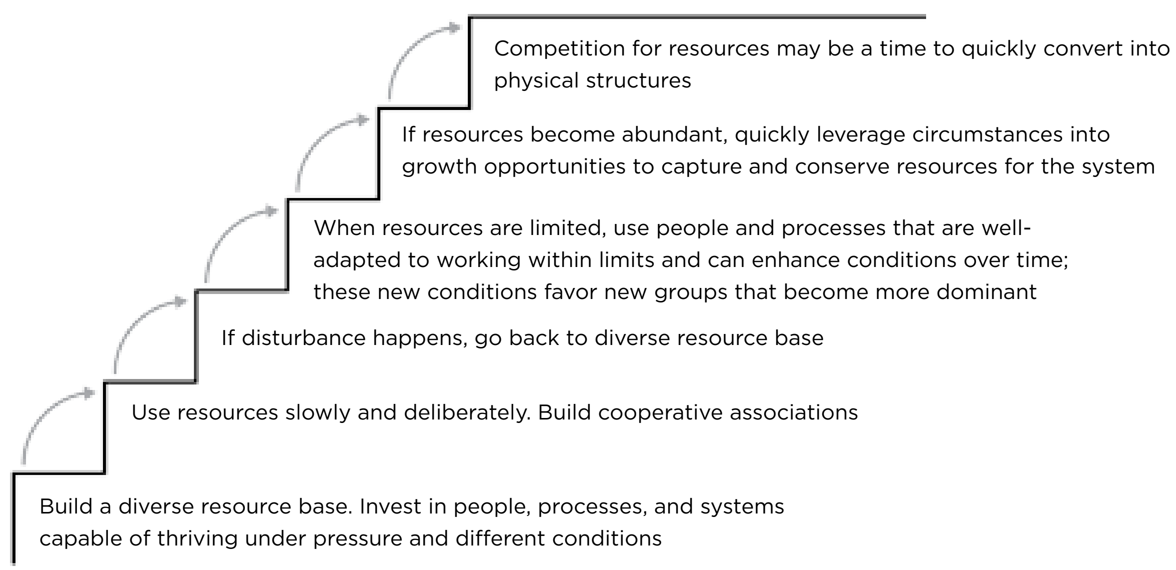
- Is a directional and predictable progression from a pioneer stage to a stable and self-replacing climax

Relay and floristics succession models:

- Describe mechanisms of vegetation change over time

Adaptive succession model:

- The adaptive mechanisms of a plant determine its optimum role
- Barren soil is colonized by pioneer species such as bacteria, algae, lichen and moss
- Next, grasses and herbs grow, producing soil fertility
- Soil mycorrhizae arrive and form mutualistic relationships with plants
- Plant species diversity increases, along with a seed bank ready to be drawn from
- Highly adapted species create a stable system

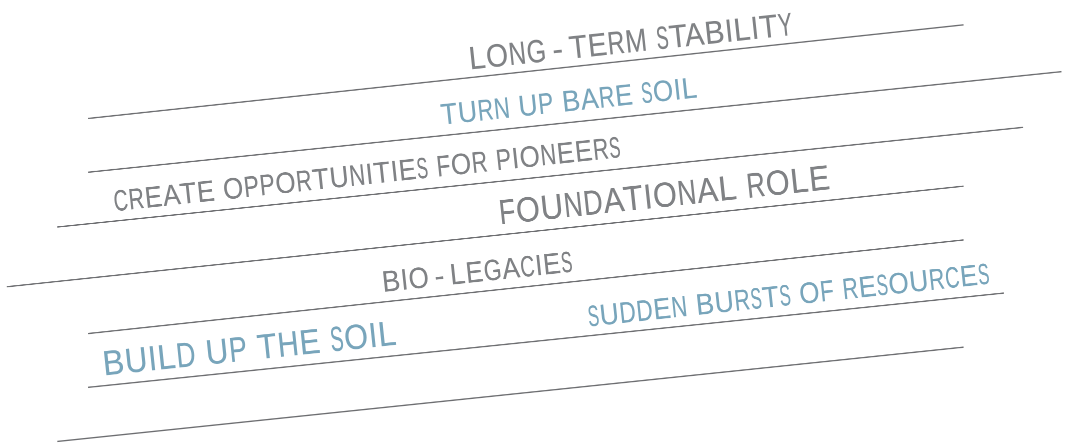


design principle

plan for efficient use of finite resources

- How efficiently and effectively a project grows or responds to disturbance depends on having a diverse resource base, resources distributed throughout the system, investment in legacy strategies, and people, processes, and systems capable of thriving under different pressures and conditions.
- Skipping important stages of development, especially foundational stages that create a system's long-term resource base, can reduce overall productivity and system stability. Slow and deliberate use of limited resources in early stages results in more long-term cooperative associations than a fast and indiscreet use of resources. The latter, based on an inaccurate representation of actual resource capacities, can actually reverse or slow progress.
- Where resources are limited, a project can include people and processes that are well adapted to working within limits, and can enhance conditions over time. These new conditions favor a new group of individuals or processes that shift into a more dominant role.
- A project could bring together all of the people and processes that will at some point have a role to play. The prevailing conditions at any given time determine which will be the most active change agents.
- If resources are abundant, a phasing process that can quickly leverage circumstances into growth opportunities can capture and conserve resources for the system.
- Competition for resources can play an important role in establishing a presence by quickly converting resources into physical structures. If left unchecked or unbounded, this could exhaust resources within a short time.
- Under stable circumstances where most of a system's resources are already bound up in infrastructure, processes that foster cooperative relationships have the greatest advantage, finding or creating opportunities to accumulate resources even during periods of no growth

Other related design principles:
- Adaptive characteristics of individuals determine optimum roles
- Functional and response diversity increases ability to respond appropriately
- Mutualistic relationships lead to success
- Maintaining resources contributes to long-term sustainability
- Create resource foundations that contribute to the next stage of planning
- Invest in legacy strategies to improve performance and resilience to disturbance
- Key, slow variable sets the pace for change
- Adaptive roles determine which species flourish under various conditions
- Elements build conditions for net phase
- Disturbances are integral part of determining appropriate adaptive response



BaDT brainstorm

design ideas

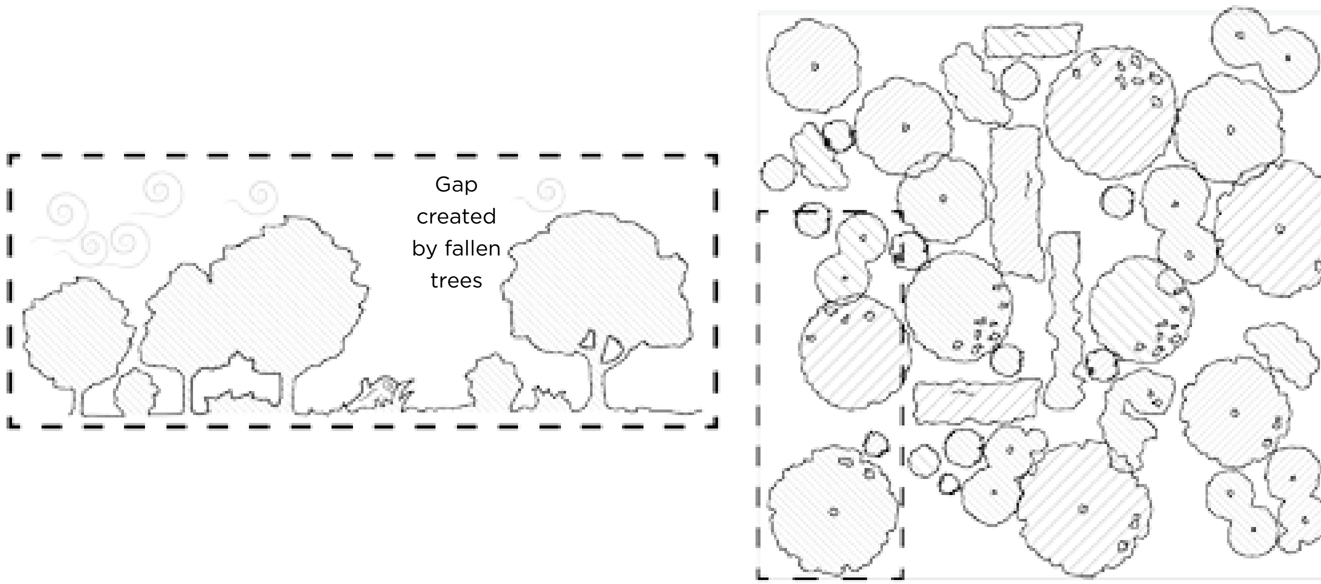
Application Ideas

- Build as resources become available and with value-producing buildings going in first; that creates short-term yields that support long-term stability.
- Metaphorically, consider whether your actions or decisions are continually turning up bare soil, forcing the system back to early stages of development and encouraging “weeds” to get established. That may be desirable if you’re trying to create opportunities for new pioneer individuals to enter the project, but detrimental if you’re trying to move forward.
- Identify key pioneer individuals or elements that should be responsible for creating, storing, and cycling resources in the early phases of the project. Encourage conditions that allow them to function well and recognize that they play a foundational role for long-term project success.
- What “bio-legacies” or inheritances could HOK invest in, both as a whole company and on a project-by-project basis? This idea of a bio-legacy is essentially any strategy, practice, or management technique that makes the system less susceptible to major setbacks in the face of minor disturbances (in this case, that may be changes to the budget, sick employees, a trade embargo on an exotic building material, etc). The legacies for any given project may differ from one to the next, as they are often context dependent
- Literally, when doing green space planning, phase landscaping to first build up soil by planting pioneer species, then phase to grasses and herbs, etc.

create system stability

forests

Diverse structures form in response to abiotic disturbances, resulting in an overall structure that creates a more resilient system.



nature's design

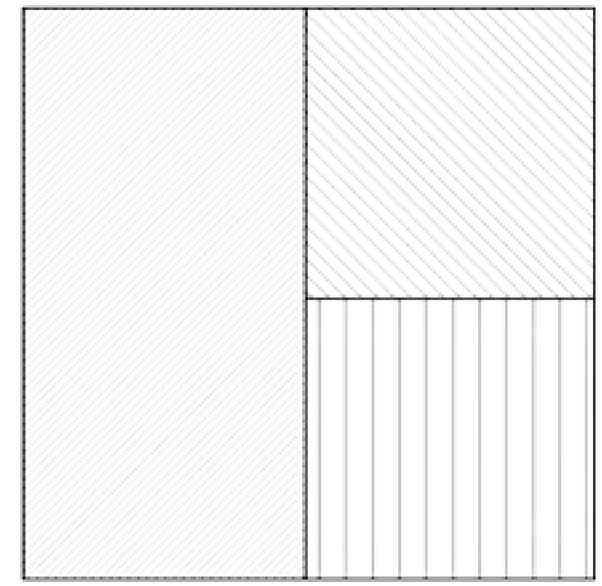
diverse structures mitigate disturbance

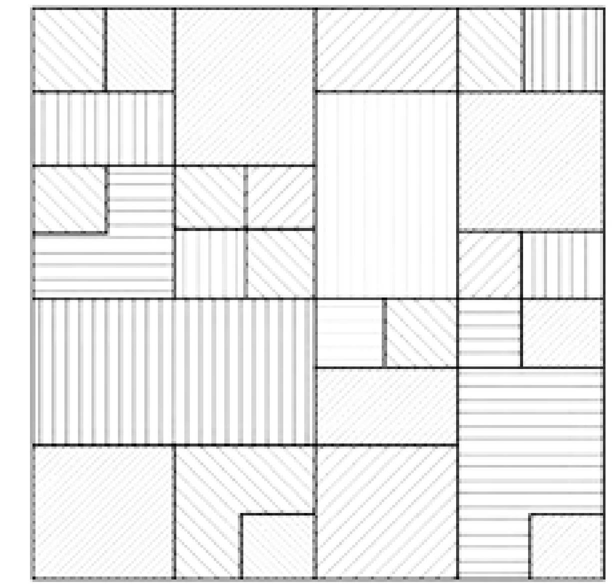
Forests are subjected to many disturbances including insect attacks, fire, ice storms, herbivores, severe thunderstorms, tornados and hurricanes. Individual trees are sometimes weakened, killed or toppled. Whole stands of trees can be destroyed. Native trees and forests tend to be more resistant. Fallen trees create opportunities for plants and animals to gain resources such as sunlight, stirred up soil, decayed wood; the tree itself becomes part of the process, adding nutrients and holding water. Groups of trees provide protection downwind for other trees and trees on the outside of a patch protect inner trees. The result of disturbance is a mosaic of habitat patches rather than a uniform forest.

A patchy forest is made up of a variety of species, spacing, ages, heights, densities, and stages of succession. Combined with equally diversified abiotic elements such as soil types, topography and microclimates, the forest becomes more resilient.

Scaling: Tree roots link together, trunks thicken and fallen trees become habitat for other organisms. At the forest scale, such adaptations, combined with fallen trees, create a heterogeneous pattern which itself becomes more resilient and resistant to disturbances. At the ecosystem level, a heterogeneous structure creates more resilience to disturbances.

- Native trees and forests are adapted to local disturbances
- Trees exhibit adaptive growth to strengthen against wind
- Tree roots interlock providing mutual support against wind
- Gaps created by fallen or broken trees increase species diversity
- Ecosystem pattern of different densities, species, ages, increases resiliency.





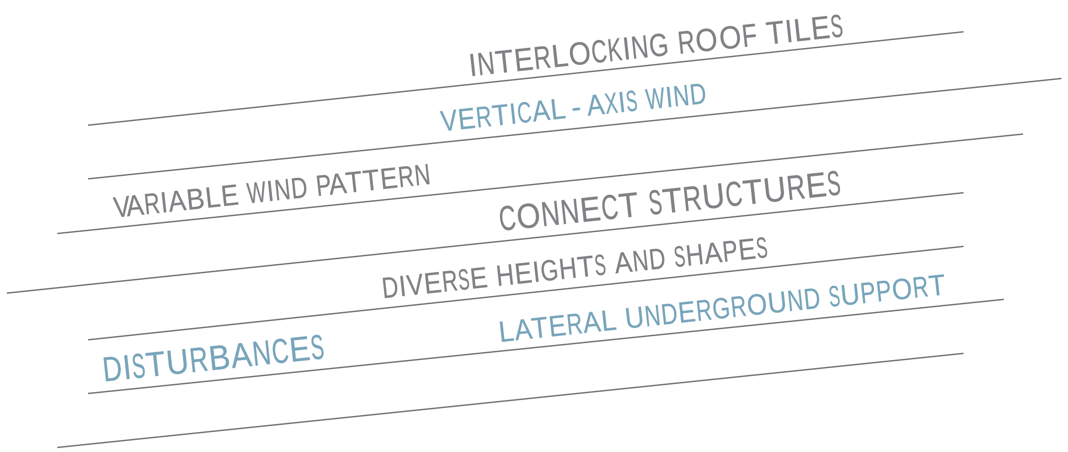
design principle

variety of structures/responses provides resilience after disturbance

Diversity in physical structures results in a variety of responses to disturbances. The same is true of a diversity of services provided within a system. When structures and services are homogeneous, the chances increase of some sort of disturbance causing widespread harm and difficulty recovering. A diversity of structures and services, on the other hand, serve to create a more resilient system.

Other related design principles:

- Disturbances create opportunities
- Holistic response provides resilience
- Deep, wide, flexible, interlocked footings and added material provide stability



BaDT brainstorm

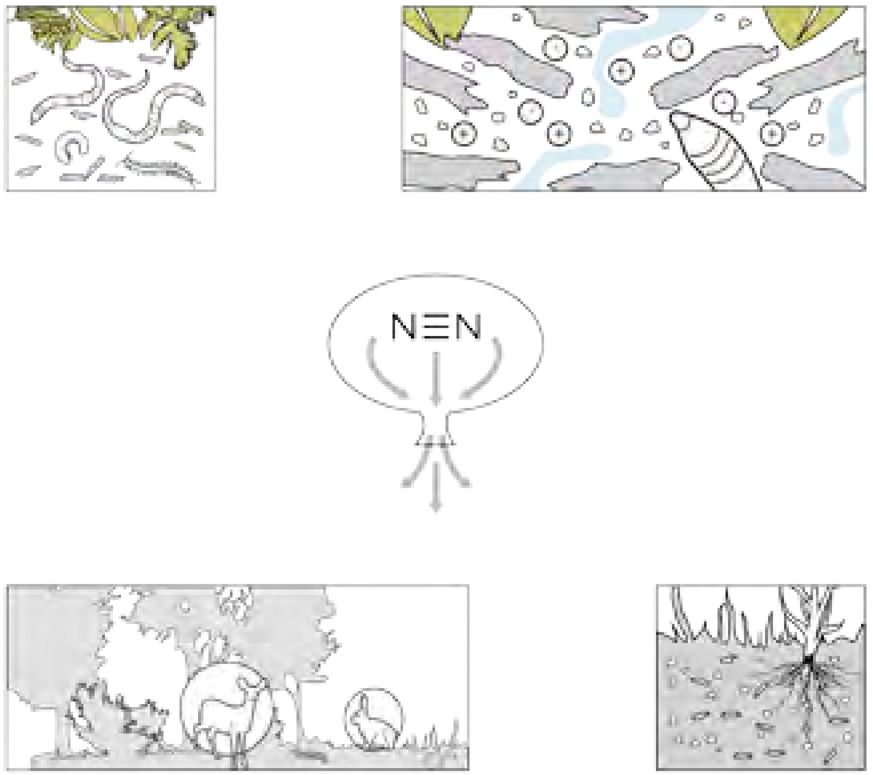
design ideas

Application Ideas
- Incorporate variation into designs to lessen the chances of future disruptions in services.
- Design to create multi-functional products, processes, structures, and infrastructure.
- When an unexpected event occurs, find value in it, from learning lessons for the future to taking advantage of resources made available.
- Look for opportunities to connect structures and communities with others for mutual benefits. This can be literally (as in underground connections between buildings or bridges between buildings) or metaphorically (as in neighborhood parties, traffic structures, etc.).
- Create community-wide diversity in structure heights, shapes, and materials, and in sources of community services (e.g., water, waste removal) to provide resiliency in the face of different types of disturbances.
- Design structures subject to wind damage, such as streetlights, bus shelters, and power poles, to have deep, flexible footings with lateral underground supports in bracket shape on the leeward side.
- Design roofing tiles to be interlocking.
- Use vertical-axis wind turbines in densely populated areas with variable wind patterns.

create sustainable value

organic soil

Organic matter in the soil moderates renewal rates for nitrogen, which is the key-slow variable in the forest biome.



nature's design

limit-based value system sustains value

Plants, organic matter and soil organisms create fertile soil. But it is the limitation of nitrogen that maintains fertility. In other words, the forest maintains its resources by growing within the limits of a key-slow factor—in this case, nitrogen.

Organic matter is formed as a result of the decaying process of once-living organisms. The primary broker is the organic matter that determines which, and at what rate, bio-geo-chemical processes function. Organic matter creates and stabilizes soil structure, maintains and regulates nutrient cycling, and provides habitat for soil organisms. Collectively, these processes create conditions conducive for plant growth.

Plants are the primary consumers of soil nutrients. Their rate of growth is regulated by the amount of nitrogen available in the soil. Nitrogen is thus a "key slow" variable that regulates the rate of growth based on the rate of nitrogen renewal in the system. Rates of nitrogen renewal are dependent on available organic matter and the activity of soil organisms. Because nitrogen is such a powerful limiting factor, all plants have evolved mechanisms to conserve nitrogen and to operate within a tight nitrogen budget.

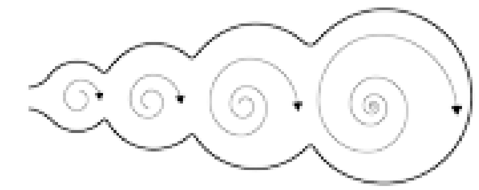
Scaling: This process occurs at the level of the individual plant species all the way through to the ecosystem level. The key-slow variable of nitrogen in soils is heavily influenced by agricultural, industrial, and urban ecosystems.

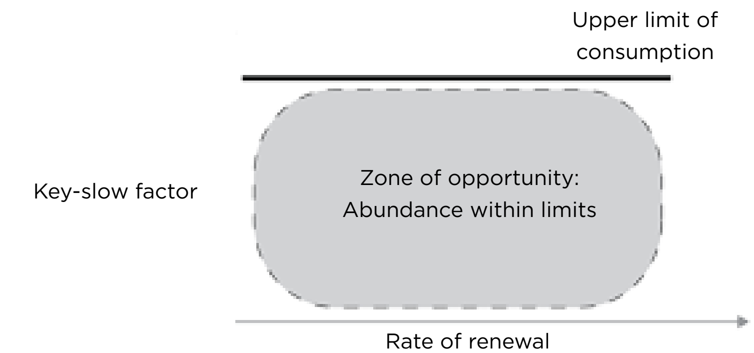
- Soil types typical of the temperate broadleaf forest are historically high in organic matter
- Organic matter in the soil is responsible for the soil's physical structure, its nutrient cycling capabilities and its capacity to support life
- Soil nitrogen is the key-slow variable that affects the rate of forest growth
- The quantity of organic matter in the soil is a key factor in rates of nitrogen renewal

Rates of Renewal

Interdependent processes can only go as fast as the slowest process will allow (like a system of gears)

Slow → Fast





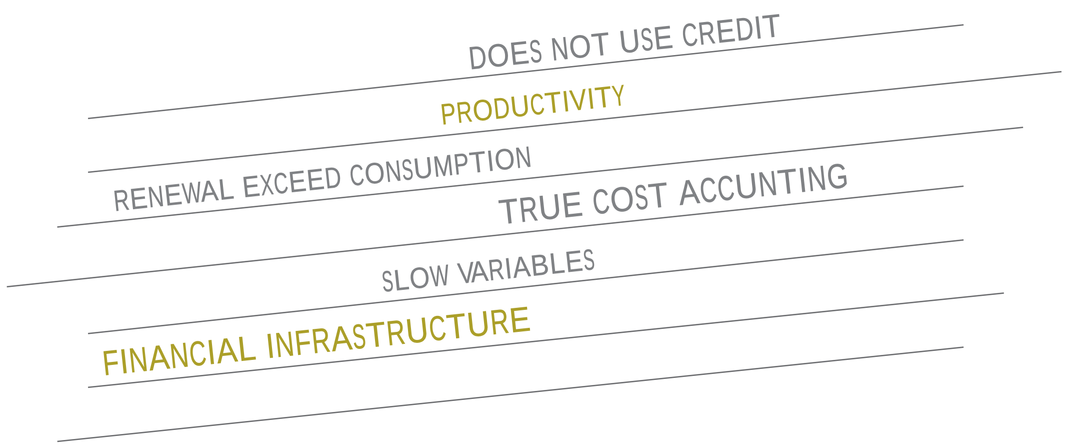
design principle

limits based on a key leverage point maintain value

Rate of consumption, not just amount of consumption, is a critical factor in maintaining resources. If the rate of consumption exceeds the rate of renewal, long-term deficits, imbalances, and systemic instability will result. The element with the slowest rate of renewal can be used to set an appropriate rate of consumption for all other resources, which are in some way linked to that slowest element. The mechanism that is responsible for renewing the slowest element is often a key leverage point in the system, and as such should be cultivated, conserved, and protected. Limitations like key-slow variables are not meant to be "overcome," or "gone around," which are actions that have consequences similar to excessive rates of consumption. Limitations are opportunities for creative abundance through cooperative relationships.

Other related design principles:

- The factor with the slowest rate of renewal defines appropriate rates of consumption for all other resources
- The primary mechanism responsible for mediating the key-slow variable should be cultivated, conserved, and protected
- Limitations provide the opportunity for creative abundance, which is most effectively achieved through interdependent, cooperative relationships



BaDT brainstorm

design ideas

Application Ideas

- The role that soil organic matter and nitrogen play in overall biome productivity illustrates what nature DOES NOT do. Nature does not use credit. Credit is essentially a mechanism that allows a rate of consumption to exceed the rate of renewal.
- Look for ways to affect the financial infrastructure of the building(s) so that use of credit is avoided. Are there ways to foster economic transactions for the users, managers, and builders that does not rely on credit? True-cost and real-time accounting is one method. Trade and barter is another.
- A mechanical application of this strategy is to identify the key, slow variables in mechanical systems. Is it water? Energy? Maintenance? Equipment? Think not only in terms of immediate building needs and performance, but also overall patterns in resource availability and consumption/renewal rates. Design mechanical systems that work within the limits of this factor, and that cultivate, conserve, and protect it. This process of inquiry may lead to solutions that solve multiple problems with a single solution, including energy, water, material, social, and economic concerns.
- Literally, use organic and regenerative practices in landscaping to build up organic matter in the soil around the site, and create or restore natural nitrogen cycling processes by mimicking the structure-function relationships of native temperate broadleaf biome species. Use income from the building(s) to support soil conservation and restoration in a nearby area. By investing and re-investing in these natural systems, over time you build capacity to draw from these resources (at an appropriate rate) for building materials, social capital resources, etc.

APPENDICES

TEMPERATE BROADLEAF FOREST

notes

ECONOMIC

USE RESOURCES EFFICIENTLY • ECOSYSTEMS

Succession was first described in the early 1900s as a directional and predictable progression from a pioneer stage to a stable and self-replacing climax. This linear theory of succession has since given way to more dynamic and cyclic theories, but many of the observations proposed over 100 years ago remain relevant today. This appendix describes some of the succession models that are represented in the Temperate Broadleaf Forest.

Ecological disturbance is defined as “any relatively discrete event in time that disrupts ecosystem, community, or population structure, and changes resources, substrate availability, or the physical environment.” Disturbance is an inevitable, inseparable element of all succession models—disturbance stimulates succession. Various factors influence the extent and severity of disturbance events, including: location of biomass reserves (above or below ground) at time of disturbance, resource base, niche strategies of species (how they respond to disturbance), relative competitive abilities, landscape characteristics, and scale.

While every disturbance can have negative impacts on individuals, because it also stimulates larger successional processes, mild to intermediate disturbances can have an overall beneficial impact on the health and vigor of the ecosystem. Indeed, research suggests that species richness is greatest in communities that experience an intermediate level of disturbance.

The largest scale disturbances in the temperate broadleaf biome are fire, ice storms, tree fall gaps and blow-down, insect attacks, and human development and resource exploitation.

Application Ideas for Disturbance and Succession

- We are not suggesting that one purposefully introduce disturbances into the project management process; rather we are suggesting that inevitable disturbances in the project management process be taken into account. That is, consider what kind of disturbances might occur in a given project, how bad might these be, and what systems are currently in place (or could be developed) that would allow a team to respond effectively. These disturbances could include changes to project funding, staffing changes, timeline modifications, permitting issues, land use conflicts, trade embargos, etc. Adopting strategies that distribute resources throughout the system (avoiding all eggs in one basket), fostering a strong resource base, and encouraging individuals that thrive in varying levels of “chaos” will help support a strong response strategy.
- As mentioned in the description, an intermediate level of disturbance on a regular basis has the potential to create “species richness,” which in this case could translate to “inter-disciplinary richness,” because that much disturbance would demand a diverse team of individuals working together to problem-solve, adapt, and advance. That much disturbance would probably be counter productive to a team’s efforts, but proceeding as if that’s how it was going to be could result in an extremely robust system.

Linear Model of Succession

In the linear model, succession begins when pioneer species colonize barren soils. Pioneer species include bacteria, algae, lichen, and moss. These species produce nutrients and habitat suitable for grasses and herbs to become established. Grasses and herbs produce organic matter that further improves soil fertility and prevents nutrients from leaking out of the system.

notes

As the diversity of plant species increases, nitrogen-fixing microorganisms called mycorrhizae colonize the soil and develop mutualisms with plants. Soil nutrients and seeds in the soil accumulate. These resources can be drawn on to stimulate succession after a disturbance. The seed bank acts as a biological legacy that influences the pace and pattern of succession.

In the linear model, succession arrives at a climax, or end point, of highly adapted species that continually replace themselves, resulting in a stable system where the character of the plant community remains largely unchanged over time. That is, unless a disturbance occurs that sets succession back to the beginning.

Application Ideas for Linear Model

- Build as resources become available and with value-producing buildings going in first; that creates short-term yields that support long-term stability.
- Metaphorically, consider whether your actions or decisions are continually turning up bare soil, forcing the system back to early stages of development and encouraging “weeds” to get established. That may be desirable if you’re trying to create opportunities for new pioneer individuals to enter the project, but detrimental if you’re trying to move forward.
- Identify key pioneer individuals or elements that should be responsible for creating, storing, and cycling resources in the early phases of the project. Encourage conditions that allow them to function well and recognize that they play a foundational role for long-term project success.
- Tie rate of project development to resource availability (money, work force, time, materials, client buy-in, etc). Are available resources “released” into the project at rates that represent their long-term availability/renewability, or are there sudden bursts of resources that may paint a false picture of long-term capacity? The most important resource to watch is the most limited one. Is there a way to pace the key resources?
- What “bio-legacies” or inheritances could HOK invest in, both as a whole company and on a project-by-project basis? This idea of a bio-legacy is essentially any strategy, practice, or management technique that makes the system less susceptible to major setbacks in the face of minor disturbances (in this case, that may be changes to the budget, sick employees, a trade embargo on an exotic building material, etc). The legacies for any given project may differ from one to the next, as they are often context dependent

Literally, when doing green space planning, phase landscaping to first build up soil by planting pioneer species, then phase to grasses and herbs, etc.

Relay and Initial Floristics Models of Succession

Another two models of succession are relay floristics and initial floristics. These models describing mechanisms of vegetation change over time.

The relay model suggests that the actions of pioneer species present in a grassy meadow create conditions favorable for shrubs. As the shrub community is established, changing dynamics make shrub growth possible but make the environment unfavorable for species in the grass community; grasses gradually die-off. Dominance is passed like a relay baton to shrub species. Over time, the shrub community will alter the environment in a way that favors a tree community, inevitably “passing the baton” once more, shifting the dominance away from shrubs and towards trees.

The initial floristics model suggests that nearly all species that will ever be present in the habitat already exist in the soil seed bank, but only grow when the right conditions are present. These biological legacies of seeds in the soil define the composition and character of the successional pathway. As environmental conditions evoke the growth of certain plants, those plants slowly change the character of the system and create the opportunity for the next wave of plants to grow.

Relay floristics tend to occur more during the primary succession of bare ground, whereas initial floristics tend to prevail in established habitats that experience minor disturbances.

Application Ideas for Relay Floristics Model

- The type of architecture or planning project at hand can determine which model might be most useful. A project that is starting from scratch or introducing a significant departure from status quo may benefit from the relay model. This model may involve a larger input of resources and management, but it is orderly and direct.
- If a project is with a well-established client and/or is in a familiar area, the “initial floristic” model may be more relevant. It may take more time to arrive at a given objective, but the potential to create a flexible team responsive to changing conditions (for better or for worse) may pay off in the long run.
- Strategically blending both approaches would likely result in the most optimized team dynamics and use of resources.

Adaptive Characteristics Model of Succession

An adaptive characteristics model describes three strategic adaptations of plants: ruderal, competitor, and stress-tolerant types.

Ruderals are short-lived plants that allocate most of their energy into reproduction. Their seeds remain viable in the soil for long periods, which allows them to take advantage of random

notes

disturbances and other rapidly changing conditions. They spend little energy on resource gathering (root and shoot growth) because their ideal disturbed environments tend to have plentiful resources. They capture and hold nutrients by quickly generating a lot of organic matter.

Competitors have an adaptive advantage in areas where disturbance is less frequent. They devote themselves to resource gathering, with reproduction a secondary priority. Rapid growth quickly converts available resources into body tissue, but very little energy goes into building longevity into those tissues. They store just enough energy and nutrients to get going the following year and aggressively consume as much space as possible as quickly as possible. This can exhaust resources.

As more resources are bound up, there are fewer readily available resources. Plants that grow rapidly are now at a disadvantage. Stress-tolerant plants are adapted to limited resources and invest much of their energy into self-maintenance and cooperative relationships. They can absorb and store nutrients when not growing and eventually replace competitors.

Application Ideas for Adaptive Characteristics Model

- A given system, for example a building project, will likely be experiencing "pockets" of different conditions; that is, some aspects have been recently disturbed, others are growing/advancing quickly, and others are progressing slowly or have limited resources.

Understanding the distribution of "pockets" and the circumstances surrounding them can help determine which individuals (based on personality type and professional experience) are best suited to move the project into the next phase, or a more desirable phase.

glossary of terms

This glossary includes common words, phrases, and comparisons that we suggest may be useful in the Genius of Biome project. All are written from the perspective of biology, but can be extracted and applied to the design and engineering disciplines.

3.85 billion years –
the amount of time life has been on earth; the research and development period of life.

Abiotic –
not associated with or derived from living organisms. Abiotic factors in an environment include sunlight, temperature, wind patterns, and precipitation.

Arbuscule –
intricately branched, threadlike structures of fungi that penetrate plant root cells like a glove in order to trade nutrients in a symbiotic relationship.

Biodiversity –
the variety of life and its processes; it includes the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur.

Biologist at the Design Table (BaDT, pronounced "bat") –
a biologist uniquely adept at combing through nature's solutions and translating nature's strategies into strategies that effectively meet the needs of human challenges.

Biologize the design challenge –
take a human need or function and rephrase it so that an answer may be found in biology. For example, "How can I make the fabric red?" becomes "How is color created in the natural world?"

Biology to design –
the biomimicry approach to design that starts with discovering natural models and goes through the steps of abstracting the design principles, brainstorming potential applications, emulating nature's strategies, and evaluating the design against Life's Principles.

Biotic –
associated with or derived from living organisms. The biotic factors in an environment include the organisms themselves as well as such processes as predation, competition for food resources, and symbiotic relationships.

Bryophyte –
land plants that do not have true vascular tissues that transport water; mosses, liverworts and hornworts.

Challenge –
a specific issue or need that an organism faces, and a specific issue or need that humans face in their designs.

Design principle –
a deep principle from nature stated in non-biological terms.

Detritus –
non-living particulate organic material, including dead organisms and fecal material which act to decompose the material.

glossary of terms

Ecosystem –
a community of organisms and its nonliving, physical environment; a dynamic complex of plant, animal, fungal, and microorganism communities and their associated non-living environment interacting as an ecological unit.

Ecosystem engineer –
any organism that creates or modifies habitats by either mechanically changing materials from one form to another (e.g., beavers) or by modifying themselves (e.g., trees create habitat for other living things).

Ecosystem services –
benefits to humans from a multitude of resources and processes that are supplied by natural ecosystems, such as clean drinking water and processes such as the decomposition of wastes. Ecosystem services are divided into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits.

Ecosystem structure –
the physical patterns of life forms at all scales from the individual physiognomy of an organism to the vertical layers of vegetation to the horizontal distribution across the landscape.

Ecotone –
a transition area between two adjacent but different patches of landscape, such as forest and grassland.

Emulate –
to mimic deep patterns or principles rather than directly copy them.

Food web –
the complex network of interactions among species observed in nature that represent food relationships such as herbivory and predation.

Function –
the action for which an organism is specifically fitted or used, or for which a thing exists; purpose. The mode of action by which something fulfills its purpose. Also in generalized application, as contrasted with structure.

Functional taxonomy –
a function-based organization scheme exploring how organisms meet different challenges. Information on AskNature.org is organized by this taxonomy, also called the Biomimicry Taxonomy.

Habitat –
the natural environment or place where an organism, population, or species lives.

Key, slow variable –
a crucial, key element involved in a gradual change occurring in an ecosystem. The element can either act as a driver in the functioning of a system, or be involved in a process that produces a negative outcome such as the gradual rise in the salt-water table to the surface in agricultural lands. Some examples of slow variables include climate, land use, nutrient stocks, human values, and policies. Slow variables are difficult to track and detect and usually only recognized after a threshold has been crossed and large-scale ecological and social changes have occurred.

Keystone species –
a species that has a disproportionate effect on its environment relative to its biomass. Such species play a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community.

Life, nature –
interchangeable terms referring to biota and the community and ecosystems in which it lives.

Life's Principles –
a set of patterns exhibited by life that contributes to life's ability to survive and thrive.

Nature as model, measure, mentor –

- **Model –** applying, imitating or taking inspiration from nature's designs and processes in order to solve human problems
- **Measure –** using an ecological standard to judge the "rightness" of our innovations
- **Mentor –** valuing nature for what we can learn from it and not for what we can extract from it.

Niche –
the functional role of a species within a community, dependent on the organism's structural adaptations, physiological responses, and behavior.

Pattern –
a reoccurring form, strategy, or principle. Also, an example or model to be imitated or emulated.

Principle –
a fundamental source from which something proceeds; a primary element, force, or law which produces or determines particular results; the ultimate basis upon which the existence of something depends; cause.

Shifting mosaic habitat –
describes the theory that landscapes change and fluctuate, and are dynamic in nature.

Strategy –
a behavior or set of behaviors or solutions used by an individual to deal with an important life-history challenge (e.g., acquiring water, accommodating growth, managing disturbance, rearing young, obtaining food, etc.).

Sustainability –
the intention and ability to continue the economic, social, institutional, and environmental aspects of human society while meetings the needs of the present without compromising the ability of future generations to meet their own needs.

Symbiotic –
an intimate relationship between two or more organisms of different species. The symbiotic relationship may be categorized as mutualistic (in which each organism benefits from the relationship), commensal (in which one organism benefits from the relationship but the other organism neither benefits nor is harmed), or parasitic (in which one organism benefits at the expense of the other).

WATER

TEMPERATE BROADLEAF FOREST

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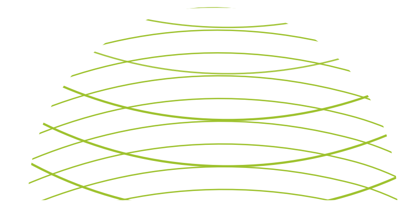

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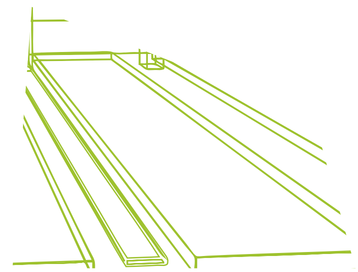

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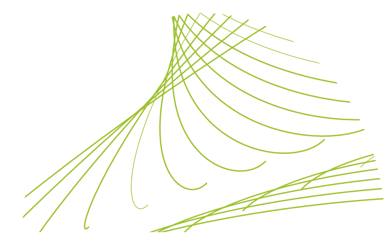

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Rose Tocke
Sherry Ritter
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Bokki Son
Brett Leonhardt
Carolina Simon
Derek Prior
Mary Ann Lazarus
May Xu
Shashi Narayanan
Thomas Knittel
Tyler Meyr

Contact

For more information regarding the content of this report, please contact:

Mary Ann Lazarus
HOK
+1 314 754 3927
mary.ann.lazarus@hok.com
211 N. Broadway, Suite 700
St. Louis, MO 63102 USA

BIOMIMICRY 3.8

Taryn Mead
Biomimicry 3.8 (a dba of Biomimicry Group, Inc.)
+1 406 543 4108
tarynm@biomimicrygroup.com
140 South 4th St West, Suite 2
Missoula, MT 59801

Biomimicry.net