PERFORMATIVE BIOMIMICRY: Design for increasingly harsh environments

INTRODUCTION

"From my designer's perspective, I ask: Why can't I design a building like a tree? A building that makes oxygen, fixes nitrogen, sequesters carbon, distils water, builds soil, accrues solar energy as fuel, makes complex sugars and food, creates microclimates, changes colors with the seasons and self replicates. This is using nature as a model and a mentor, not as an inconvenience. It's a delightful prospect."
(Braungart & McDonough in *Cradle to Cradle*)

In order to properly employ performative biomimicry within architectural design, humanity must first have a concrete understanding of nature's general principles and functionality. Biologist Shauna Price states that nature functions by following some fundamental rules and regulations which are employed throughout its various interconnected systems. They include the following:

1. Nature follows a series of regulations that Shuana Price calls "Ecosystem Principles"

On earth, these principles have created and maintained the following three complex ecosystems:

- Terrestrial ecosystem.
- Freshwater ecosystem.
- Marine ecosystem

Each ecosystem listed above is composed of hundreds of sub- ecosystems which represent earth's diversity and its ability to achieve equilibrium.

2. Every niche of an ecosystem functons in close-loops.
A closed-loop cycle is "a system where nothing is wasted, only returned to the cycle itself to sustain and further strengthen it." Life on earth was created and sustained within closed-loop cycles, think of it as our default mode. Everything that an organism takes over its lifetime is ultimately returned to the earth to sustain the cycle indefinitely. Nature is hence, balanced and resilient.

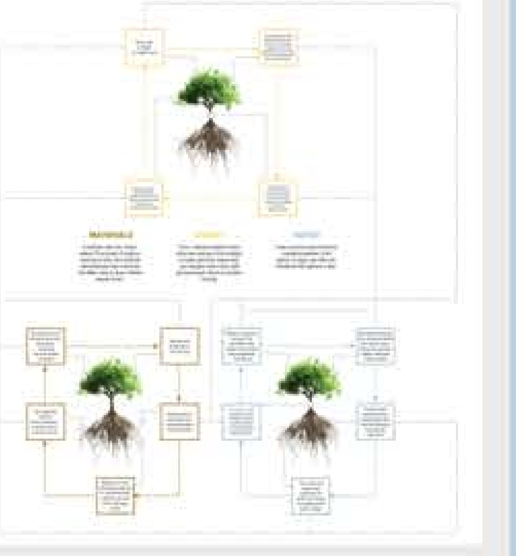
1 **The earth has had 3.8 billion years of evolutionary refinement to create biological systems and strategies which allow the planet to achieve true sustainability and longevity. This is its ecology**

3. Ecosystem networks thrive via the their ability to maintain, conserve, and reuse three critical and essential resources:

WATER **ENERGY** **MATERIAL**

How an oak tree performs like an ecosytem.

The oak tree is one of nature's most brilliant examples of sustainable ecosystem design. As a model, it manages to do everything we as architects want to achieve when it comes to buildings and cities in that it reuses the output resources as input materials creating a closed-loop ecosytem that conserves materials, energy, and water. This type of ecosystem inspired Exploration Architecture to design a biomimetic building refered to as the "Mobius Project" that mimics the oak tree's ability to conserve materials, energy, and water.



Dark Ecology by Timothy Morton

Timothy Morton argues that "ecological awareness in the present Anthropocene era takes the form of a strange loop or Möbius strip, twisted to have only one side." Ecological awareness takes this shape because ecological phenomena has a loop form that is also fundamental to the structure of how things are. The logistics of agricultural society resulted in global warming and hardwired dangerous ideas about life-forms into the human mind. Dark ecology puts us in an uncanny position of radical self-knowledge, illuminating our place in the biosphere and our belonging to a species in a sense that is far less obvious than we like to think. Morton explores the logical foundations of the ecological crisis, which is suffused with the melancholy and negativity of coexistence yet evolving, as we explore its loop form, into something playful, anarchic, and comedic. Ultimately, Morton hopes to reestablish our ties to nonhuman beings and to help us rediscover the playfulness and joy that can brighten the dark, strange loop we traverse.

Today, humanity see itself as masters of the planet.

"Man sees himself as the decison maker for all."

2 **Humans are NOT independent of that ecology. In fact, we are entirely dependent on that ecology.**

But in reality, we are a part of the ecology.

Hyperobjects

"those concepts that must be thought of at the scale of Earth rather than of the individual"

"A human is made up of nonhuman components and is directly related to nonhumans" -Morton

Humans need to reposition the idea of themselves as central to the natural landscape, and to think about the world from an ecological rather than anthropocentric perspective. The natural world is not merely the condition of our existence but, as Morton notes:

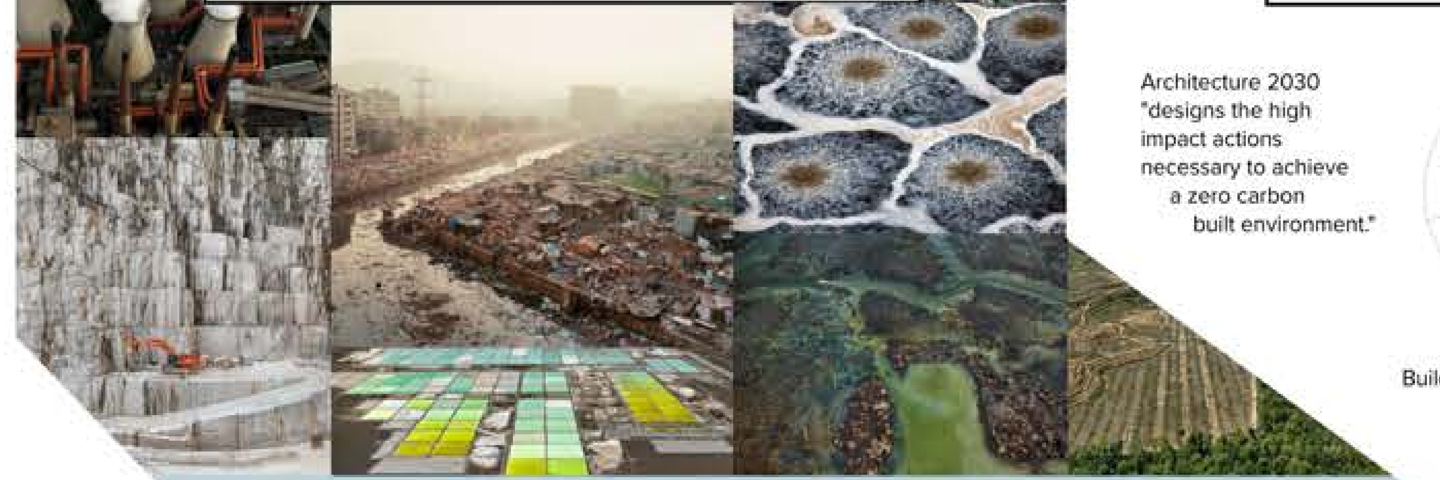
"...a mess of lungs and bacterial microbiomes and nonhuman ancestors and so on—along with their agents such as cows and factories and thoughts, agents that can't be reduced to their merely human use or exchange value."

Morton's book poses a challenge in which humanity as it currently exists must remove itself from the equation to ensure the continuation of a healthy planet. The world is made up of so much more than can be imagined by our human minds, and a deeper understanding of its mystery may lead to a more positive engagement with that world.

When a closed loop cycle is disrupted an imbalance occurs within an ecosystem, and it can lead to extreme consequences on a global scale.

The most daunting example of this is climate change. We are emitting more greenhouse gases than ever before in the history of man. In addition, we are taking more and more from our planet in the name of industry and not giving enough back in return. These are some of the results & consequences:

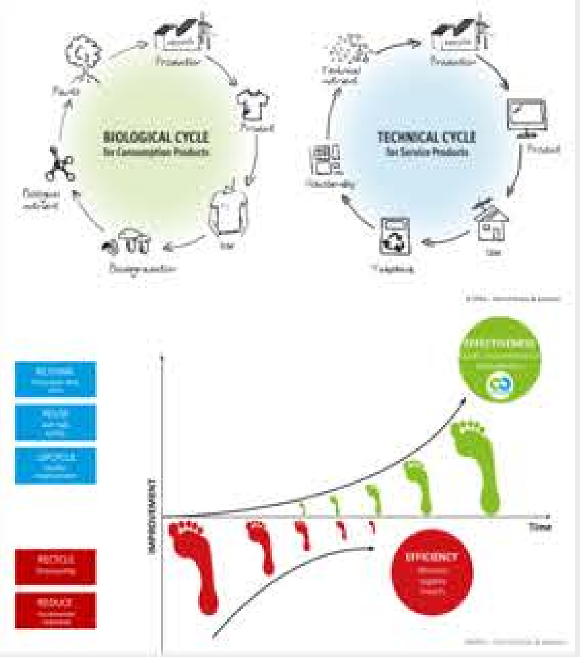
When a closed loop cycle is disrupted, an imbalance occurs within an ecosystem, and it can lead to extreme consequences on a global scale.



Anthropocene photographed by Edward Burtynsky

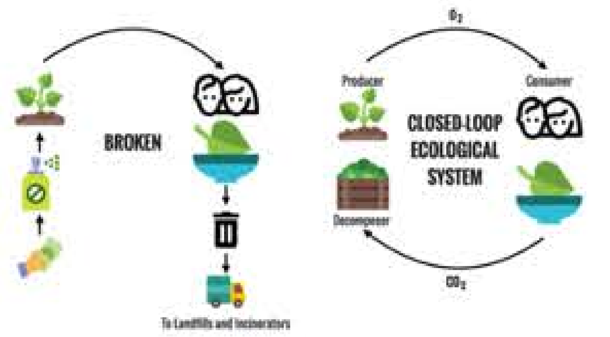
"Our planet has borne witness to five great extinction events, and these have been prompted by a variety of causes: a colossal meteor impact, massive volcanic eruptions, and oceanic cyanobacteria activity that generated a deadly toxicity in the atmosphere. These were the naturally occurring phenomena governing life's ebb and flow. Now it is becoming clear that humankind, with its population explosion, industry, and technology, has in a very short period of time also become an agent of immense global change. **Arguably, we are on the cusp of becoming the perpetrators of a sixth major extinction event. Our planetary system is affected by a magnitude of force as powerful as any naturally occurring global catastrophe, but one caused solely by the activity of a single species: us**. I have come to think of my preoccupation with the Anthropocene — the indelible marks left by humankind on the geological face of our planet — as a conceptual extension of my first and most fundamental interests as a photographer. I have always been concerned to show how we affect the Earth in a big way. **To this end, I seek out and photograph large-scale systems that leave lasting marks**. As a collaborative group, Jennifer, Nick and I believe that an experiential, immersive engagement with our work can shift the consciousness of those who engage with it, helping to nurture a growing environmental debate. We hope to bring our audience to an awareness of the normally unseen result of civilization's cumulative impact upon the planet. This is what propels us to continue making the work. We feel that by describing the problem vividly, by being revelatory and not accusatory, we can help spur a broader conversation about viable solutions. We hope that, through our contribution, today's generation will be inspired to carry the momentum of this discussion forward, so that succeeding generations may continue to experience the wonder and magic of what life, and living on Earth, has to offer." -Edward Burtynsky

Cradle to Cradle by Michael Braungart & William McDonough



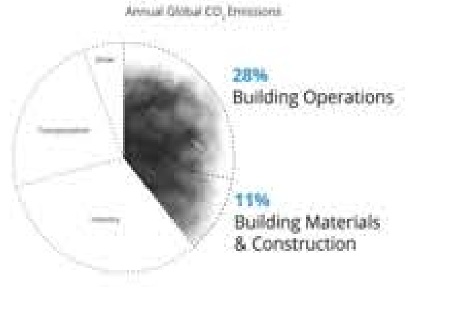
This book is a manifesto detailing how to achieve a design model that transitions from the cradle to grave pattern towards a cradle to cradle system. It argues that a linear system has existed since the industrial revolution that is immensly damaging the natural world and that this is why humanity must make a change towards a **closed-loop system**. The authors specifically looks towards nature itself as a model to accomplish this transition. In addition, the book discourages downcycling and replaces it with the idea of upcycling where biological nutrients re-enter the environment and technical nutrients remain within the closed-loop industrial cycle.

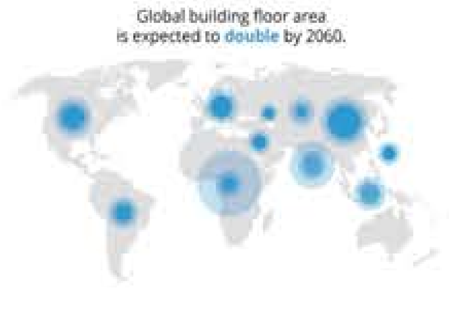
"The circular economy is an economic model that deviates away from the take- make- dispose thinking of the original industrial era, an era of mechanistic thinking, to one where the opportunities increasingly lie with closed-loop, feedback-rich systems." -Michael Pawlyn



4 **The built environment is the most prominent example of a linear, wasteful cycle of using resources as buildings emit about 40% of all carbon emissions. If humans began to create, maintain, and dissassemble buildings in regenerative closed-loops like the earth does all matter, then we could reverse our harmful, linear behaviors and become a part of the earth's healthy ecology.**

Architecture 2030 "designs the high impact actions necessary to achieve a zero carbon built environment."





Buildings are the largest source of the world's carbon emissions globally. When accounting for the embodied carbon of building interiors, systems and associated infrastructure, that percentage is substantially higher. (Architecture 2030)

Man made v.s Ecological

MAN MADE SYSTEMS	ECOLOGICAL SYSTEMS
Linear flows of resources	Closed- loop flow of resources
Disconnected and monofunctional	Densely interconnected and symbiotic
Resistent to change	Adaptive to constant change
Wasteful	Everything is nutrient
Toxins frequently used	No persistent toxins
Centralised and monocultural	Distributed and mad of diverse components
Hierarchially controlled	Panarchially self- regulating
Fossil- Fuel Dependent	Uses solar enegy
Engineered to maximise one goal	Optimised as a whole system
Extractive	Regenerative
Uses global resources	Uses local resources

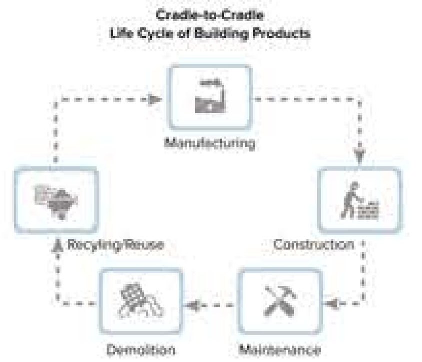
Achieving zero embodied emissions will require adopting the principles of:

- **Reuse**, including renovating existing buildings, using recycled materials, and designing for deconstruction.
- **Reduce**, including material optimization and the specification of low to zero carbon materials.
- **Sequester**, including the design of carbon sequestering sites and the use of carbon sequestering materials.

Just three materials – concrete, steel, and aluminum – are responsible for 23% of total global emissions (most of this used in the built environment). There is incredible opportunity for embodied carbon reduction in these **high-impact** materials.

Cradle-to-Grave
Life Cycle of Building Products

Cradle-to-Cradle
Life Cycle of Building Products



History of Biomimicry

1505 — Leonardo da Vinci writes *Codex on the Flight of Birds*, which speculates that human air travel could be modeled on the mechanics of avian flight.

1851 — Joseph Paxton builds the 990,000-square-foot Crystal Palace for the Great Exhibition. The design, which uses crisscrossed iron girders to support nearly 300,000 panes of glass over a vast, open space, is inspired by the leaf of a water lily: Interconnecting ribs help the plant support substantial weight in water.

1969 — American biophysicist Otto Schmitt invents the term "biomimetics" after he invents an electrical circuit modeled after the neural impulse systems of squids.

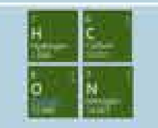
1997 — Scientist Janine Benyus publishes the book *Biomimicry: Innovation Inspired by Nature*. She becomes the first real leader of the biomimcry movement and frames the concept of biomimetics around the urgent goal of ending environmental destruction.

2006 — The Biomimicry Institute was founded by Janine Benyus as a non-profit organization with the goal of empowering people to seek nature-inspired solutions for a healthy planet. It unites a global network of educators, innovators, changemakers, scientists, and others trying to save our environment.

2011 — Lynn Reaser, chief economist, establishes the Da Vinci Index which aims to quantify the expansion of bio-inspired research and innovation. According to his report, by 2050 the field is set to explode. Biomimicry could represent $300 billion of U.S. GDP annually, 1.6 million jobs, and $50 billion in terms of resources conserved.

Biomimicry in Architecture

Criteria critical to creating regenerative closed- loop systems within the built environment.

	STRUCTURE	MATERIALS	THERMAL ENVIRONEMENT	ENERGY	WATER
CRITERIA	efficiency	self-assembly non-toxic	passive systems smart systems	O_2 and CO_2 balance solar	Harvesting Storage
BIOMIMIC EXAMPLE					

5 **In order to design regenerative building ecosystems which integrate harmoniously with natural ecosystems, it is critical that architects look towards the science of Performative Biomimicry which is an approach to innovation that emulates nature's sustainable time tested processes.**

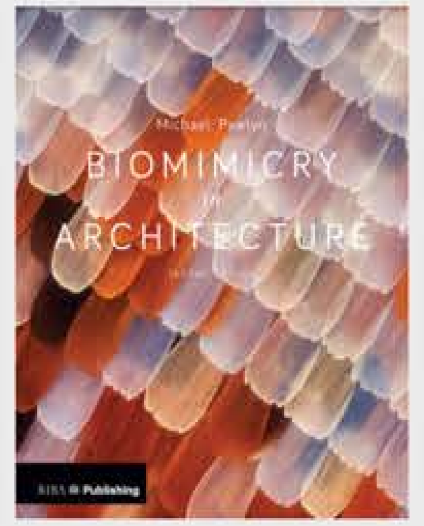
Biomimicy Defined by Pioneers in the Field

"**Biomimicry** is basically taking a design challenge and then finding an ecosytem that's already solved the challenge, and literally trying to emulate what you learn." - Janine Benyus

"**Biomimicry** is innovation inspired by nature" - Michael Pawlyn

"**Biomimicry** is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies. The goal is to create products, processes, and policies—new ways of living—that are well-adapted to life on earth over the long haul."

Biomimicry in Architecture by Michael Pawlyn



Michael Pawlyn is british architect noted for his work in biomimetic architecture and innovation. He was part of the principal team of architects that conceived and designed The Eden Project, is a regular keynote speaker at events on innovation and environmental sustainability, and established the biomimic firm Exploration Architecture in 2007.

His book Biomimicry in Architecture looks towards nature to find genuinly sustainable building design and technology that goes beyond conventional sustainability and instead, towards the truly restorative. Pawlyn explores various examples of forms, systems, and processes that the earth has utilized over the past 3.5 billion years of natural history and applies them to the design of modern green buildings.

This newest edition of the book attempts to achieve radical increases in resource efficiency. It includes chapters on structures, materials, waste, water, thermal control, energy, and light. In addition, each chapter contains a multitude of case studies that both explore what trends in biomimicry exist today and what future trends could exist.

ABSTRACT

Humanity is not acting as a symbiotic part of earth's ecology. Since the industrial age, humans have settled on a linear, wasteful cycle of using resources. These unsustainable practices have disrupted the earth's natural processes and caused imbalances within its ecosystems such as climate change, extreme weather events, and natural resource depletion which immenently threaten the longevity of a healthy planet.

Architects have a responsibility to adapt their design thinking for the well being of the people and places affected by these imbalances. Even more so, they have a responsibility to provide closed-loop, adaptive, and regenerative design responses that aid in reversing the damage humans have inflicted on the planet.

Fortunately architects have an invaluable precedent to better understand how to solve these functional problems: biology. The earth has had 3.8 billion years of evolution to create closed-loop, regenerative biological systems even within the harshest planetary conditions. The practice of taking a design challenge and then finding an ecosystem that has already solved the challenge and emulating its behaviors and function is called performative biomimicry. Through the implementation of performative biomimicry, architects can design adaptive and regenerative ecosystems within increasingly harsh environments.

This investigation tests the role that performative biomimicry might play in aiding architectural design in the harsh African Sahel region, the location most threatened by desertification due to increasing global temperatures. Exploring the reversal of desertification towards the return of a lush, restorative ecosystem via biomimetic principles is a key outcome of the exploration.

THESIS STATEMENT

Through the implementation of performative biomimicry, architects can design adaptive and regenerative building ecosystems within increasingly harsh environments.

BREAK THE CYCLE

DISCOVER - 5 different microinterventions that begin to define a new ecology

TRADITIONAL BATTERIES HARM ENVIRONMENT

Today, the world is showing a lot of excitement about the quickening shift towards cleaner electricity. But, if we're to truly make the leap to an electric, solar- powered future, there's an important hurdle to overcome: **we need genuinely clean batteries.**

There are many different kinds of batteries and they are made using a variety of materials, but something they all have in common is that they significantly harm the natural environment. The two primary reasons why they are dangerous to the environment are the following:

1. Making batteries involves the mining of non-renewable resources.
2. The metals and the chemicals within batteries are hazardous, toxic, and corrosive materials.

Non-renewable resources mined to make batteries:

- lead
- zinc
- silver
- nickel
- manganese
- lithium
- mercury
- cadmium

Toxic chemicals found in batteries: sodium chloride, chloric acid, nitric acid, potassium nitrate, hydrocholoric acid, sulfuric acid, sodium hydroxide, magnesium hydroxide, and sodium acetate.

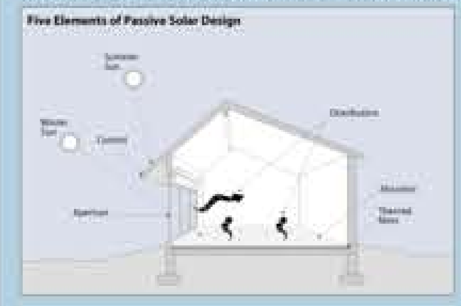
So how do batteries harm the environment?

1. **Air pollution**: batteries undergo a photchemical reaction as they decompose in landfills. This causes emissions of greenhouse gases which result in global warming.
2. **Water pollution**: The harmful chemicals found in batteries also find their way into the local water supply, killing plants and animals, which negatively affect the ecosystems of streams, lakes, rivers, and oceans. This contaminated water also negatively affects the health of humans.
3. **Soil Pollution**: Most batteries end up in landfills instead of being recycled or disposed of properly. The toxic elements they contain are absorbed by the soil, killing plants and harming animals.
4. **Health Problems**: Lead can be absorbed into the body through inhalation and ingestion and can have permanent effects such as brian damage and impaired hearing. Sulfuric acid is highly corrosive and can cause permanent blindness or fatally damage internal organs if ingested. Cadmium is even more dangerous as it is considered a carcinogen.

TRANSITION TO AN ENTIRELY SOLAR ECONOMY AS SOLAR ENERGY IS INDEFINITE BUT MAKE SURE TO USE GENUINLY GREEN ENERGY STORAGE

A. MAXIMIZE PASSIVE STRATEGIES TO MINIMIZE ENERGY STORAGE.

Always take advantage of a building's site, orientation, climate, and materials to minimize energy use. A well-designed passive solar home first reduces heating and cooling loads through energy-efficiency strategies and then meets those reduced loads in whole or part with solar energy.



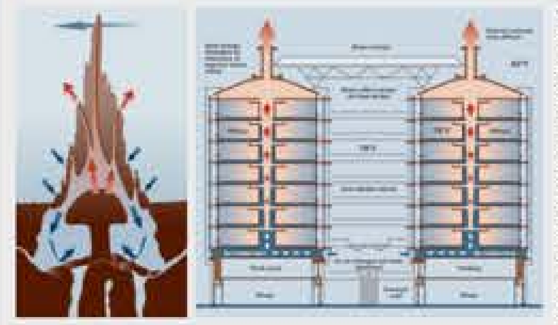
5 Elements of passive solar design

1. Aperture/collector (south-facing windows)
2. Absorber (usually hard & dark surface of wall or floor material)
3. Thermal mass (material that retains and stores heat)
4. Distribution (circulation of heat through natural conduction, convection and radiation)
5. Control (roof overhangs, blinds, awnings, shade trees)

B. UTILIZE BIO BATTERY WHEN NECESSARY

A partnership between UK biotech company Touchlight Genetics and the Minteer Research Group at the University of Utah has designed a bio-battery with DNA. The Bio-battery is a biofuel cell powered by enzymes that break down organic compounds for fuel. DNA turns out to be a good fit owing to its double helix structure which naturally holds onto enzymes. Besides efficiency, the DNA-based bio-battery offers several advantages over conventional fuel cells and lithium-ion batteries. First, they consist of DNA, enzymes, lactate, protein, and water-- all of which are biodegradable, non- toxic, and safe materials. The casing can also be made of biodegradable materials.

PRECEDENT: Self-cooling Eastgate Centre in Harare, Zimbabwe inspired by Termite Mounds



Termites were the primary source of inspiration for the Eastgate Centre. This office building achieves steady conditions all year round without conventional AC or heating, and uses only 10 per cent of the energy of a standard approach. Pearce based the design of the ventilation system of termites which appeared to use a combo of steady ground temperatures and wind-induced natural ventilation as their means of thermo regulation. ($3.5 million saved in AC costs)

Caballar, Rina Diane, et al. "Living Power: This Bio-Battery Is Harnessing the Power of DNA." SynBioBeta, 21 Apr. 2021, Web.

EcoFriendlyLink. "Batteries and Their Effects on the Environment." EcoFriendlyLink, 4 May 2021, Web.

"Passive Solar Design - Lesson." TeachEngineering.org, 5 Oct. 2021, https://www.teachengineering.org/lessons/view/cub_housing_lesson05.

"Passively Cooled Building Inspired by Termite Mounds - Innovation - Asknature." AskNature Passively Cooled Building Inspired by Termite Mounds Comments, https://asknature.org/innovation/passively-cooled-building-inspired-by-termite-mounds/.

SUBTRACTIVE MANUFACTURING RESULTS IN EXCESS WASTE

Traditionally, there are three ways of making things that have been used since antiquity. They are the following three methods:

1. Subtractive (such as carving wood, shaping flint)
2. Moulding (such as clay pottery, cast metal, and moulded plastic)
3. Forming' (such as bending, forging and stamping).

The primary problem with these manufacturing processes are that **they are top-down approaches which inevitably result in an excess amount of unnecessary waste**. When it comes to material, human are masters of overconsumption. The goal should be to reduce this unnessesary waste by building efficient structures that use just the right amount of material to accomplish their task both successfully.

So how much material is actually wasted in subtractive manufacturing methods?

- PwC analysts used data from the U.S. Geological Survey to determine that American manufacturers waste almost 1/4 of the raw materials they purchase. Sometimes, as much as 90% of the material is wasted.

In addition, this waste inflates the cost of production, leading to higher-than-necessary price quotes.

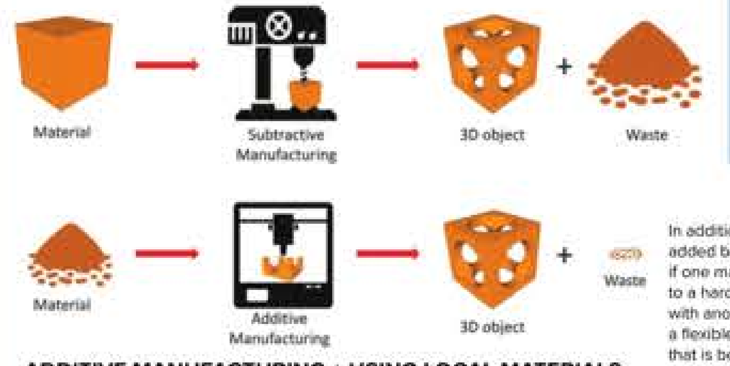
Most subtractive manufacturing is done via CNC machines, lazer cutters, and water jet cutters, all machines that are pre-programmed to yield a final form.

Other cons of subtractive manufacturing technologies include:

1. Cannot alter volumetric density of building material.
2. Process planning is a both a laborious and mandatory task that requires a lot of data input
3. There is a limited capability in form as enclosed features cannot be generated.
4. A very expensive process as you pay for excess material.

ADDITIVE MANUFACTURING HEAVILY REDUCES MATERIAL WASTE

Designer Geoff Hollington states that new technologies are starting to challenge the three traditional methods of making things that have been used since antiquity. Specifically, he is referring to "additive approaches" which can approximate the molecular, bottom-up, manufacturing that occurs in biology." He states that "Machines now exist that allow mixed materials, like nanoparticles in solution, to be deposited from a jet that is similar to that of an inkjet printer. The very small scale of the material allows low-energy bonds, such as van der Waals forces, to assist in assembling the particles." This appraoch results in little to no waste as only the necessary material is printed."



In addition, an added benefit is that if one material that cures to a hard finish is combined with another material that dries in a flexible form, then an an element that is both tough and flexible is formed...in other words, a structurally efficient material is formed.

ADDITIVE MANUFACTURING + USING LOCAL MATERIALS REDUCES WASTE AND EMBODIED ENERGY.

Probably the most notable technology that makes additive manufacturing a possibility today is 3D printing. 3D printing mimics biological processes by creating products layer-by-layer. There are already various examples of how 3D printing may be used in the construction industry to build entire buildings. Pair 3D printing with utilizing local materials, and now we can create structures with a fraction of the embodied energy of conventional approaches, displaying the elegance of animals ability to build with materials that are readily available.

PRECDENT: TECLA (combination of words technology & clay) by WASP & Mario Cucinella

One example of addidive manuufacturing using local materials is the project by Italian company WASP who brought a 3D printer range onto the market that could 3D print an entire home. WASP collaborated with Mario Cucinella Architects to design and build the first 3D printed all-natural, recyclable, carbon-neutral home using an easily accessable raw material: earth.

"Additive Manufacturing & Subtractive Manufacturing: Pros & Cons, Applications." Minaprem.com, Web.

Pawlyn, Michael. Biomimicry in Architecture. 2nd ed., RIBA Publishing, 2020.

Pintos, Paula. "Tecla Technology and Clay 3D Printed House / Mario Cucinella Architects." ArchDaily, ArchDaily, 27 Apr. 2021, Web.

HIGH ENERGY BOND MATERIALS BREAK CLOSED-LOOP CYCLE AS THEY CANNOT DECOMPOSE

The most ecofriendly way to dispose of material is via the process of decay which is how nature disposes of all it's matter. **Biodegradation, also called decay, is "the process by which organic substances are broken down into smaller compounds by living microbial organisms."** Decomposers are made up of three categroies: fungi, bacteria, and invertebrates (worms and insects). So what building materials are most commonly used and which of them naturally decompose with time?

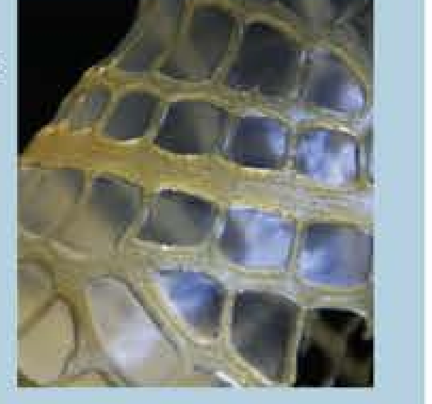
The most common building materials used in the construction industry today include wood, stone, brick, aluminum, steel, and concrete. Wood and stone are two materials found in nature and therefore, cause no harm to the environment as wood decomposes with time and stone erodes with time. Brick is an environmentally friendly material in that can be recycled and reused for hundreds of years, but will eventually naturally break apart and decopose. Concrete is the most widely used substance on earth and one of the earth's largest CO2 emitters, but it does actually break apart and corrode with time. Conserve Energy Future says the following: "Although concrete is not biodegradable, it is very much recyclable. That means it can be reusable almost indefinitely. There always will be applications for old concrete." Most of the harm concrete has on the environment occurs in making of it and in its inability to allow the absorption of stormwater. Since, it is reusable, I will speak on the potential of solving concrete's biggest problems in the next section. **But what about the metals we use in the building industry?**

Metals are considered "high energy bond materials" because their metallic bonds are strong and require a great deal of energy to break. Therefore, they tend to have high melting points and boiling points, which is the result of the strong bonds between their atoms. **Microorganisms do not consume metal particles for nutrition because of their inability to break apart these high energy bond materials.** In addition, various heavy metals cause detrimental effects on microorganisms due to their high toxicity. Heavy metal toxicity involves the initiation of several destructive mechanisms such as the "breaking fatal enzymatic functions, reacting as redox catalysts in the production of reactive oxygen species (ROS), destructing ion regulation, and directly affecting the formation of DNA as well as proteins." In addition, the physiological and biochemical properties of microorganisms can be altered by the presence of heavy metals. For example, Chromium and cadmium are capable of inducing oxidative damage and denaturation of microorganisms as well as weakening the bioremediation capacity of microbes. At best, metals eventually rust and break apart into smaller pieces.

Nature is is able to utilize decomposition for all of its matter because roughly 96 percent of all living matter is made from four elements which microorganisms can consume: carbon, oxygen, hydrogen, and nitrogen. Calcium, phosphorous, potassium, sulphur, sodium, chlorine and magnesium make up nearly all the remaining 4 percent. In other words, nature uses a very limited subset of the periodic table, all which are consumed and cycled by microorgainsms. In comparison, engineering and the built environment virtually use every element in existence, some that are extremely toxic and some that never truly biodegrade. So what materials should we be using to build if we want to close the loops from material birth to death?

LOW ENERGY BOND MATERIALS RESTORING CYCLE AS THEY CAN DECOMPOSE

Equivalent technology to biological growth processes do not exist yet, but they are close to becoming a reality. So what should these machines print with? **Ideally, the answer is biological raw material which could self-assemble into polymer chains**. We could then assemble those chains in a controlled way. Perhaps the closest to achieving this has been the work of Neri Oxman and colleagues at the 'Mediated Matter' laboratory at MIT Media Lab, "who have managed to print with chitosan (a deacetylated form of chitin – one of the substances from which insect carapaces, prawn shells and crabs shells are made) and functionally graded materials with spectacular results." . Mogas-Soldevila et al. have observed that natural polymers and polysaccharides represent a vast renewable resource that could be used to build in the future. She even states that eventually it will be possible to include interfaces and many levels of hierarchy. This could achieve a degree of resource efficiency and resilience similar to that found in many of the biological sources that will continue to be studied by collaborative teams of scientists and designers. In addition, this process is carried out at ambient temperature and pressure and therefore offers the potential for much lower-energy fabrication than conventional approaches.



BIOLOGICALLY RAW MATERIAL CAN ALSO ACHIEVE GREATER RESOURCE EFFICIENCY, RESILIENCE, AND ADAPTABILITY.

At the end of their lifespan, biological materials can be composed and completely reabsorbed into the biological cycle, yielding a net zero waste.

Libretexts. "Metallic Bonding." Chemistry LibreTexts, Libretexts, 15 Aug. 2020, https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Chemical_Bonding.

PRECEDENT: Hi-Fi by The Living Architect

The architect Magnus Larsson pursued a form of microbial material growth with the intention of forming structures in desert areas. His experimental architectural practice "The Living" has explored bacterial growth as a way of literally growing materials, specifically using fungal mycelia to bind together discarded corn stalks into bricks with sufficient compressive strength to be used in construction. The firm assembled these into a temporary installation called 'Hy-Fi', The structure was built from 10,000 living fungal mycelian bricks that were grown in molds. It takes them five days to go from organic mush to solid brick.

After dismantling, the bricks were composted and completely reabsorbed into the biological cycle, resulting in net zero waste.

Igiri, Bernard E., et al. "Toxicity and Bioremediation of Heavy Metals Contaminated Ecosystem from Tannery Wastewater: A Review." Journal of Toxicology, Hindawi, 27 Sept. 2018, https://www.hindawi.com/journals/jt/2018/2568038/.

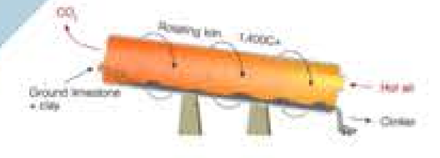
Pawlyn, Michael. Biomimicry in Architecture. 2nd ed., RIBA Publishing, 2020.

CONCRETE CAUSING C02 & O2 IMBALANCE

Concrete is, the most widely used building material on earth today. It is the main material that our generation is going to leave behind for new generations. It also happens to be one of the earth's largest CO2 emittors (contributing 8% of all carbon emissions), therefore aiding in the disruption of the CO2 and O2 balance we need in the atmosphere for a healthy planet. This makes it one of the primary contributors to climate change.

There are few other reasons why concrete production and lifecycle are so unhealthy for the planet. They are the following:

1. Concrete is made from raw, non-renewable resources, primarily limestone, clay, gravel, and sand. Their removal also causes extreme land degredation.
2. Concrete prevents leads to surface runnoff as it prevents the absorption of stormwater into the ground
3. The process of making concrete realease an immense amout of carbon dioxide emissions and clinker accounts for most of those emissions



The current production process of cement

One reason why the carbon emissions are so high is because cement has to be heated to very high temperatures in order for clinker to form. A major culprit of this is alite, a mineral in concrete that cures within hours of pouring and is therefore responsible for much of its initial strength.

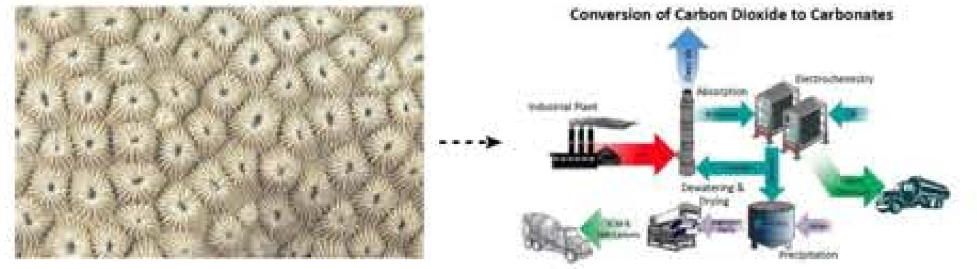
"If you look at man's history, the main thing we've left behind is the built environment. If we look at civilizations 5,000 years ago, we see today, the pyramids, for example. When we look at the last few centuries in Europe, we see these massive buildings, bridges, dams, and roadways. When you go forward a hundred years from now, you'll see that, looking back, there's been this transition from using stone and ancient mortars that are derived from limestone, to concrete. Concrete is, in fact, the most-used building material today. The main thing that our generation is going to leave behind for new generations is massive amounts of concrete. - Brent Constantz

So how can concrete be rethought in such a way as to restore the CO2 to O2 balance needed?

CORAL REEFS & CARBON SEQUESTERING RESTORING CO2 & 02 BALANCE

Blue Planet is a Silicon Valley company, founded by Brent Constantz in 2012, which has developed a novel carbon capture and utilisation system that permanently removes carbon dioxide from the air, cost effectively. Its technology uses CO2 as a raw material for making carbonate rocks which are used in place of natural limestone rock mined from quarries, the principal component of concrete. The waste CO2 flue gas from a local power plant is dissolved into seawater to form carbonate, which then mixes with calcium in the seawater and creates a solid. **This is how corals form their skeletons, and how Constantz creates cement.** This process is what differentiates Blue Planet from most carbon capture methods as the captured CO2 does not require a purification step, which is an energy and capital intensive process.

An an expert in biological and geological mineralisation, Brent Constantz looked toward biomimicry in his development of this cement manufacturing process which is equivalent to the biological version found in the natural building of coral reefs. The process is called "biomineralisation" which means "the sequestering of an atom of carbon with every atom of calcium in the process of forming calcium carbonate." Cement production, by contrast, releases a molecule of carbon dioxide for every atom of calcium. In other words, Blue Planet's cement production actually sequesters carbon dioxide rather than releasing it into the atmosphere, just like coral reefs in the ocean do!



Biomineralisation in coral reefs inspires Blue Planet's cement production process with sequesters carbon.

PRECEDENT: Amazon HQ2 by ZGF Architects, using Carbon Cure Concrete

The company Carbon Cure utilizes the same carbon sequestration process developed by Brent Constantz. Specifically, they are using it for Amazon's HQ2 metropolitan project which will become an urban campus for 25,000 Amazon employees. By using Carbon Cure, the CO2 saved will be approximately 1,261 TONS per 1,144 TONNES.

1 lb CO2 sequestered/ 30 masonry blocks

25- 40 lb CO2 sequestered/ cubic yard

25 lb CO2 sequestered/ cubic yard

"Brent Constantz Builds Cement like Corals: Human World." EarthSky, 9 Dec. 2017, https://earthsky.org/human-world/brent-constantz-builds-cement-like-coral-do/.

Burbidge, Manon. "Blue Planet." World Cement Association, https://www.worldcementassociation.org/about-us/our-members/associate-corporate-member-blue-planet.

"Concrete: The Most Destructive Material on Earth." The Guardian, Guardian News and Media, 25 Feb. 2019, https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth.

Quick Facts Amazon HQ2 - Go.carboncure.com. https://go.carboncure.com/rs/328-NGP-286/images/CC_OP-MillerandLong-AmazonHQ2.pdf.

DRINKING WATER SHORTAGES ARE RAMPANT DUE TO STRESSED FRESH WATER ECOSYSTEMS

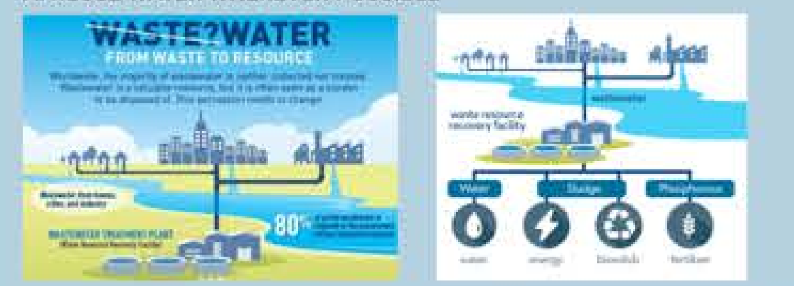
Water covers approximately 70% of our planet, leading humans to think that it will always be plentiful. However, freshwater is incredibly rare. It makes up only 3% of the world's water, and two-thirds of that is frozen in glaciers which are unavailable for our use. As a result, some 1.1 billion people worldwide lack access to water, and a total of 2.7 billion people experience water scarcity for at least one month of the year.

So how is the little available freshwater used around the world? At a whopping 70%, agriculture uses most of the worlds accessible freshwater. However, it is estimated that about 60% of this water is wasted due to "leaky irrigation systems, inefficient application methods as well as the cultivation of crops that are too thirsty for the environment in which they are grown." Rivers, lakes and underground aquifers are drying up due to this wasteful usage of of water and the high demand of fresh water needed for rising populations. In addition, countries that produce large amounts of food such as India, China, Australia, Spain and the United States are close to reaching their water resource limits.

Furthermore, population growth has nearly doubled in the last 50 years and is continuing to grow at alarming rates, particularly in underdeveloped countries like Africa and Asia. This rapid population growth has transformed water ecosystems around the world and resulted in a massive loss of biodiversity. The World Wildlife Fund specifically states that freshwater species are declining at the alarming rate of 76 % which is much faster than both terrestrial and marine species. In fact, they claim that fresh water scarcity is one of "the most pressing threats to the diversity of life on Earth." It is critical that we find solutions to counter the unsustainable usage of freshwater both for the health of humans and the natural ecosystem.

REUSING WASTEWATER + RAINWATER HARVESTING + DESALINATION CAN REDUCE DRINKABLE WATER SHORTAGES

A. REUSE WATER WHEREVER POSSIBLE



Treated Water for:

- energy sector
- industrial processes
- irrigation
- reacreational use
- replenishing aquifers
- drinking water
- Anaerobic Digestor
  - A. Biogas
  - B. Biosolids
- ferilizer

Thirty-two billion gallons of municipal wastewater are produced everyday in the United States but less than 10 percent of that is intentionally reused. This is highly unfortunate considering that reusing water greatly decreases the demands and stress on freshwater sources such as groundwater, rivers, and reservoirs.

B. RAINWATER HARVESTING

In places where resusing wastewater is still not enough, you can collect rainwater. This is particularly useful in arid climates. For example, Warka Water is a group that is helping impoverished communities in Cameroon, Haiti, and Togo attain clean drinking water. Specifically, they designed the Warka Tower which harvests water from the atmosphere (rain, fog, dew). The design was in part inspired by the Dakling beetle which uses micro-sized grooves on it's hardened forewings to help condense and direct water toward it's mouth. In addition, a combination of hydrophilic (water attracting) and hydrophobic (water repelling) areas on these structures increase fog- and dew-harvesting efficiency.

- designed to be easily built with simple tools
- made using only local, natural, biodegradable, and 100% recyclable materials (no concrete, plastic, or steel)

C. DESALINATION WHEN NECESSARY

PRECEDENT: HYDROUSA Mangrove Still System

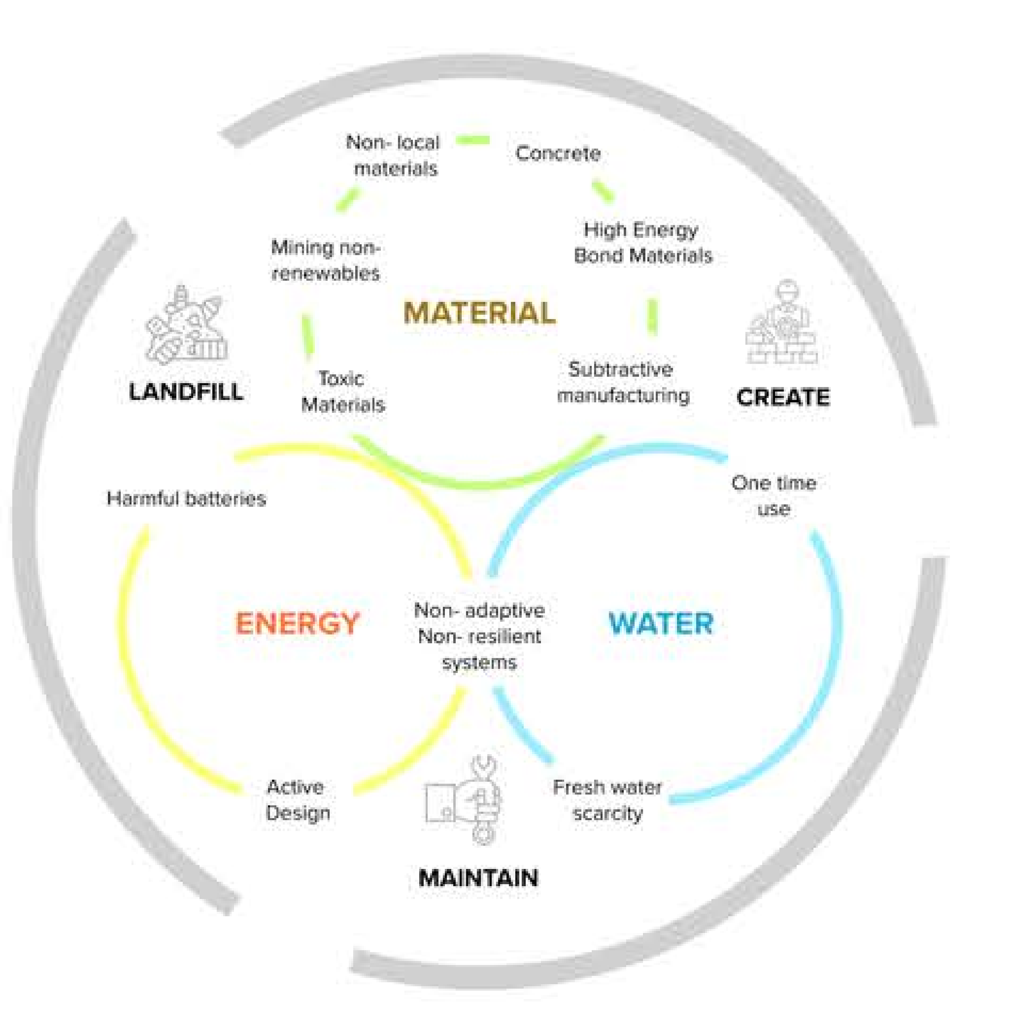
Each summer, fresh water becomes scarce in Mediterranean coastal regions. This company called HYDROUSA aims to change that by implementing a wide-scale demonstration of nature-based solutions that create an entire closed-loop water system, one of which is the Mangrove Still System.

"Mangrove Still System Presented in Dubai Expo." Hydrousa, 21 Mar. 2020, Web.

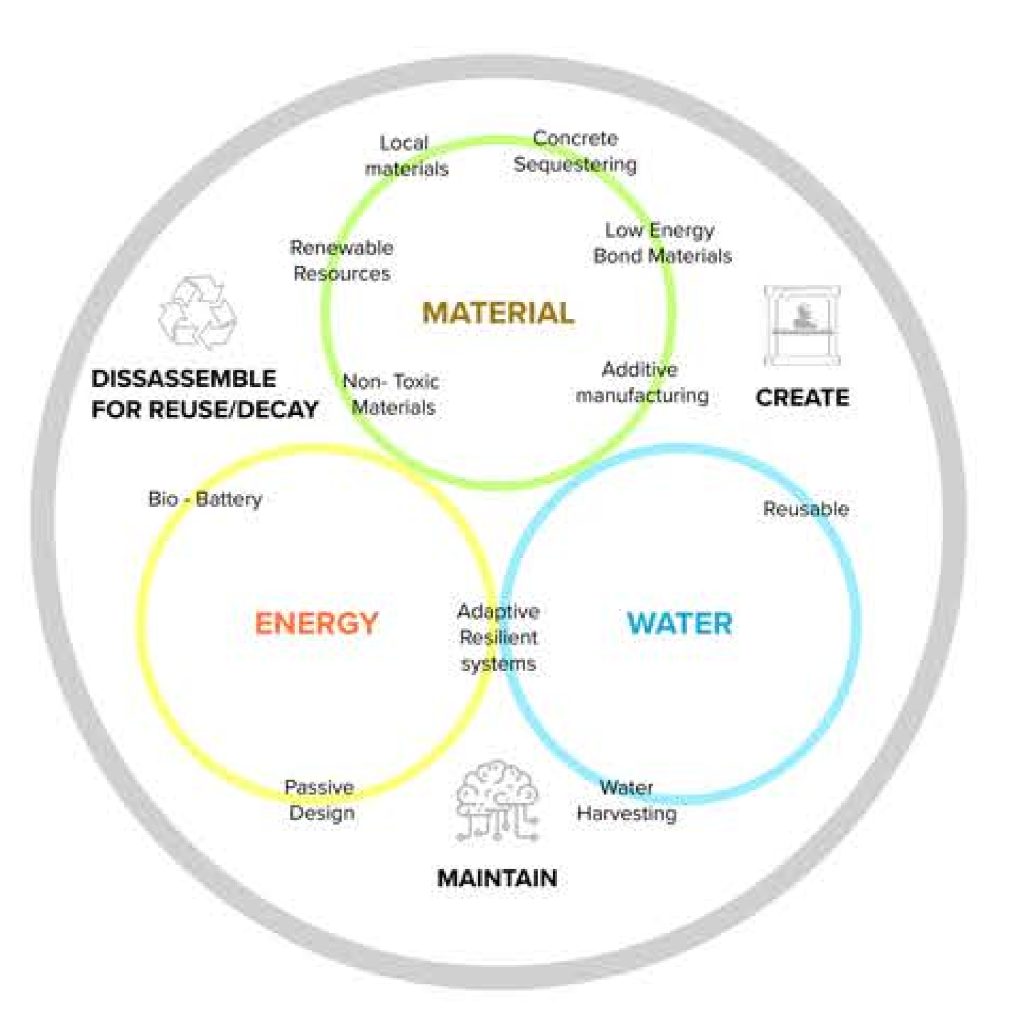
Meeker, Melissa. "The Water Crisis in the West." The New York Times, The New York Times, 30 June 2014.

"Warka Tower." Warka Water, 28 October 2020, https://www.warkawater.org/warkatower/.

BROKEN LOOPS IN BUILDING ECOSYSTEM



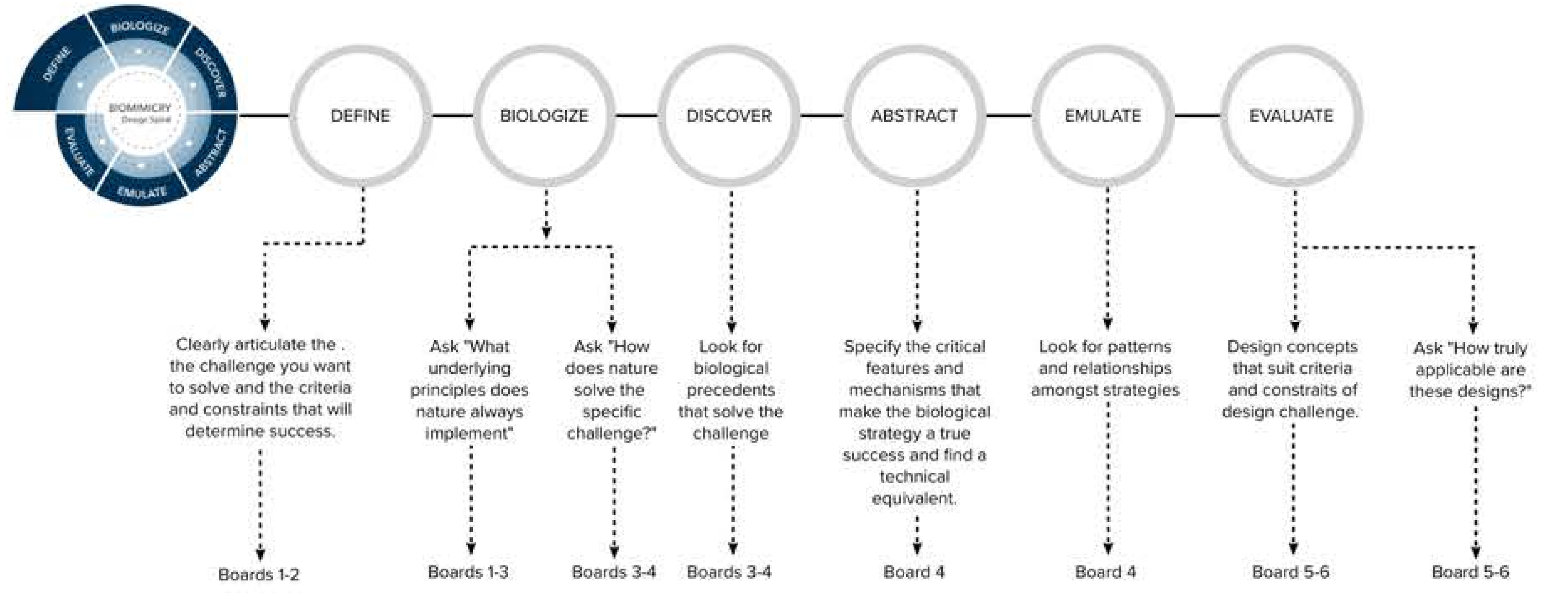
CLOSING LOOPS IN BUILDING ECOSYSTEM



Any resource entered into a building ecosystem will eventually come out from it. This is the law of resource conservation. Nature reuses the output resources as input materials, creating a closed loop ecosystem that conserves materials, energy, and water. The material, energy, and water cycles within nature are separate closed loop systems within the bigger picture closed-loop ecosystem. They are critical in that they collaborate together to form an ecosystem that is able to continuously grow and sustain itself. It is vital that the building ecosystem mimic nature's ecosystem principles if it is to become a healthy part of the planet.

DESIGN APPROACH: DOMAIN TO DOMAIN TRANSFER

The five microinterventions mentioned define a set of general criteria which align with the systems in which nature functions and hence, begins to define a healthier, symbiotic ecology that integtrates man-made design within natural design rather than in opposition to it. However, in order to adequately apply this research to a design proposal, it is essential that a specific situation and environment be chosen as a key principle of ecosystems is that they are "attuned to and dependent on local conditions." Only then can the application of performative biomimicry truly yield restorative architectural responses. The biomimicry design spiral serves as a tool to begin this process.



RESEARCH METHODS

DARK ECOLOGY BY TIM MORTON

Theoretical Argument

The fundamental premise of *Dark Ecology* is precisely the idea that there is a distancing between humanity and geology, or the continuation of a culture of distancing between the human being and their natural environment. The beginning of this book is the end and the end is the beginning. This formal experimentation reflects the loop-like eco-logic that must be cultivated if we care at all about the future of humans and nonhumans on this earth. (pg 152)

Anthropocene

The period of time during which human activities have impacted the environment enough to constitute a distinct geological change

Agrilogistics

Morton's designation for the past 12,000 years. It denotes the period beginning with Mesopotamia and agriculture in the Fertile Crescent and the logic produced by this shift from nomadic to place-based living. This is when knowledge based on linearity, boundaries, and consistency came to be.

Morton seeks to replace the Agrilofistics logic of the past 12,000 years with Ecognosis

Ecognosis

A type of knowing akin to ecological awareness, logic of coexistence "Knowing in a loop—a weird knowing." (5)

Morton refutes short-term explanations of how and why humans caused the Anthropocene, claiming that they are merely symptomatic of a deeper, older, set of assumptions that are based on a faulty ontology. According to Morton, the "logistics" behind this agricultural venture are what eventually determined and required the invention of the steam engine. It is agrilogistics, not merely capitalism, that is "the smoking gun behind the smoking chimneys responsible for the Sixth Mass Extinction Event" (43)

THREE AXIOMS THAT MUST BE ADRESSED TO COUTERACT ANTHROPOGENIC THREATS

The Law of Noncontradiction

Opposites cannot be true at the same time. This has resulted in a system of thoughts based on harmful and rigid boundaries: humans vs. nonhumans, 'productive' life forms vs. pests

Existing means being constantly present.

This system requires and perpetuates an essentialism based on the second axiom: "a metaphysics of presence" that transforms dynamic relationships and beings into static, quantifiable data. (48)

Existing is always better than any quality of existing.

The focus on accumulating quantities without regard for the resulting quality of existence

Morton seeks to show how human actions have planetary implications and how computational power has opened our frame of reference to inc lude "the task of thinking at temporal and spatial scales that are unfamiliar, even monstrously gigantic" (25).

Object-Oriented Ontology

OOO believes that reality is mysterious and magical, because beings withdraw and because beings influence each other aesthetically, which is to say at a distance.

Hyperobjects

Those concepts that must be thought of at the scale of Earth rather than of the individual

Morton's emphasis on the perception of distance between things is presented as an opportunity to let go of human assumptions about power and supremacy. The notion that nature is outside of us also means that nature is beyond our control, and this sense of the tangible otherness of nature is in fact at the heart of what Morton means by the terms "mysterious and magical," which underlines the importance of humility.

KEY MESSAGE

If there is one key message to be gleaned from *Deep Ecology* it is that "a human is made up of nonhuman components and is directly related to nonhumans" (18). Humans need to reposition the idea of themselves as central to the natural landscape. The natural world is not merely the condition of our existence.

Citation

Morton, Timothy. *Dark Ecology: For a Logic of Future Coexistence*. Columbia University Press, 2018.

Research Statement

Dark Ecology by Timothy Morton is a deeply theoretical argument for how humans came to be so removed from nature. This source is a form of psychological analysis of the human psyche and it will require analyzing human behaviors, patterns, and social interaction via both historical evidence and psychological principles of the mind.

I claim that that the entire reason why my thesis focuses on transitioning from a linear model towards a closed-loop model is because humanity has become extremely removed from it's place in nature, and therefore had caused repeated harm to the planet. In order to make any shift towards harmony with nature, we must understand how the human mind got us here in the first place.

LIVING BUILDING CHALLENGE

Regulations/Standards in Practice

The Living Building Challenge is an attempt to, in the words of Buckminster Fuller, "make the world work for 100% of humanity in the shortest possible time though spontaneous cooperation without ecological offense or the disadvantage of anyone." It is in essence a unified tool for transformative thought that allows humanity to envision a future that is socially just, culturally rich, and ecologically restorative. The Living Building Challenge is organized into the following seven performance areas: place, energy, water, health/ happiness, equity, beauty/spirit, and inspiration/education. It has been refered to as the most rigorous benchmark of sustainability in the built environment and an exceptional model for the future of architecture.

WATER

Intent of the Water Petal: to realign how people value water; to address the energy and chemicals involved in transporting, purifying and pumping water; and to redefine "wastewater" as a precious nutrient and resource. Closed loop systems based on the resources available, with localized treatment, can help mitigate environmental issues and create a more resilient water future.

Environmental Impacts: The scarcity of water is a serious issue, as many countries around the world face severe shortages and compromised water quality due to global climate change. Even regions that have avoided the majority of these problems to date due to a historical presence of abundant fresh water are at risk: the impacts of climate change, highly unsustainable water use patterns, and the continued drawdown of major aquifers suggest significant problems ahead.

I-05 RESPONSIBLE WATER USE

The intent of this imperative is to encourage projects to treat water like a precious resource, minimizing waste and the use of potable water, while avoiding downstream impacts and pollution.

I-06 NET POSITIVE WATER

The intent of this imperative is for project water use and release to work in harmony with the natural water flows of the site and its surroundings. All projects must supply one hundred percent of the project's water needs through captured precipitation or other natural closed-loop water systems, and/or through recycling used project water, and all water must be purified as needed without the use of chemicals.

ENERGY

Intent of the Energy Petal: to create new sources of renewable energy that allow projects to operate year-round in a resilient, pollution-free manner. In addition, the Energy Petal prioritizes energy efficiency as a means to reduce wasteful spending, of energy, resources, and capital.

Environmental Impacts
Today, buildings consume more energy than any other final use. Most of the energy generated for these buildings is from ecologically destructive and often politically destabilizing sources that include coal, gas, oil, and nuclear power.

I-07 CARBON REDUCTION

The intent of this imperative is to treat energy as a precious resource and minimize energy related carbon emissions that contribute to climate change.

I-08 NET POSITIVE CARBON

The intent of this imperative is to foster the development and use of carbon-free renewable energy resources.

MATERIALS

Intent of the Materials Petal: to help create a materials economy that is non-toxic, ecologically restorative, and transparent. The imperatives in this section aim to remove the worst known offending materials and practices and to drive business toward a truly responsible materials economy.

Environmental Impacts: Throughout their life cycle, building materials are responsible for many adverse environmental issues, including personal illness, habitat and species loss, pollution, and resource depletion.

I-12 RESPONSIBLE MATERIALS

The intent of this imperative is to set a baseline for transparency, sustainable extraction, and waste diversion

I-13 RED LIST

The intent of this Imperative is to foster a transparent materials economy free of toxins.

I-14 RESPONSIBLE SOURCING

The intent of this imperative is to support sustainable extraction of materials.

I-16 NET POSITIVE WASTE

The intent of this imperative is to integrate waste reduction into all phases of projects and to encourage imaginative reuse of salvaged "waste" materials.

"The main objectives of sustainable design are to reduce, or completely avoid, depletion of critical resources like energy, water, land, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are livable, comfortable, safe, and productive."

Citation

International Living Future Institute. "Living Building Challenge 4.0: A Visionary Path to a Regenerative Future." Living Building Challenge, 2 May 2019, living-future.org/wp-content/upload /2019/04/Living-Building-Challenge.

Research Statement

The Living Building Challenge will be analyzed as a starting referance point for current regulations and standards in practice for the design of sustainable architecture. This source is a form of disciplinary research in that it adopts a standard of precedent and norm for rating the level of building sustinability.

I claim that because my thesis seeks to transition from a linear way of using resources to a closed-loop model, I must look at current architecural standards of practice that have already attempted to define what regulations and standards would help yield closed-loop, regenerative solutions.

"Regardless of the size or location of the project, the Living Building Challenge provides a framework for design, construction and the symbiotic relationship between people, our community, and nature. The Living Building Challenge calls for action to restore the relationship between people and nature in an increasingly urbanized world as we become more and more disconnected from the world with which we evolved. It is a challenge to immerse ourselves in such a pursuit—and many refer to the ability to do so as a paradigm shift. Whether the project is restorative, regenerative, or operates with a net zero impact, it has a home in the construct of the Living Building Challenge."

Citation

Pawlyn, Michael.. Biomimicry in Architecture. 2nd ed., RIBA Publishing, 2020

HOW TO CRETE ZERO WASTE SYSTEMS? (Chap. 3)

Correlational Research

Biological systems have evolved to thrive in closed-loops, in which the concept of waste does not exist and everything is nutrient. Ecosystems are regenerative, resilient and run entirely on solar energy. We could do the same with our buildings and cities. To start, waste is an area that is largely ignored by designers as it is typically seen as "worthless" material. In addition, much more value can be made from the same resources, while moving towards zero waste. Biological systems teach us to see waste as an opportunity: a vital lesson. In regards to energy, Michael Pawlyn states that it is critical we transition towards relying primarily on solar energy just as ecosystems do. Lastly, water systems should be recycled in closed-loop systems.

Ecosystems: Basic Biomimic Principles
Michael Pawlyn defines the ecosytem as a system which, at its simplest, depicts elements and interconnections, harnessed to a function or purpose. The chart below delineates the primary differences between human-made systems and ecological systems.

Applying ecosystem models to cities, or parts of cities, is a much more appropriate starting point than the metabolism of a single organism because the source is one that comprises a wide variety of different actors with a high degree of interdependence and operates in equilibrium.

CONVENTIONAL HUMAN-MADE SYSTEMS	ECOLOGICAL SYSTEMS
Linear flows of resources	Closed loop/feedback rich flows of resources
Disconnected and mono-functional	Densely interconnected and symbiotic
Resistant to change	Adapted to constant change
Wasteful	Everything is nutrient
Persistent toxins frequently used	No persistent toxins
Often centralised and mono-cultural	Distributed and diverse
Hierarchically controlled	Panarchically self-regulating
Fossil fuel dependent	Run on current solar income
Engineered to maximise one goal	Optimised as a whole system
Extractive	Regenerative
Use global resources	Use local resources

Ecosystems have the further advantage that they have evolved to minimise the amount of energy and resources they have to draw from elsewhere and to minimise the amount that are lost.'

LIMITATIONS TO THE BIOLOGICAL MODEL APPLIED TO HUMAN-MADE SYSTEMS

In biological systems, the death of an organism is a transition point rather than an end point, for the materials. The equivalent can be achieved for buildings if information flows are managed properly. From a materials perspective, waste is simply material without an information strategy.

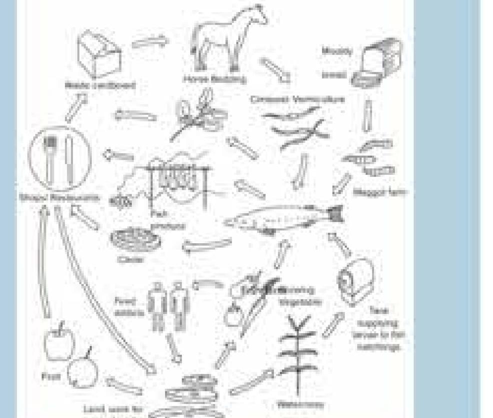
Generally, we manufacture materials with high-energy bonds, which makes them difficult to integrate into systems modelled on biology. If buildings, cities and products were made from stuff like natural polymers, with low-energy bonds, then there could be a perfect fit and we would see more building materials featured in these cycles. This shift in materials is already under way, so the wider system context becomes not only possible but essential to address.

RESILIENCE

Donella Meadows observed that 'A diverse system with multiple pathways and redundancies is more stable and less vulnerable to external shock than a uniform system with little diversity'.Judith Rodin defines resilience as 'the capacity of any
entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience. Rodin goes on to define five characteristics of resilient systems as being 'aware, diverse, integrated, self-regulating and adaptive'.

THE CARDBOARD CAVIAR PROJECT

This an inspired example of how linear, wasteful systems can be transformed into closed loop systems that produce no waste and yield much greater productivity. Conceived by Graham Wiles of the Green Business Network (GBN) in Kirklees and Calderdale, northern England, the scheme started as a way of involving people with disabilities in a recycling initiative.



Waste cardboard was collected from shops and restaurants and was shredded for sale to equestrian centres as horse bedding. The second stage was to compost the used bedding through vermiculture. Working now with recovering heroin addicts, Wiles established a fish farm to raise Siberian sturgeon. He noticed that many of the youngsters were coming to the site each day with junk food, so he decided to involve them in growing vegetables and learning about healthier eating. And this cycle continued forth to create an extensive closed-loop system where nothing was lost to waste.

It is clear that the Cardboard to Caviar Project has developed into a complex system of interdependent activities and there is a sense in which, just as with ecological succession, the more the project grows, the more the possibilities expand. It transformed a number of waste streams into valuable products.

Research Statement

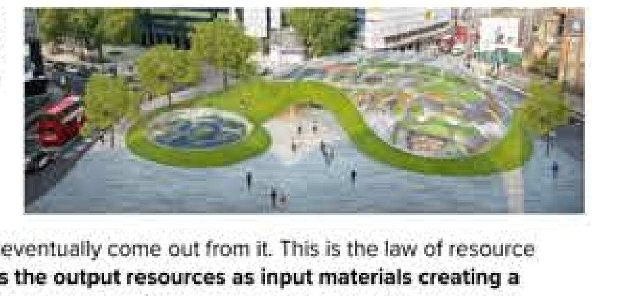
Chapter three in the book Biomimicry in Architecture looks at how to create zero-waste systems in the real world based on inspiration from nature's ecosystems. This source is a form of correlational research in that it attempts to determine the extent of a relationship between two sysrtems. Therefore, I will be looking for trends and patterns in the data, statistics, and the distribution of variables.

I claim that because my thesis is looking toward biomimicy as inspiration for closed-loop systems in the build environement, then I must look at sources that have already compared the two systems to provide me with evidence, guidelines, and precedents of both obvious overlap and limitations.

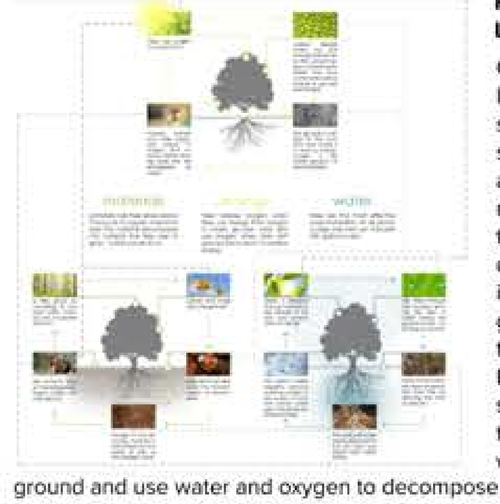
THE MOBIUS PROJECT

Architectural Precedent at Ecological Level

This project draws its inspiration from the way in which "ecosystems in nature work, where the waste of one organism becomes the input of the next, maintaining nutrients in a perpetual closed cycle with zero waste." For example, it is dedicated to revolutionising the food production industry by taking what humanity needs less of (waste) and turning it in to what we need a great deal more of (locally grown, low carbon nutritious food.) The overall goal was to create a replicable urban infrastructure system with the potential to manage a large amount of a cities production through a closed-loop circular economy approach which yields self-sustainability.



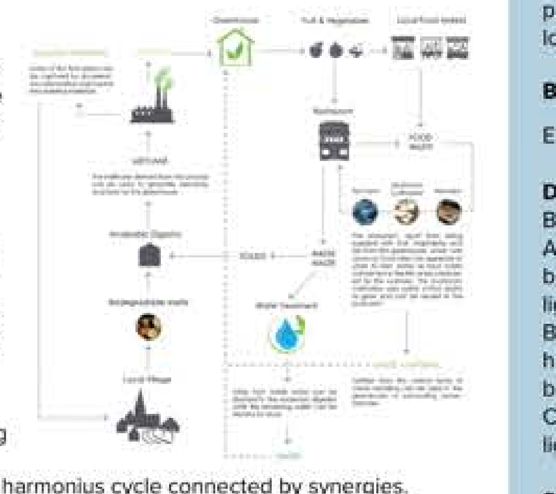
Humans design with a linear system whereas nature creates a closed-loop network, utlizing all of it's products in some form. The Mobius Project takes inspiration specifically from the oak tree's closed-loop network. As a model, the oak tree achieves everything an architect should follow while designing buildings and cities. Kim and Rigdon point out that "in the long run, any resource entered into a building ecosystem will eventually come out from it. This is the law of resource conservation." **The oak tree reuses the output resources as input materials creating a closed loop ecosystem that conserves materials, energy, and water.** The material, energy, and water cycles of the oak tree are separate closed loop systems. However, there are many synergies that coexist between them that collaborate together. Maximizing these synergies permits the oak tree to grow and sustain itself.



HOW AN OAK TREE PERFORMS LIKE AN ECOSYSTEM

Carbon dioxide enters the leaves through the stomata and then sunlight causes a chemical reaction that will turn carbon dioxide and water into oxygen and glucose, allowing the tree to grow. Raw materials such as leaves, twigs, and acorns will fall to the ground and use water and oxygen to decompose. This waste material covers the forest floor slowing down evaporation, giving the roots time to absorb water. This water is then transported up the tree to the leaves through the water column where it will be released through the stomata and evaporate into the air. If any part of the once cycle fails, the closed-loop opens and the system becomes innefficent as "these cycle thrive on each other, and the oak tree is healthiest when they are all functioning as one."

HOW THE MOBIUS PROJECT EMULATES THE OAK TREE



The Mobius Project is a scheme inspired by the innovative processes of the oak tree. There are three focal sequences: water treatment, food production, and energy generation. Just like the oak tree model, the Mobius Project innovatively integ rates these processes into a harmonius cycle connected by synergies. However, if one element fails, the system will not function. This is a designer's biggest challenge when mimicking biological models.

Citation

Iguana Architects. "The Mobius Project: Iguana-Architects." *The Mobius Project*, 2019.

Research Statement

The Mobius project is an ecological architectural precendent that utilized the ecological model of the oak tree as inspiration for a closed-loop architectural system in three areas: water, energy, and material. It is a specific example that uses correlational analysis and as such, I will be looking for patterns, statistics, and variables.

I claim that because my thesis is looking toward biomimicy as inspiration for closed-loop systems in the build environement, then I must look at specific sources that have already compared the two systems to provide me with evidence, guidelines, and precedents of both obvious overlap and limitations.

THE BIOMIMIC OFFICE BUILDING

Architectural Precedent

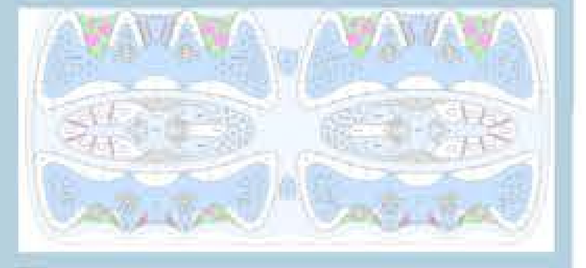
The Biomimetic Office represents a new paradigm as the first office building that has ever been comprehensively designed with biomimicry. The team worked through all the key functional aspects of office design and found inspiration from spookfish, stone plants, and brittlestars in devising daylighting solutions; bird skulls, cuttlebone, sea urchins and giant amazon water lilies for the structure; termites, penguin feathers and polar bear fur for the environmental control; and mimosa leaves, beetle wings and hornbeam leaves for the solar shading. The environmental engineer on the team has predicted that, when built, the Biomimetic Office will be one of the lowest energy office buildings in the world.

Interior Courtyard

The Biomimetic Office Building is the latest project undertaken by Pawlyn and his Exploration Architecture team.

Section

3D Section



Plan

The design uses biomimicry to rethink the workplace into a self-heated, self-cooled, self-ventilated, day-lit structure that is also a net producer of energy, will strengthen the case for biomimicry by drawing a brighter line between restorative, responsible design and cost savings. In addition to biomimicry, the project incorporates the principles of psychologist, Craig Knight, such as plants in the workplace, to address employee well-being, job satisfaction and productivity. Upon completion the Biomimetic Office Building promises to be one of the world's lowest energy office buildings.

BIOMIMIC INSPIRATION

Exploration Architecture analyzed 100 differnet biological examples. Some examples:

DAYLIGHT: sunshine as primary driver
Biomimic Inspiration
A. Spookfish: mirror structure in eye which point downwards and focus low level bioluminesence onto its retina. The central atrium was designed with a spookfish inspired light reflector
B. Brittle star: lives as far as 500 meter below in ocean surface where little light reaches, it has near optically perfect lenses that focus light on to receptors so it can dedect predators before they see it
C. Stone plant: most of it's mass is below ground for thermal stabilization, a roof light brings light downward for photosynthetic purposes

STRUCTURE: goal to reduce material
Biomimic Inspiration
A. Internal structure of the cuttlefish bone: efficient placement of material that equals rigid form and thin lamenent at top and bottom that yields 30% saving of concrete
B. Curved leaves/shells: new curved glazing system that yields 50% saving in glass

Research Statement

The Biomimic Office building is an architectural precedent that utilizes organism level biomimicry to achieve a
self-sufficient, highly sustainable building. To analyze this source, I will look at the documentation of the building to see how successful or unsuccessful the biomimic principles have proven to be.

I claim that in order to discover how useful biomimicry could be at yielding sustainable solutions in the built environment, then I must look at architectural precedents that use biomimicry at the organism level.

SOLAR SHADING
Biomimic Inspiration
A. Mimosa leaves/beetle wings: a shading system that lets in exactly the right amount of light and converts surface light to electricity learned from curved forms leaves, and shells to produce new glazing system 50 percent saving in glass

Citation

Thomson, Dave. "The Biomimetic Office Building." Exploration Architecture, 2018, www.exploration architecture.com/projects /biomimetic-office-building.

TRANSLATING BIOLOGY INTO TECHNOLOGY

Technical

STRUCTURAL EFFICIENCY: reduction in material quantity

Precedent: 3D Printed Bridge by Joris Larman Lab

Biomimic Inspiration: Trees

Material efficient results of designing with SKO software.

RESPONSIBLE MATERIALS: non-toxic elements

What elements should be used? The differences between engineering and nature become even clearer when one looks at which elements of the periodic table are used in the two approaches. Roughly 96 % of all living matter is made from four elements: carbon, oxygen, hydrogen and nitrogen.

A further seven elements constitute nearly all of the remaining 4 %: calcium, phosphorous, potassium, sulphur, sodium, chlorine and magnesium. There are then a small number of trace elements that are used in absolutely minute quantities. So, nature uses a very limited subset of the periodic table, whereas we use virtually every element in existence, including some that really would be better left in the laboratory.

MOLECULAR SELF-ASSEMBLY

Nano-scale self-assembly is crucial to how nature operates. A major opportunity to mimic this is the prospect of growing materials for buildings by accretion or self-assembly that mimics natural processes. 3D printing' or 'additive manufacturing' (AM), is the closest we have to self assembly today. It allows to approximate the bottom-up manufacturing that goes on in nature, in the way that material can be positioned exactly where it needs to be. Consequently, it offers the ability to achieve efficiency of materials through complexity of form at no added cost , simply by using less material. What should these machines print with? "What we ideally want is to be able to use a biological raw material, get it to self-assemble into polymer chains and then be able to assemble those chains in a controlled way." Machines now exist that allow mixed materials, as nanoparticles in solution, to be deposited from a jet that is similar to that of an inkjet printer.

Pneuma by Neri Oxman, demonstrating the potential for 3D printing to produce functionally graded materials in complex forms

Chitosan (one of the substances from which insect carapaces and crabs shells are made) This structure was 3D printed with biological raw materials by Neri Oxman and colleagues at MIT Media Lab

ENGINEERING	BIOLOGY
Mostly monolithic structure; little or no hierarchy	Hierarchical structure
Few interfaces; poor fracture control	Interfaces: separate control of stiffness and fracture
Fabrication from powders, melts and solutions	Growth by adaptive accretion
Externally imposed form	Environmentally influenced self-assembly
Very little environmental response	Environmentally responsive
High degree of obsolescence	Capable of growth and self-repair
Uses all elements in the periodic table	Uses limited subset of non-toxic elements

Precedent: Calera Carbon Sequestering by Brent Constantz

Biomimic Inspiration: Coral Reefs

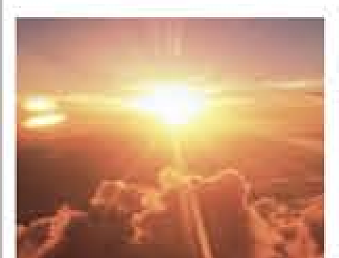
Biomineralization expert Brent Constantz of Stanford University was inspired to make a new type of cement for buildings by the way corals build reefs. The process of making this cement actually removes carbon dioxide from the air. The company Constantz founded, called Calera, has a demonstration plant on California's Monterey Bay. The installation takes waste CO2 gas from a local power plant and dissolves it into seawater to form carbonate, which mixes with calcium in the seawater and creates a solid. It's how corals form their skeletons, and how Constantz creates cement.

Carbon-cured concrete block

Energy is one of our greatest challenges, partly due to the increasingly urgent realities of climate change and partly due to a failure of strategic planning. Michael Pawlyn argues that applying biomimetic principles to energy planning inevitably leads to the solar economy as a critical goal. This has significant implications for architects and urban designers. A 'solar economy' is one in which "all our energy needs are met with renewable forms of generation." There are four principles for a biomimicry solution to energy:

1. Demand reduction via radical increases in efficiency as the priority
2. A source of energy that will last indefinitely
3. Resilience through diversity and distributed networks
4. Resource flows that are non-toxic and compatible with a wide range of other systems.

The energy received from the sun every year represents approximately 10,000 times as much as we currently use. This bountiful source of energy has sustained life on earth for billions of years and could supply all of our needs indefinitely. A nuclear-powered future is not our only option. For example, building concentrated solar power plants over roughly 5 per cent of the world's deserts would be enough to provide all of our energy needs.



A solar economy is one that is powered entirely by forms of renewable energy:

1. direct solar energy: principally photovoltaics and concentrated solar power
2. indirect solar energy: wind, wave and biomass
3. related natural-source: tidal and geothermal energy

How nature stores energy:

How humans store energy:

SMART SYSTEMS & SYSTEM COMPATIBILITY

The other way in which nature manages fluctuations in energy supply is by simply doing more growing or metabolising when there is energy available, and less when there isn't. We can apply the same principles by using smart controls that switch equipment off during short-term peaks or varying the cost of electricity to redistribute demand.

DEMAND REDUCTION

What levels of energy saving are realistically achievable? Using only current technologies and maintaining or improving the average European's quality of life, David MacKay186 shows that we could reduce our energy demands from 125 kWh per day per person down to 68. Many of these savings involve the built environment.

Precedent: Eastgate Centre in Harare, Zimbabwe

Biomimic Inspiration: Termite Mounds

The consensus amongst climate scientists predicts that much of the developing world in tropical latitudes will experience a substantial loss of agricultural productivity due to temperature increases and a reduction in rainfall. Other parts of the world, generally temperate regions, are likely to experience increased precipitation. Agriculture will change under these pressures. Rethinking our waste-water treatment methods could help to restore the fertility of our soils and re-plumbing buildings and cities with energy. This new context should be viewed as a challenge to design: we can ameliorate both lack of water and its excess using biomimetic design.

The good news is that many comparable problems have already been solved by organisms that have had to adapt to environments in which water is scarce, intermittent or excessive.

MINIMIZING WATER LOSS: HARVESTING & STORAGE

All creatures adapted to living in arid conditions have some means of reducing water loss. This often involves using non-living matter to create shade, trapping a layer of air next to the organism's surface to reduce the evaporative gradient, or a combination of the two.

Precedent: The Seawater Greenhouse

Biomimic Inspiration: Namibian fog-basking beetle

The Seawater Greenhouse is an invention by Charlie Paton that uses the evaporation of seawater to achieve factor-8 savings in irrigation. Wind drives air over evaporators at the front of the greenhouse, creating a cool and humid growing environment for crops in arid regions, while the plants inside benefit from lower temperatures and the high humidity, reducing their transpiration rates. The building essentially mimics and enhances the conditions in which the beetle harvests water. Saline water is turned into fresh water using just the sun, the wind and a small amount of pumping energy

CLOSING WATER LOOPS: HYDROUSA

European Union funded project that is using nature-based systems to close water loops, feed the soil, and promote local economies. Each summer, as temperatures climb and a crush of tourists descends, fresh water becomes scarce in Mediterranean coastal regions. This ambitious project called HYDROUSA aims to change that by implementing a wide-scale demonstration of nature-based solutions that create an entire closed-loop water system. The goal is to use wastewater, rainwater, humidity, and seawater to create a regenerative system that will produce fresh water for agricultural and household use, plus create jobs in the region.

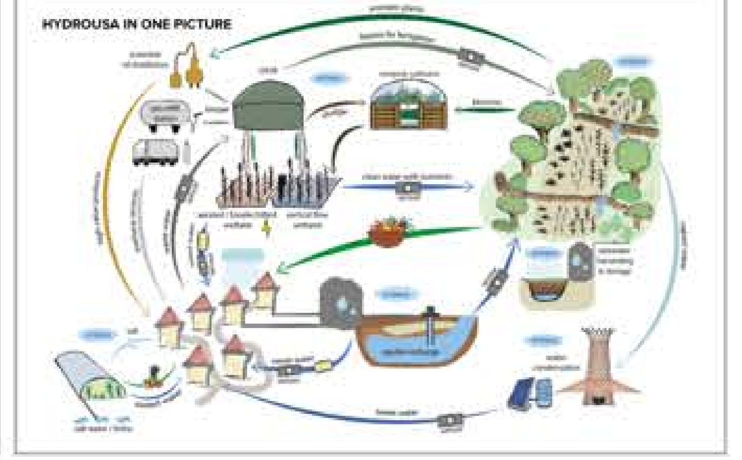
Precedent: HYDROUSA Biomimic Inspired Technologies

Desalination

Biomimic Inspiration: Mangrove Trees

Design Solution: Mangrove Still System

HYDROUSA IN ONE PICTURE



Citation

Pawlyn, Michael. *Biomimicry in Architecture*. 2nd ed., RIBA Publishing, 2020.

Salazar, Jorge. "Brent Constantz Builds Cement like Corals: Human World." EarthSky, 9 Dec. 2017, earthsky.org/human world/brent-constantz-builds-cement-like-coral-do/.

Research Statement

The Biomimicry in architecture book has chapters on water, energy, and material. After much reading, it is clear that in order to implement biomiimicry into the build enviornment, we must have technologies that can emulate nature's functions. This source looks at what we can learn from nature's closed-loop use of water, energy, and material in order to implement closed-loop systems in all three areas within the built environment. In addition, it specifies technologies that would serve those functions.

I claim that in order to create closed-loop systems in the built environment, we need to create and utilize technologies that do not harm the enviornment, but rather, aid the environment in achieveing self-sufficiency and that is this sources function.

Biomimicry works at all scales of architecture and can even be extended to scales beyond the reach of conventional architecture. It is ultimately a systemic approach that involves translating the biological into the technological equivalents.

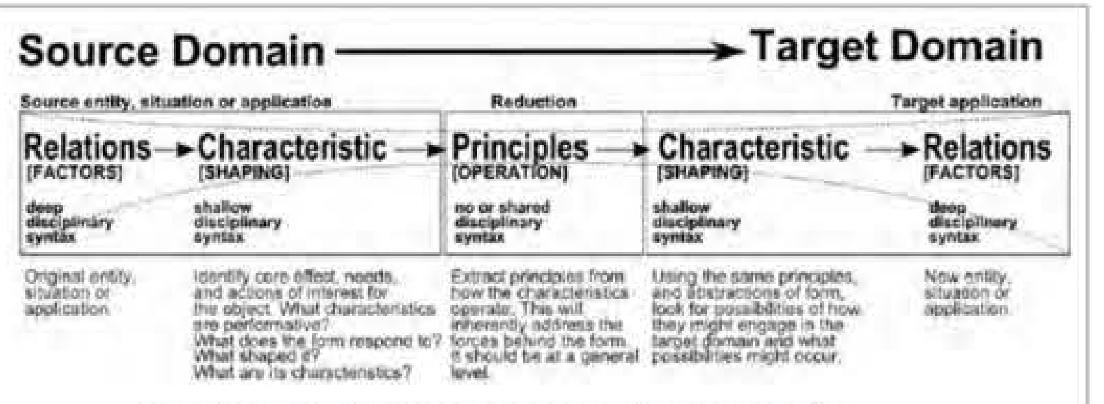


Figure 7.4: Diagram of cross-domain mapping through first principles reduction

CONTEXT: How biomimicry can inform architectural design in harsh desert environments

ANTI-DESERTIFICATION ARCHITECTURE BY MAGNUS LARRSON

Desertification is major threat on some continents. It affects approximately 110 countries and baout 70 percent of the world's agricultural drylands. It primarily affects both Africa and China and leads to crashing food and water systems, forced migration, political instability, animal extinction, and the destruction of healthy ecosystems.

Desert habitats created using microbe

Dune Anti-Desedrtification Architecture investigates adaptive (as opposed to mitigatory) strategies leading to the creation of a climate conscious architecture that responds to the extreme environments of tomorrow's globally-warmed world. The scheme aims to find innovative solutions to combat desertification in the Sahel region of Africa, where sand dunes are currently moving southward at a breathtaking pace of around 600 mm per year, ruining the land and making it impossible for the inhabitants of this area to make a living or even stay in their homes. The forced migration of desertification refugees is perhaps more threatening in Nigeria than anywhere else. With a population of over 140 million people, Nigeria is the most populous country in Africa, with serious desertification issues throughout its northern states.

Magnus Larsson has proposed creating habitable spaces from the desert sand itself. The desert sand can be solidified using bacillus pasteurii, a microorganism with which professor Jason DeJong can turn sand into sandstone in a mere 1,400 minutes. In other words, organically cementing networks of sand dunes can become habitable barriers that stop the desert from spreading. By cutting through the sand dunes and difing down to find water and sahde, an artificial oasis can be formed underground for people to live in. This sandstone habitable space further provides a physical structure to which trees can be planted, reducing desertification even more so. Sand stopping devices made of sand could become a poetic proposal for desert regions and simultaneously works n a sustainable way by using local materials and renewable resources.

"Sand stopping architecture made from sand"

SAND BABEL: SOLAR- POWERED TWISTING SKYSCRAPERS 3D PRINTED WITH DESERT SANDS

Chinese designers Qui Song, Bai Ying, Ren Nouya, Kang Pengfei and Guo Shen thought of utilizing deserts to provide more housing as the world population increases and deforestation makes deserts increase in number and size.

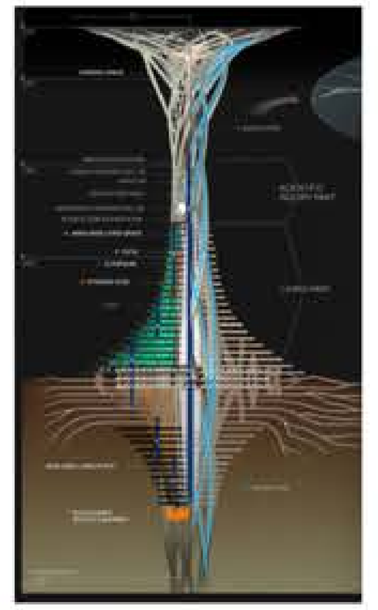
Their desert skyscraper dubbed Sand Babel is a twisting, solar powered, 3D printed skyscraper built from desert sand. With the Sand Babel, the designers envisioned makng Sahara a residential colony with a network of skyscrapers across the heart of the desert.

The Sand Babel will be manufactured using a solar powered 3D printer and would be constructed using almost entirely sand. Designed in shape of twisting skyscrapers, Sand Babel will have a network of underground tubes, which would comprise of residential spaces, facilities built for tourism, and soaces for carrying out research.

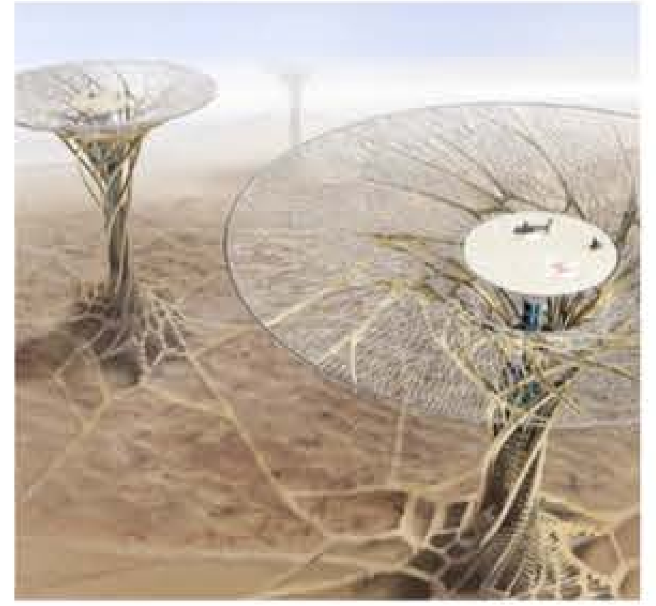
The forward thinking Sand Babel has two chief sections- one is underground and the other above ground. The skyscraper upper section is a kind of spiral skeleton, while the treelike lower structure is made to keep the building stable and to prevent sand from flowing in. The underground section as mentioned, acts as the root of the structure and comprises of all communication facilities. Interestingly,

The spiral skeleton would have a water generating system located on its mushroom-shaped roof, which uses temperature differences to generate water through condensation. Dual funnel cross ventilation would run along the entire building and keep the interiors cool during the day. One of the key aspects of this project is multiplicity. In other words, this design is intended to be a series of towers that creates a livable human environment (city-scape) and increases the bio-diversity of the desert area.

The spiral section of the skyscraper will have a mushroom shaped roof with a water generating system. The roof would use temperature difference in the structure to generate water through condensation. The building also boasts a Dual funnel cross ventilation system, which would keep the interiors of the structure cool all day. For its futuristic design, the desert skyscraper earned an honorable mention at the annual eVolo skyscraper design competition.



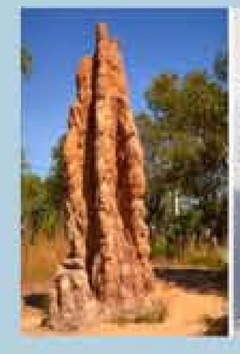
"Additive Manufacturing - using desert sand itself "



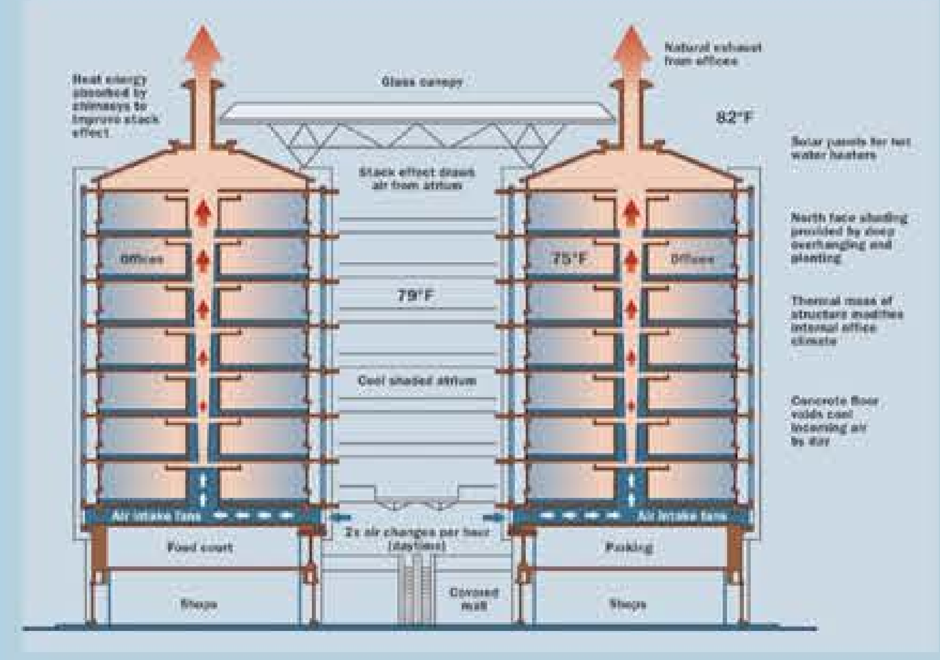
EASTGATE CENTRE IN HARARE, ZIMBABWE INSPIRED BY TERMITE MOUNDS

Termites were the primary source of inspiration for the Eastgate Centre, an office building located in Harare, Zimbabwe. Termites in Zimbabwe build gigantic mounds inside of which they farm a fungus that is their primary food source. The fungus must be kept at exactly 87 degrees F while the temperatures outside range from 35 degrees F at night to 104 degrees F during the day. The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. They essentially make use of stack effect, convective airflow from cool to warm. The termites are constantly tweaking these openings for optimum performance, sometimes adding wet mud that aids cooling with its evaporative effects.

The complex is actually two buildings that shelter an interior atrium. Heat gain is reduced by limited glazing, deep overhangs, and the building mass, and the architect took advantage of night cooling, thermal storage, and convective air currents to moderate temperatures. During the day the heavy building mass and rock storage in the basement absorb the heat of the environment and human activity. At night, cool air is allowed into the bottom of the building and starts the convective flow that vents the hot daytime air through roof vents. This cool air is also stored and then distributed the next day into offices via hollow floors and baseboard vents.



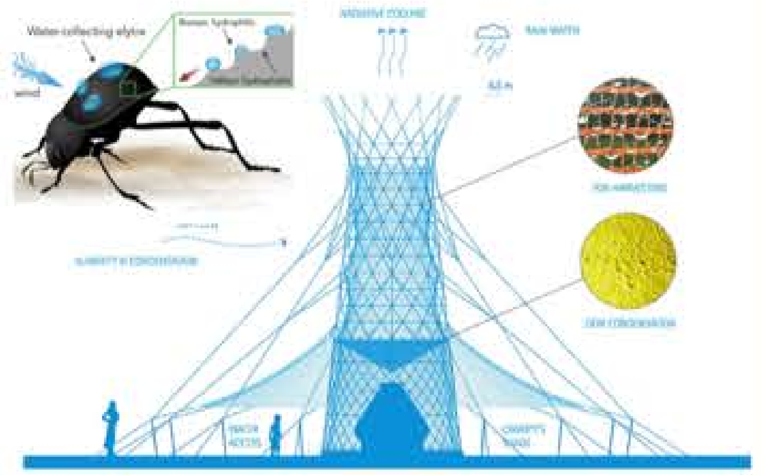
Biomimic Inspiration: Termites Mounds utilize a series of heating and cooling vents throughout the day



These passive techniques, although not able to supply all of the climate control for the building, contribute to some impressive building conservation statistics. The 32,000 square meter building was built with 10 percent of the typical ventilation costs for the area, 35 percent less energy costs, and 10 percent fewer typical capital costs, translating to a savings of $3.5 million for a $36 million. The building does not have nor require an air conditioning system.

WARKA WATER RAINWATER HARVESTING

Warka Water is group that is helping impoverished communities in Cameroon, Haiti, and Togo attain clean drinking water. Specifically, they designed the Warka Tower which harvests water from the atmosphere (rain, fog, dew). The design was in part inspired by the Darkling Beetle which uses micro-sized grooves on it's hardened forewings to help condense and direct water towards it's mouth. In addition, a combination of hydrophilic (water attracting) and hydrophobic (water repelling) areas on these structures increase fog and dew harvesting efficiency.



The tower not only provides a fundamental resource for life- water- but also creates a social place for the community, where people can gather under the shade of its canopy for education and public meetings. The cycle does not stop there though. Warka Sanitation provides safe water for personal hygiene and adequate latrines. With a dry system, human waste is turned into useful compost. The urine, diluted, is used as a natural fertilizer. The human waste produced (feces and urine) is turned into useful compost and recycled to support agriculture and reforestation. In other words, human feces helps support vegetative growth which could be useful in restoring desert biodiversity.

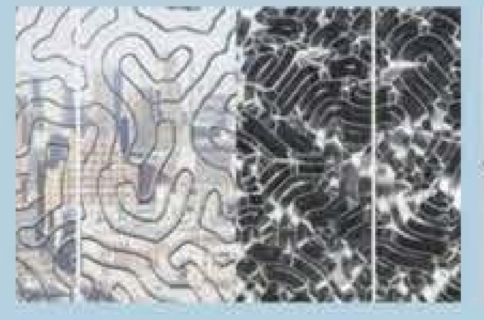
Warka Sanitation allows safe and convenient urination and defecation in an accessible, and dignified setting. With separated rooms for men and women, each toilet has 2 outlets: for urine, and excrement (liquid/ solid waste). It provides safe water and facilities for washing (sanitation and personal hygiene). It is designed to effectively capture human waste in a safe compartment and store it. A dry system operates without flush water. The soil is added so that the excrement dries out quicker. This is useful because water is not easy to come by in desert climates. It also supports a cycle where excrement has a purpose, seen as a nutrient rather than as waste to be dispoed of or to pollute an already healthy environment.

SOLAR ADAPTIVITY: SELF-REGULATING HOMEOSTATIC FACADE SYSTEM BY DECKER YEADON

Inspired by the compression of human muscles and homeostasis in biological systems. the Homeostatic Facade System regulates a building's climate by self-shading. It was designed by the architectural material technologist firm Decker Yeadon.

So how does it work? The homeostatic Facade System has a double-skin glass facade system that opens and closes itself in response to the internal temperature of the building. Smart materials regulate the building's climate, just as many organisms maintain their own temperatures through homeostasis.

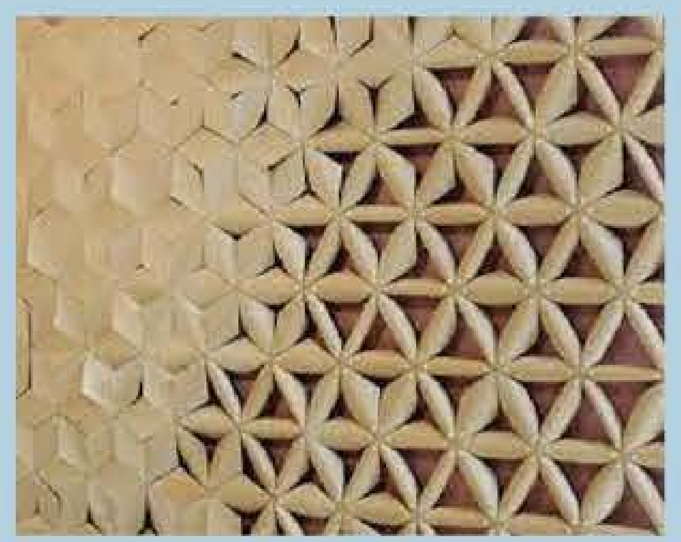
The facade looks like a window with swirling lines. Those are ribbons of an elastomer wrapped over a flexible polymer core. A silver coating on the elastomer can be polarized by applying an electrical current. The ribbon then distributes that electrical charge across its surface causing it to deform. When sinlight warms the interior of the building during part of the day, the elastomer expands, creating shade inside the building. When the interior cools, contraction occurs allowing more light to penetrate the building's interior.



WATER REACTION FACADE INSPIRED BY PINECONE

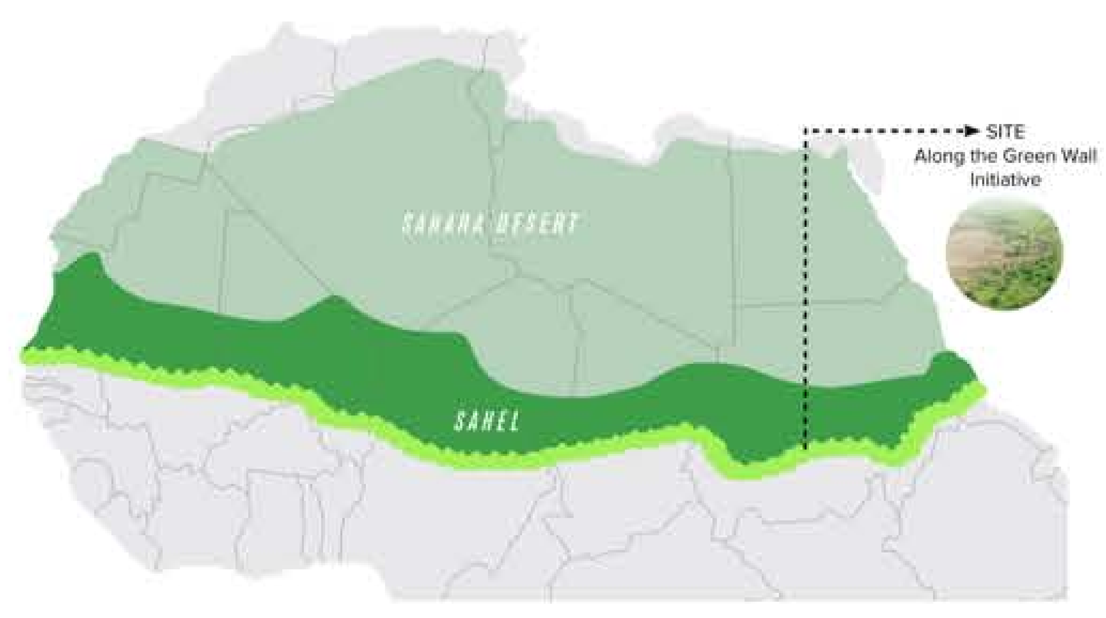
Water Reaction is an attempt by architect Chao Chen to create a material that reacts to external rainfall conditions with no human input required. Chen was inspired by a pinecone, knowing that pinecones naturally open and close ot protect their seeds from wet weather and allow them to be spread when it's dry. Interested in how this could be replicated,

Chen discovered that pinecones were actually made up of two layers, one of which is more porous than the other. When wet, the outer layer expands more than the other layer, causing the scale to bend and close the cone. Using fabric, a thin fil and a layer of veneer wgere the fibres expand across the grain , he created a tile where the outer layer elongates and curves the material away when wet. While not yet implemented, this tile has the potential to create a highly responsive facade.



PROPOSED SITE

Nature's responses are always dependent upon the specific ecosystem in which they inhabit. As a result, the implementation of performative biomimicry must always be situational. For the purpose of this investigation, the city of Sokoto, Nigeria located within the Sahel Region of Africa was chosen as the architectural proposal site location due to a few key reasons.



REASONS FOR PROPOSED SITE

1. **Desertification:** A goal of this investigation is to design an architectural proposal within an environment increasingly threatened by the effects of human ensued climate change. Desertification, or the process by which dryland becomes degraded permanently, happens to be one of the most catastrophic results of climate change. In addition, the Sahel Region is one of the most threatened locations in the world by oncoming desertification. Currently classified as a semi-arid region, it becomes more and more threatened in transitioning toward a hyper arid region as the Sahara desert just north of it ventures south.

   Effects of desertification: persistent droughts, decrease in agricultural yield, resulting in famine, conflicts over dwindling natural resources, Mass migration, Loss in natural biodiversity, Increased overty throughout continent, Stunted physical & cognitive development, premature death

2. **A clearly definable threatened border:** The Sahel region spans across the entire width of Africa, along the southern edge of the Sahara desert. In other words, this location is an opportunity for design that not only halts the spread of desertification across the entire continent, but regenerates this increasingly harsh ecosystem.

3. **Nature has solved complex functional challenges amongst even harsher planetary conditions than those in the Sahel:** In other words, nature most certainly has adapted solutions and evolved responses for living in areas like the Sahel Region. This makes it an ideal location for the implementation of performative biomimicry to aid in architectural design

4. **The Green Wall Initiative:** In addition, the chosen site peaks interest as attempts to restore the Sahel region have already begun. The group behind these attempts is called The Green Wall Initiative, an African-led movement whose aim is to reduce the effects of desertification in Africa. It intends to do so by creating a wall of plants along the Sahel region. As of 2020, the organization has already restored about 15 million hectares of degraded land in Ethiopia alone. Additionally, 12 million drought resistant trees have been planted in Senegal. Their goal is not only to rehabilitate the land, but to create a symbol of sustainable environmental practices in the region. The proposed design will be weaved within the Green Wall Initiative, not only to strengthen its efforts, but to pay homage to humanity coming together to solve an environmental crisis.

THE SAHEL REGION AS PHOTGRAPHED BY SEBASTIAO SALGADO

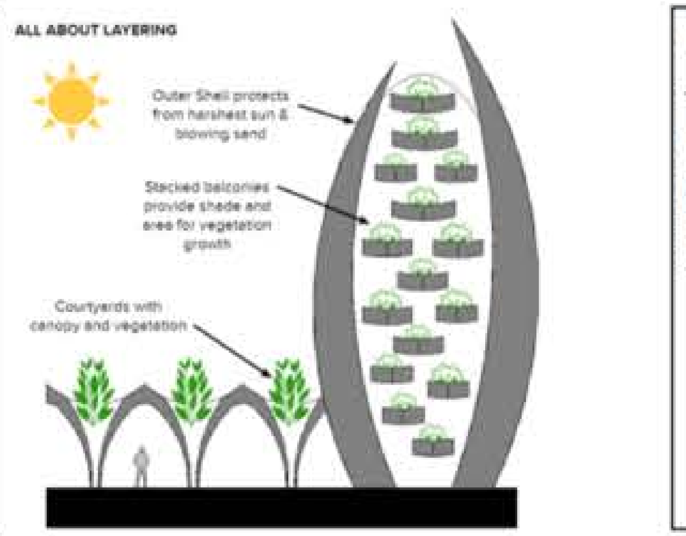
SYNTHESIS: DOMAIN-DOMAIN TRANSFER

Architecture as a discipline inherently has knowledge that is found inside and outside of the domain. In Phillip Plowright's book "Revealing Architectural Design: Methods, Frameworks, and Tools" he states that "Outside knowledge cannot be used directly in architectural processes and proposals. There will always need to be a form of translation which mediates non architectural knowledge into an architectural response. This is called domain-to-domain transfer. The following precedents did just that. The sketches to the right have begun isolating the knowledge from the source domain (nature) found in the precedents and reapplied them to achieve other taget domains (architectural designs).

Example: "A tree, as an object, is part of the biological domain, but if reduced to its operational factors, such as the nature of its shading function or a system for conducting nutrients, these fundamental principles can be accessed by other domains, such as architecture or engineering." -Plowright

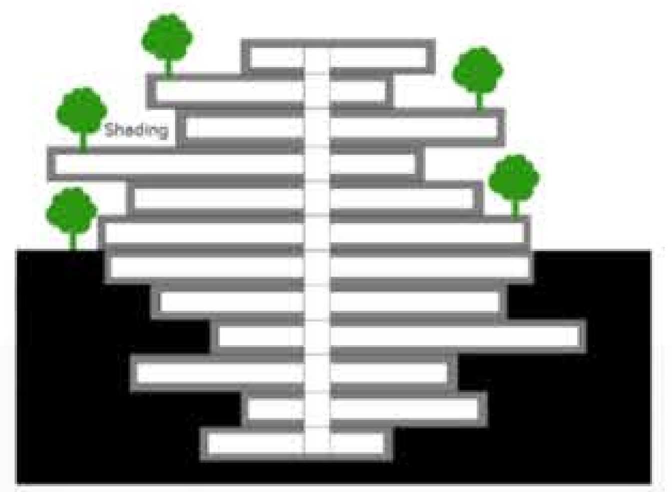
How do we build in deserts in order to prevent desertification?

- Layering, layered building envelopes (shadows allow for creation of a microclimate)
- Multiplication (an architectural ecosystem similar to a forest)
- Inversion (bigger at top than bottom)
- Vegetation (Also called "desert greening," it has the potential to help solve global water, energy, and food crises by altering the natural ecosystem via the reclaiming of biodiversity)
- 3D printing with the local sand itself or sand-stone habitats via sand solidifying bacteria
- tall buidlings to prevent sand spread



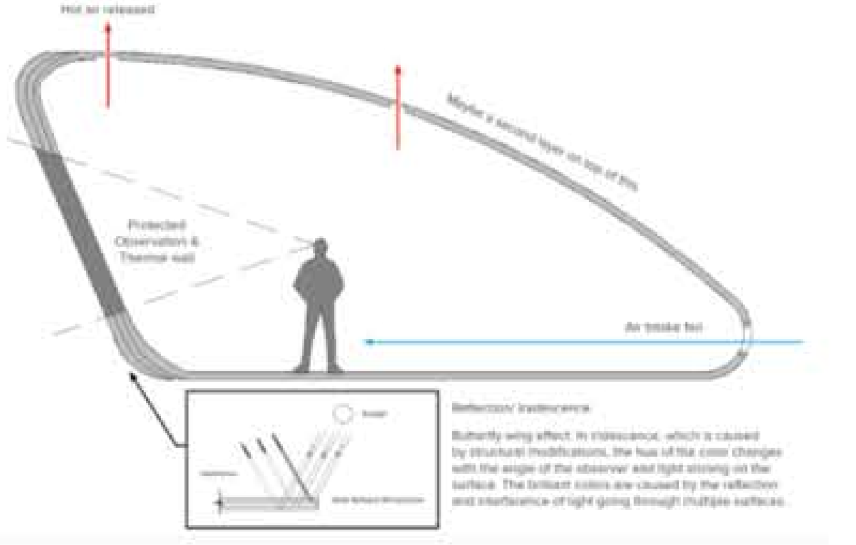
Utilizing the earth beneath

The ground provides significant protection from the balring desert heat. A building partially beaneath the ground is not only cooler but it is also more structurally sound as sand is not the most stable. There is also an opportunity to overlap the different levels and create additive shade above ground.



Heating/Cooling

This model is essentially a reimpretation of the techniques employed above, but this time on a smaller scale (a home or small dwelling.) In additon, other differences include a fluid form and a reflective facade which is modeled after butterfly wings. The stacked multiple surfaces which reflect also result in an iradescent facade.

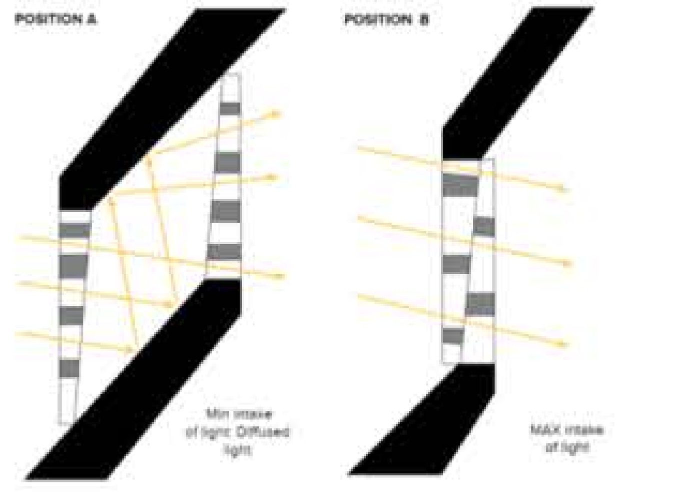


Rainwater Harvesting system

A building envelope that uses a series of discs to capture mositure from the morning desert fog similar to how the Nabibian beetle perfoms its "fog basking" ritual. Each disc is set on a pivot and tilts when enough water has accumulated. It then runs down a roof membrane and into an inverted planter which can create vegetative biodiversity within desert buildings, maybe even grow food. This technology has the potential to maybe even deviate the water in two streams, one for the collection of drinking water and one for the planters to grow food solving the lack of food and water problem.

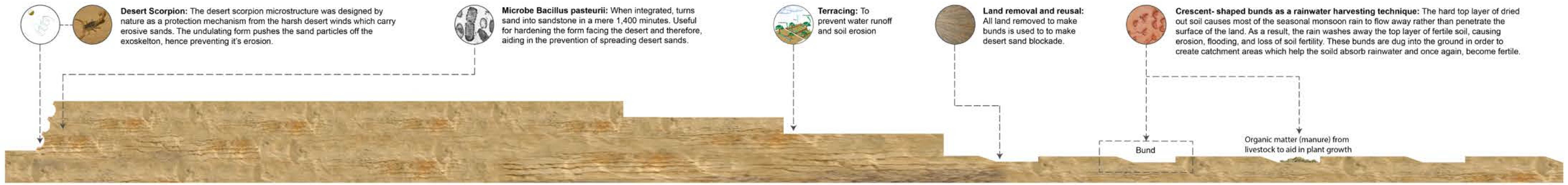
Adaptive facades could be the future of thermoregulation and light entry regulation.

This panel was designed with the intent of using solar sensors. During the day, the panel slides in position to allow an air pocket within and deviate direct sunlight entry. The interior result is both cooler indoor temperatures and diffused light. At night, the panel (which also doubles as a thermal mass), slides in such a way as to maximize sunlight entry. It also releases the heat sotred in the thermal mass to heat at night.

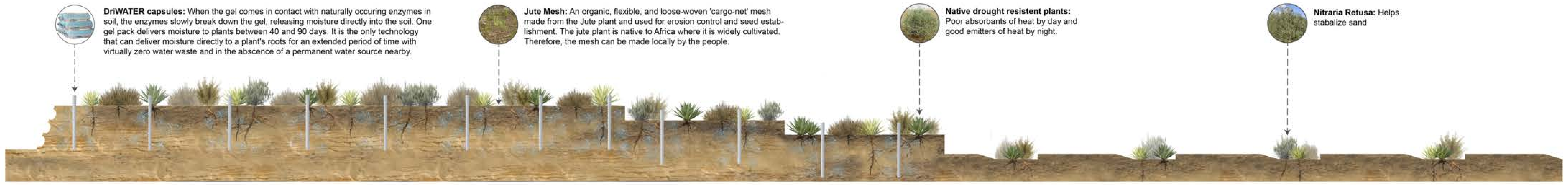


DESERTIFICATION PREVENTION & LANDSCAPE RESTORATION

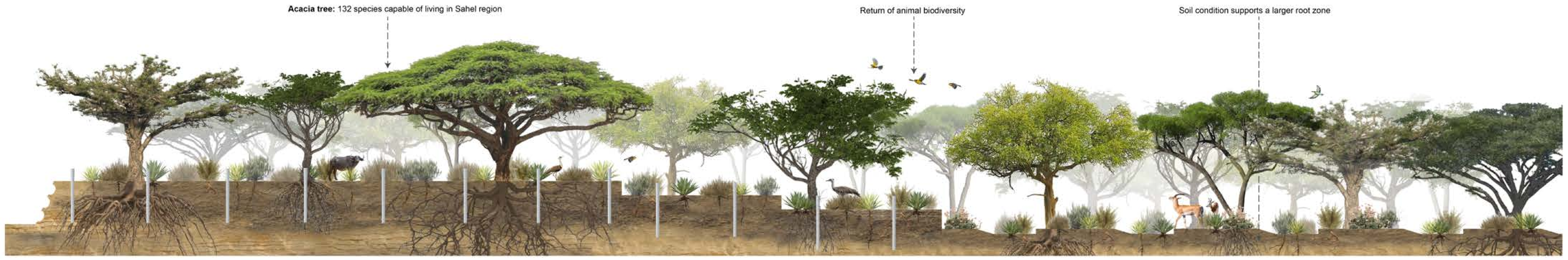
YEAR 0-2 Mold and form the natural environment to prevent the spread of traveling desert sands. Start this phase during the dry season.



YEAR 2-5 Begin phase one pioneer planting to stabalize and add organic material to sand. This is the first step in soil creation. Integrate Driwater Wells for soil hydration and Jute Mesh for further soil stabilization. Start this phase during the wet season.

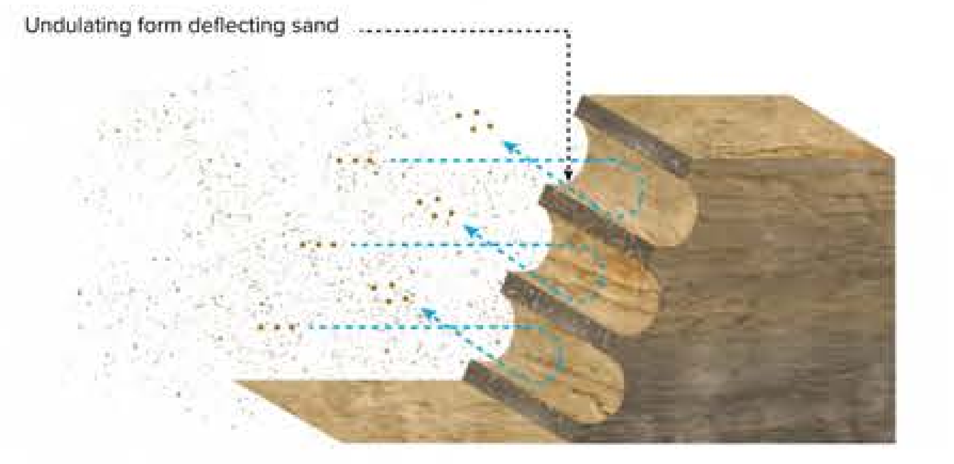


YEAR 5-10+ Begin phase two pioneer planting now that soil conditions can support a larger root zone. This phase includes larger plants such as trees and the beginning of the return of biodiversity and healthy crop cultivation. Start this phase during the wet season.

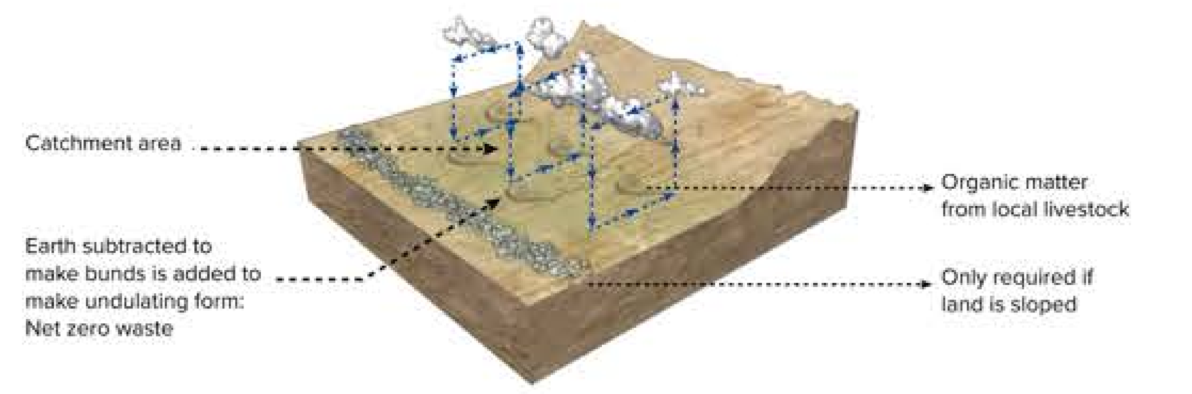


TOOLBOX FOR SUCCESSFULL IMPLEMENTATION

Sand stopping form and bund integration The earth dug up to make bunds is utilized to build undulating form.



The majority of sand from the Sahara desert travels to the Sahel region at an elevation of 0 to 40 feet. Therefore, a 30 foot height is recommended with plant and tree growth above to make up the remaining 10 feet.

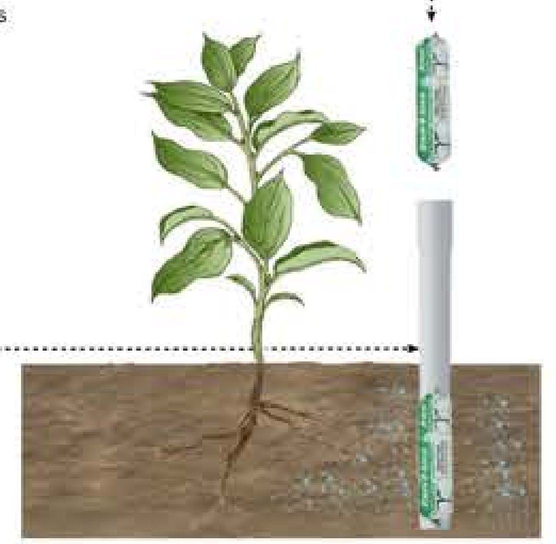


For a fairly flat surface like that of the Sahel region, the recommended bund spacing is 32 feet between each bund with a following row of bunds every 40 to 50 feet. They should each be dug about 3 feet deep and organic matter, such as livestock waste, should be incorporated to promote plant growth.

Driwater capsule and Jute Mesh integration Both are critical for soil stabilization and successful plant growth.

Break open gel pack and insert into PVC piping. One pack delivers moisture between 40 and 90 days with virtually zero water waste.

Plants in arid regions have adapted to grow very deep roots to both tap into deeper groundwater and to prevent from erosion caused by spreading sands. Therefore, PVC piping should be dug into the ground at a depth of about 3 feet for the smaller plants in phase 1 pioneer planting and and 7 feet for trees in phase two pioneer planting as these are the average root lengths for desert plants and trees respectively.



Jute mesh can be made in various sizes. However, the recommended opening size has to do with finding a balance between maximum soil stabilization and open area for vertical plant growth. It is generally 70-75 percent of the plant full grown size. The mesh itself should be 0.25 inches thick

The Jute mesh plant is native to the Sahel region where it is widely cultivated. Therefore, it is recommended that locals are contracted to create the Jute mesh required for soil stabilization. This is an excellent opportunity for the women of the region, who often have a difficult time finding jobs.

Plant and animal species for re-integration All species are local to Sahel region and thrive in arid environments.


Ephedra Alata (medicinal plant)

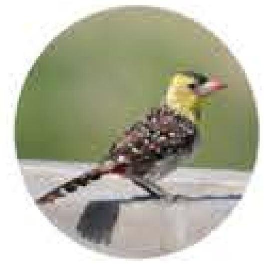

Acacia Tree (drought resistant)


Nitraria Retusa (erosion control)


Wild Desert Gourd (fruit Bearing)


Lapperine Olive Tree (erosion control)


Red Fronted Gazelle


Yellow Breasted Barbet

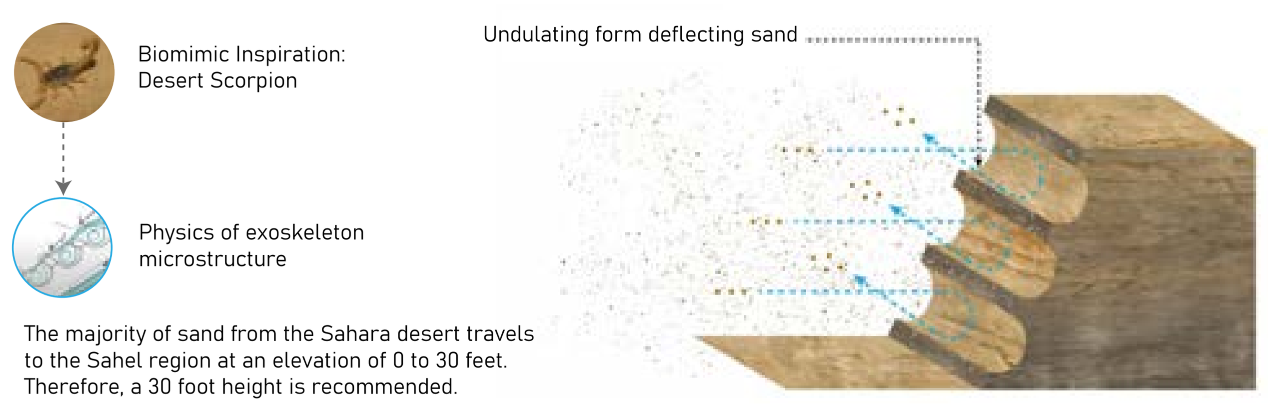

Arubian Bustard


African Buffalo


Cut Throat Finch

SERIAL INVESTIGATION: ARCHITECTURAL PROPOSAL

ANTI-DESERTIFICATION STRUCTURE: Anchor for all serial investigations



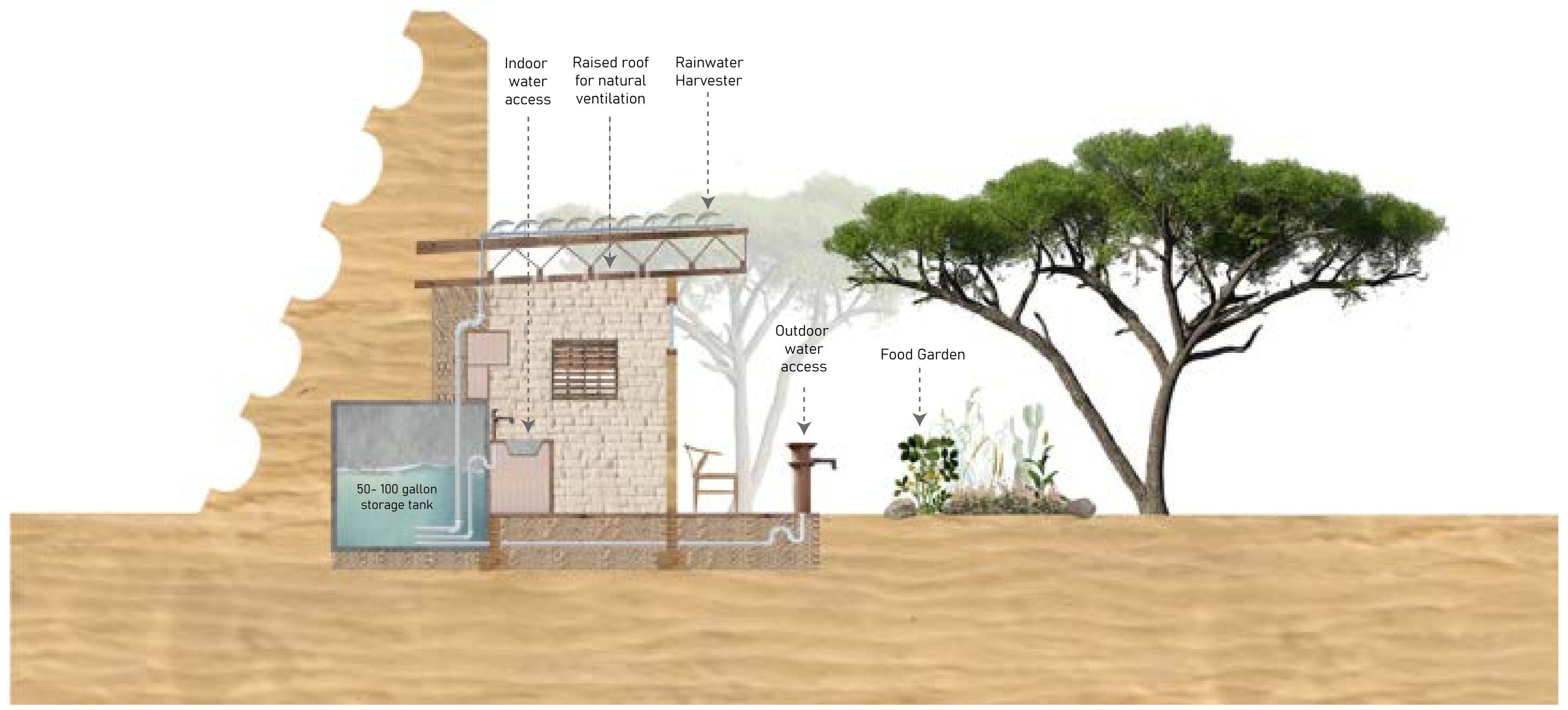
The majority of sand from the Sahara desert travels to the Sahel region at an elevation of 0 to 30 feet. Therefore, a 30 foot height is recommended.

INTRODUCTION

The serial investigations shown below are intended to be viewed as a kit of parts which could integrate, somewhat in a modular fashion, to the southern edge of an anti-desertification structure. The anti-desertification structure is central to all of the serial investigations. Specificall, the structure would span the width of the African Sahel with the purpose of preventing further desertification going south. What I theorize would make the structure effective is the physics behind its northern face. Designed as an undulating mass, it emulates the microstructure of the desert scorpion exoskeleton which was designed by nature as a protection mechanism from the harsh desert winds that carry erosive sands. In other words, the form of the scorpion's microstructure pushes incoming sand particles off its exoskeleton, hence preventing erosion. As seen in this image to the left, I believe the proposed anti-desertification structure would act in a similar fashion.

It is important to specify that each proposal represents a general design which would be tailored more specifically to the needs and culture of the community implementing it. For example, the people would first determine what spaces or systems are missing within their communities. Then, they would implement the desired design from the kits of parts while simultaneously incorporating their cultural aesthetics within the design. This kit of parts hopes to help close ecosystem loops in what is one of the most harsh environments of the world not only to restore the landscape but to support both the existing architecture and the people living within these harsh regions.

WATER COLLECTION



RESIDENTIAL SCALE: Drinking water, cooking, sanitation, small scale gardening/agriculture

BIOMIMIC INSPIRATION: Darkling Beetle

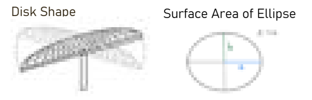
TECHNOLOGICAL EQUIVALENT: Rainwater Harvester

PROOF OF CONCEPT

The roof uses a series of mesh discs to capture moisture from the morning fog. Each disc is set on a pivot and tilts when enough water has accumulated. The water is then stored in an underground tank, where it is kept cool until later use.

WATER ACCESSIBILITY AND USAGE IN SAHEL REGION: The average household living in the Sahel Region needs to send a family member to walk about 4 miles a day to get to a groundwater well or spring that may or may not be clean and only provides them with between 3-5 gallons of water a day.

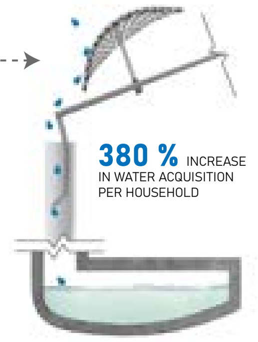
POTENTIAL DEW CAPTURE WITH RAINWATER HARVESTER: Based on comparing proposed technology with a prior study done by the company Warka Water which gathered 20 gallons of water a day in the Sahel region. (Surface Area: 862 ft^2, 20 gallons/day)



Proposed Disk Dimensions
a= 4 inches b= 3 inches
Disk Surface Area
A=pi(4)(3)
A= 37.7 inches^2

20 gallons/862 ft^2= x gallons/37.7 inches^2
x= 0.87 gallons water per disk
Therefore, a standard household would only need to have 6 mesh disks to obtain 5 gallons of water per day with no travel required.

However, according to the United Nations, 6 gallons of water is recommended each day per person to satisfy proper drinking, cooking, cleaning, and sanitation needs. Therefore, in a 4 person household, 24 gallons are needed per day, meaning 28 mesh discs would suffice all water needs.



380 % INCREASE IN WATER ACQUISITION PER HOUSEHOLD

INDUSTRIAL SCALE: Greenhouse, Agricultural Support

BIOMIMIC INSPIRATION: Darkling Beetle, Nature as a closed-loop system

TECHNOLOGICAL EQUIVALENT: Rainwater Harvester, Farm to Kitchen to Compost

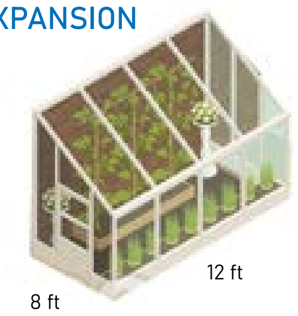
PROOF OF CONCEPT

Greenhouses provide a controlled environment which aid in cultivating agricultural production, specifically in harsh environments which have a difficulty growing crops on their own, such as that of the Sahel Region.

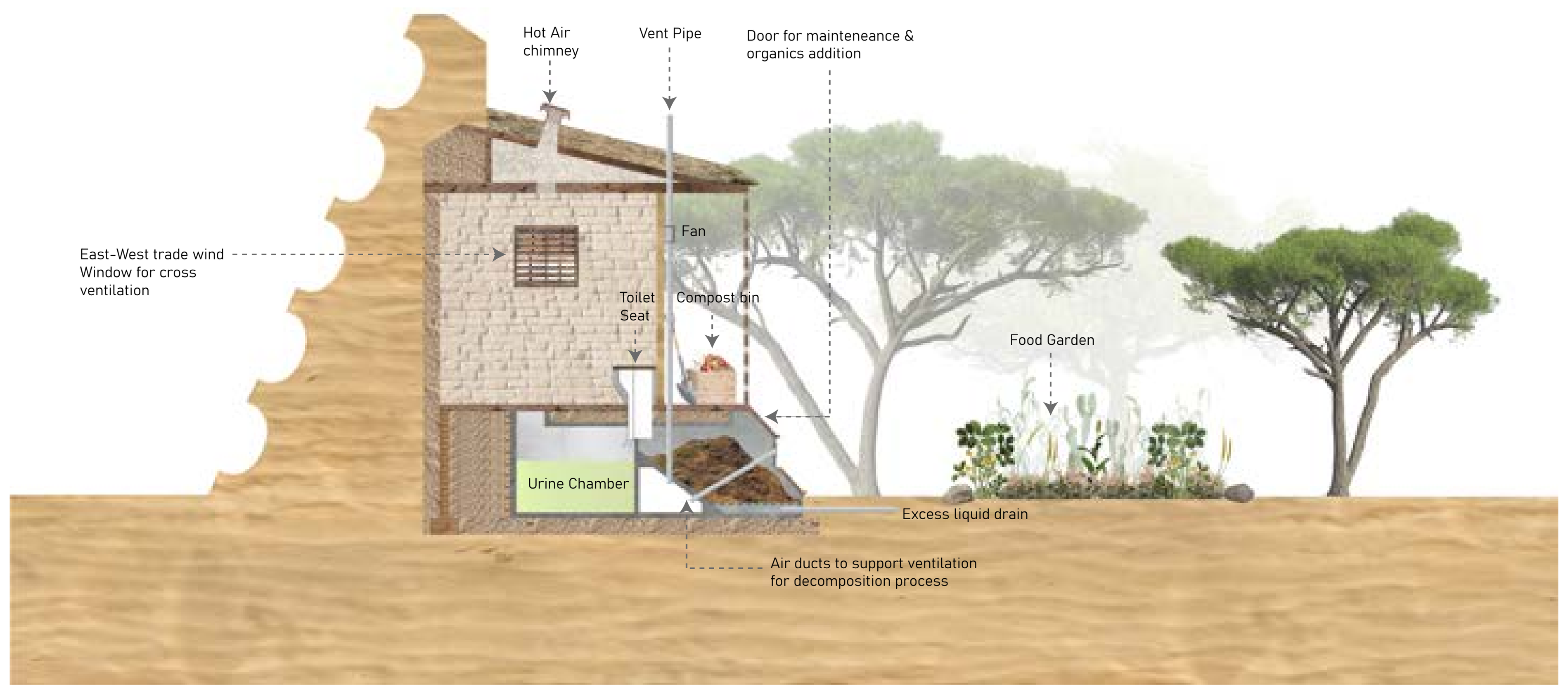
GREENHOUSE STATISTICS: A rule of thumb is to have 0.3 to 0.4 gallons per square foot of growing area per day as a peak-use rate for the warmest day. For example a 30-by-100-foot greenhouse with 2,400 square feet of bench area would require a peak-use rate of 720-960 gallons per day.

GREENHOUSE SELF-SUSTAINABILITY & SCALING POTENTIAL: Standard commericial greehouses in this region are actually quite small. Typically, they come in the follolwing two sizes: 8 x 12 and 12 x 20 because there is not enough water to support larger greenhouses. Most of the water needed to support the greehouses is taken from groundwater aquifers or imported from rivers quite far away. An 8 x 12 greenhouse would need between 28.8 and 38.4 gallons a day in water. If the rainwater harvesting technoogy were implemented, the 8 x 12 greehouse would require 44 mesh discs to satify its daily water needs. This technology provides an opportunity to scale up in the size of greenhouses, hence resulting in a greater crop yield.

MINIMUM 100% EXPANSION



MATERIAL HANDLING



RESIDENTIAL SCALE: Bathrooms, supports small scale agriculture, sanitation

BIOMIMIC INSPIRATION: Burrowing Nature as a closed-loop system, Termite Mounds

TECHNOLOGICAL EQUIVALENT: Passive Ventilation, Manure Composting

PROOF OF CONCEPT

There are four ingredients are required for fast-cooking hot compost: Nitrogen, carbon, air, and water. Together, these items feed microorganisms, which speed up the process of decay. Carbon rich materials include material such as dead leaves, branches, sawdust, wood chips, and hay. Nitrogen rich materials includes manure, fruit and vegetable scraps, and living plants.

LACK OF MATERIAL: Soil in the Sahel Region has inherently poor fertility due to land overuse, poor land management, desertification, soil erosion, and extreme heat. SPecifically, there is a lack of living organic matter within the land to sustain large scale plant and agricultural production. However, the solution may lie in the waste that humans create and so easily ignore .

REUSING WASTE AS AN INPUT MATERIAL: Composting in desert environments has proven to increase crop yields by approximately 10 to 15 percent in desert environments. At the residential scale, it allows the individual to become self-sustainable by growing a majority of their fruits and vegetables from the compost they create.

10-15% INCREASE IN CROP YIELD

20%- 60% DECREASE IN PURCHASING FOOD FROM OUTSIDE MARKETS

INDUSTRIAL SCALE: Livestock manure, supports phase 2 pioneer planting, agriculture, water & interior heating

BIOMIMIC INSPIRATION: Nature as a closed loop system, biodegredation

TECHNOLOGICAL EQUIVALENT: Manure Composter, Heat storage tank

PROOF OF CONCEPT

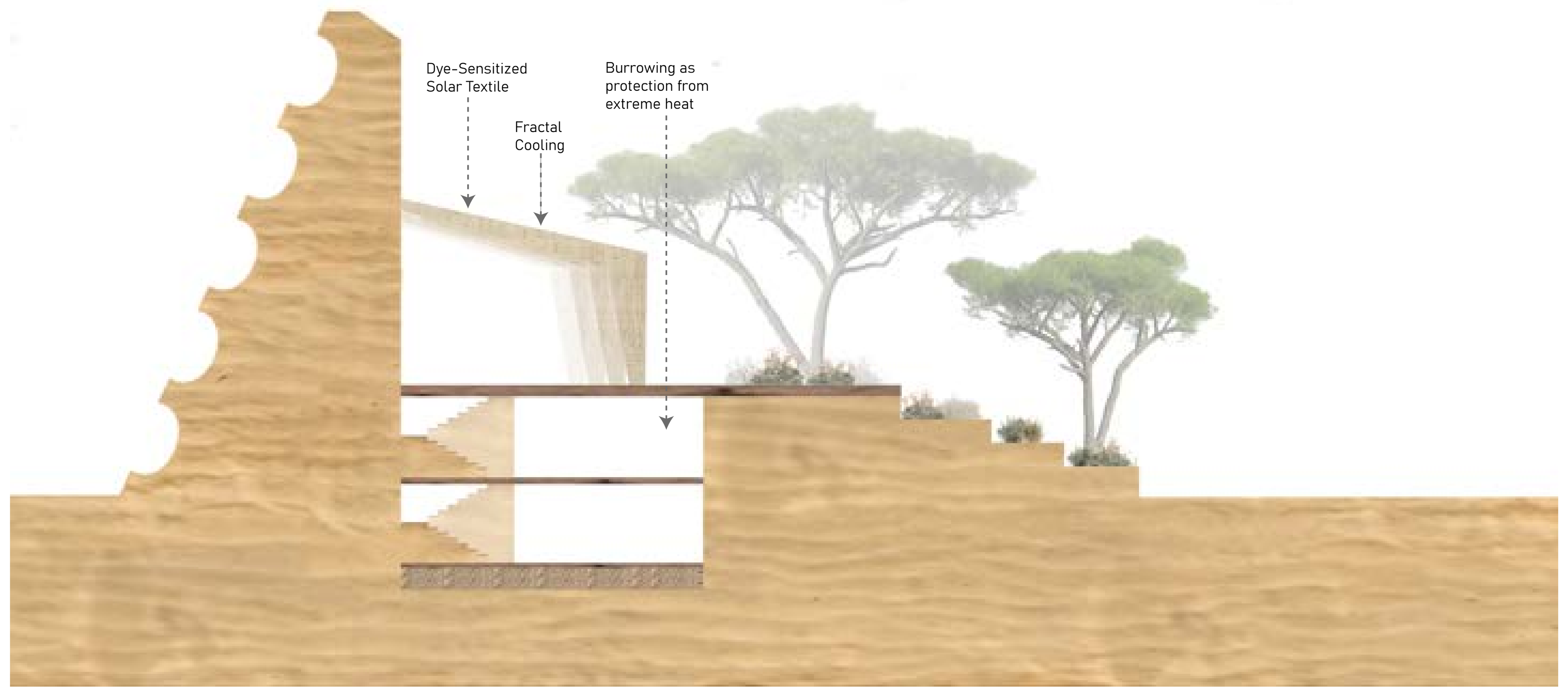
Compost heat is produced as a by-product of the microbial breakdown of organic material. The heat production depends on the size of the pile, its moisture content, aeration, and Carbon/Nitrogen ratio. Additionally, ambient (indoor or outdoor) temperature affects compost temperatures.

LACK OF ELECTRICITY: Approximately 50% of the 340 million people living in the Sahel region do not have access to electricity, representing one of the lowest modern electricity consumption rates for any region on Earth. In addition, approximately 80% of them living in the region do not have access to resources such as hot water and the ability to contorl indoor air temperatures.

COMPOST AS ELECTRICTY: If done correctly, a compost pile will heat up within 24 to 36 hours to the ideal temperature of 160 degrees farenheit. (Looking into how much heat a comost pile can produce per square footage)

1,000 BTU PER HOUR PER TON COMPOST

ENERGY GENERATION



RESIDENTIAL SCALE: Large scale agricultural support, large scale energy generation

BIOMIMIC INSPIRATION: Cacti fractal cooling, solar economy

TECHNOLOGICAL EQUIVALENT: Solar storage textile, form

PROOF OF CONCEPT

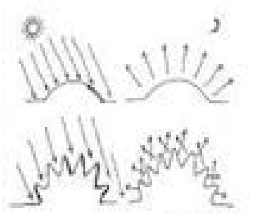
Smooth bodies are better at absorbing heat and poor emitters of heat at night where as prickly or ridged bodies are poorer absorbers of heat by day and good emitters of heat at night. A prickly form is exactly what the cacti developed in order to disperse the hot desert heat. Another method of hear protection is burrowing, commonly adopted by desert animals. These are two tactics which both the pavillion and residence incorporate.

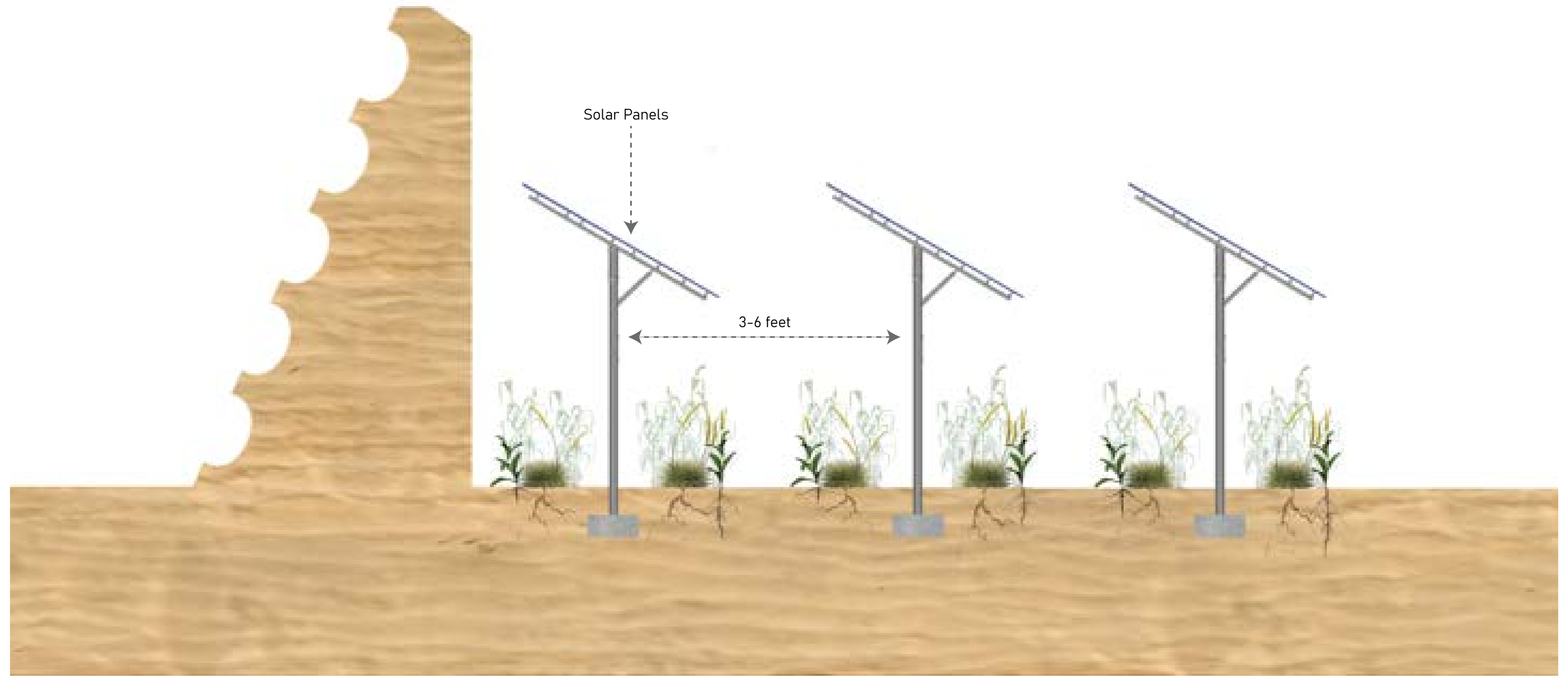
MISSED OPPORTUNITIES: The textile industry is enormous in the Sahel Region, with it encompassing 50% of female jobs. About 50% of people in the Sahel Region do not have access to energy. This percentage is especially higher in the more remote areas. At the residential scale, there may benew technologies that take advantage of the sun to power indvidual residences.

USING TEXTILES AS ENERGY CAPTURE: A majority of women in Sokoto, Nigeria work in the textile industry which presents an enormous opportunity to develop dye- sensitized solar cells. Natural photosensitizer dyes can be extracted from parts of plants to create energy. These dyes can absorb wavelengths between 450 and 580 nm from the visible light spectrum. Testing is currently happening on implementing these technologies in arid environments, where they are expected to make the most difference.

55% SUN DEFLECTION

12% SUNLIGHT CONVERTED TO USABLE ELECTRICTY





INDUSTRIAL SCALE: Large agricultural support, large scale energy generation

BIOMIMIC INSPIRATION: An entirely solar economy, burrowing/sun shading

TECHNOLOGICAL EQUIVALENT: Solar panels, energy storage

PROOF OF CONCEPT

Nature has evolved to become a fully self-sustainable and solar dependent economy. There is not better location than a desert environment to take advantage of this sunlight, as there are 12 hours of sunlight almost every day of the year. Not only does this present a tremendous opportunity for electrical generation and storage, agriculture.

AGRICULTURAL PRODUCTION IN ENVIRONMENTS OF EXTREME HEAT: Plants can experience a heat related sickness often referred to as heat stress which is the result of extreme heat damaging photosynthetic tissues to the point that the plant often dies. Desert plants have specifically evolved to protect themselves from extreme heat, but as temperature continue risiing, they too are experiencing death via heat stress. Crop producing plants are even more susceptible. As of 2020, heat stress related plants deaths have increased by 10% since 2020.

SOLAR PANELS TO THE RESCUE: Not only are solar panels an exceptional way to gather and store energy, but they have the ability to simultaneously alleviate the effects of heat stress by being placed above agricultural farms. This helps support nutrient production, recharge of degraded lands, water use reduction, and it extends growing seasons

20% INCREASE IN CROP YIELD

7 X's MORE ENERGY GENERATION THAN NON DESERT ENVIRONMENTS

100 Mw PER SQUARE MILE