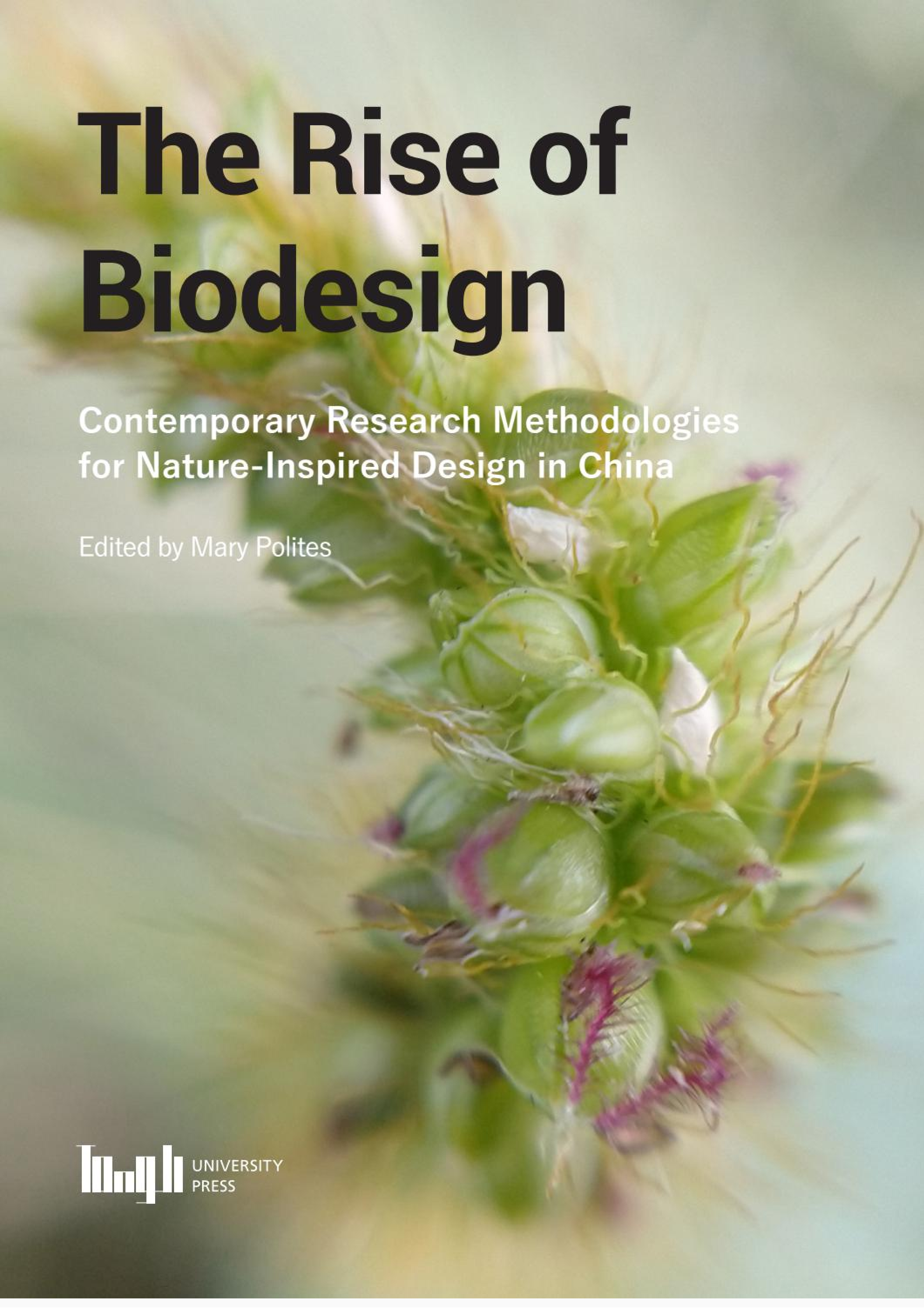
The Rise of Biodesign

Contemporary Research Methodologies for Nature-Inspired Design in China

Edited by Mary Polites



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Preface

Bioinspired design is both simple and complex.

Simple as it provides an easy reference to discuss ideas through a means we all can relate and feel inspired by – *the natural world*. Nature easily engages those from a wide range of backgrounds, from environmental enthusiasts to professional designers and scientists, as well as the general public.

Complexity arises when we need to understand beyond what we see. At many levels, we are still exploring how natural systems are interrelated and how to start mapping these connections. Whether in science research or in design practice, interdisciplinary collaboration is one of the main paths to unlock the complexity of the natural world, and aim to successfully confront today´s environmental challenges. Despite this, even nature-inspired fields are not immune to fragmentation, and the reason is well-known: scientific reductionism allows us to move faster. But do we know where we are heading? The biomimicry movement initiated by Janine Benyus two decades ago fused the principles of biomimetics with those of environmental awareness and ecological design. The statement was clear, we should continue learning from nature and aiming for innovation, but with a clear purpose: the preservation of our planet and the reconnection of the human species with the natural world.

In this context, the BiDL (Biomimetic Design Lab) was established as the first Biomimicry lab[1] in China in 2012, as part of the College of Design and Innovation (D&I) at Tongji University in Shanghai. The lab represented a merger between sustainability and contemporary design methods applied in a wide variety of fields, from architecture to industrial, interaction and service design.

1 Biomimicry is defined by the Biomimicry Institute as the intended emulation of nature which focuses on the methods and concepts of study revolving around sustainability. BiDL lab fully recognizes other biomimetic labs in China having been established prior and includes them in this book to encompass the whole field of nature inspired design.

The BiDL is an unusual entity in the Chinese education environment, as courses associated with biomimicry or biodesign are typically reserved for master or expert level training. This means that specialized level education is made accessible for younger students, and opened to a variety of design degrees. Additionally, through the core sustainability classes, biomimicry is an integral topic for the undergraduate and graduate lectures.

This book has a double purpose: it celebrates the initial 5 years of BiDL, highlighting the efforts, challenges and achievements in education through a collection of students' work at the D&I, from undergraduate studios to master thesis.

And second, there was a strong interest to expand discussions about bioinspired design beyond our classroom, thus initiating conversations with other Chinese biomimetic labs[2] as a way of exchanging methodologies, sharing ambitions, and building collaborations.

This book offers unique insight into the current state of biomimetics and biomimicry in a challenging but exciting moment for bioinspired fields. Through professional research and students projects, this collection of work shines light on educational methods currently being explored in some of China's top institutions, as part of a national environmental agenda that is critical, not only for the future of the country, but for our entire planet.

2 See Biomimicry Labs Map in pp. 20-25 for comparison.

Introduction

Bioinspiration is a broad field that encompasses many facets of biology, engineering and design. The research and development of materials, systems and techniques based on natural phenomena is considered one of the main contributors for innovation in applied sciences, and a critical driver for future advances in sustainability.

Bioinspiration is anticipated to have a significant contribution from the emerging markets in growing economies, such as India and China, and the byproducts from this field are estimated to greatly help towards the alleviation of world pollution in the next 20 years. However, the inspired-by-nature label does not necessarily imply a sustainable process, a waste-free outcome or an ecologically driven agenda. And that is how the biomimicry movement initiated by Janine Benyus in 1997 stood out among the rest of the biologically inspired fields.

In the last two decades, a growing number of biomimetic labs in China have been focusing on new approaches in the fields of material design, mechanics and engineering based on natural logics. However, the concept of biomimicry is still novel and abstract for many Chinese audiences. In this context, BiDL lab was established as one of the first centers to integrate sustainability, design and innovation within a Chinese university.

Leaf Veins

Detailed view of a leaf

The Rise of Bioinspiration

Although nature has been inspiring humankind in every possible field (science, art, design...) for thousands of years, there has been a cyclical interest in the natural world undeniable linked to historic environmental crisis caused by human activity. Today, due to a general awareness of global warming and its consequences, a renovated environmental concern has emerged since the beginning of the 21st century.

In addition, major technological breakthroughs experienced since the 1990s have allowed for unprecedented improvements in the measurement, analysis and understanding of any natural phenomena, including the simulation and prediction of environmental processes. Consequently, a closer relationship between nature and humankind is "in high demand" today, thus resulting into the widespread of nature-related fields in contemporary culture.

Despite the fact that bioinspiration has been recurrently present in scientific research since the 1950s, it was Janine Benyus' book, *Biomimicry: Innovation Inspired by Nature* (1997), a main trigger for the term to come out of the lab and dive into our daily life. In this regard, she managed to make the biomimicry movement stand out from previously established fields (biomimetics, bionics) by adding environmental awareness and sustainability to the inspired-by-nature equation.

Today, the concept of bioinspired design is developing at an impressive rate, and it is attractive enough to a wide audience. However, the extent to which bioinspiration can influence our lives through its different ramifications is still relatively unknown. In that sense, this book aims to serve as an introduction to the umbrella term of bioinspired design, and bring clarity to the field by explaining the similarities and dissimilarities between its different specializations.

Human Cities

D&I presented six projects that showcased approaches to social design, system design, open design, and strategic design, developing strategies for sustainability innovation.

On the other hand, the word "biomimetics" can be also found translated as "仿生" in academic papers, but this is not widely used. And in the case of biomimicry, there is no actual translation that implies its environmental implications, this being one of the reasons why biomimicry is difficult to grasp by researchers in China. In general, the distinction between the different words appears to depend on the context and background of the research, rather than on a definition.

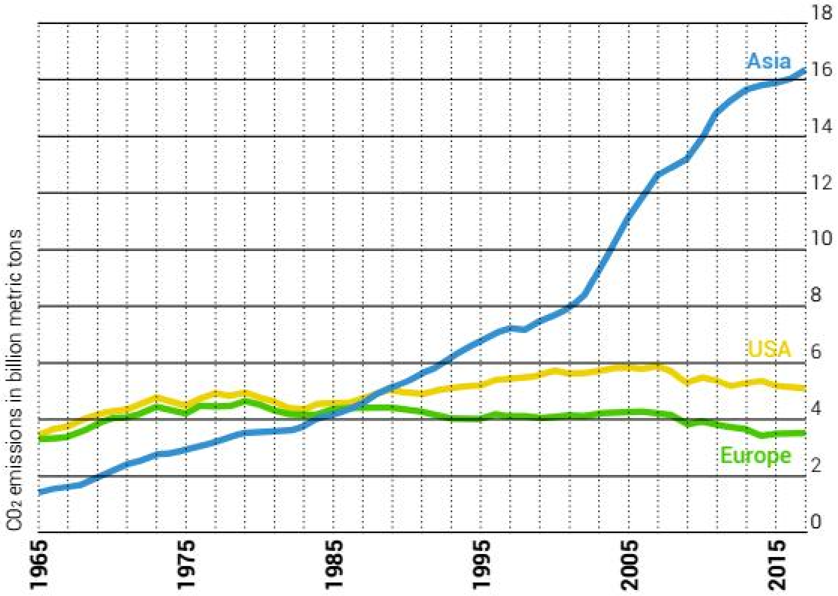
China, between Pollution and Innovation

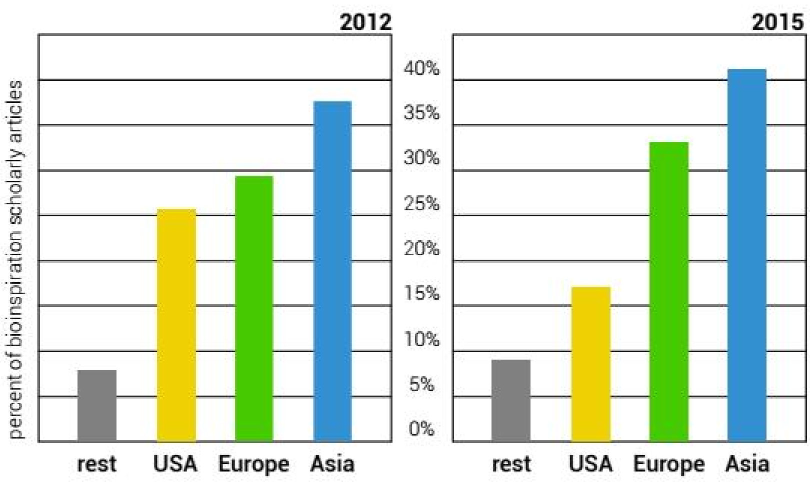
Since the late 1980s the Asia Pacific region has surpassed both the United States and Europe as the main emitter of carbon dioxide into the atmosphere. The combination of fast growth and high population of countries like China, India, Indonesia, Pakistan, Bangladesh and Vietnam, has made this part of the world responsible for almost 50% of the global carbon dioxide emissions today.[11]

Interestingly enough, according to the Da Vinci Index, a database tracking scholarly activity in the field of bioinspiration[12], Asia is also the world leader in research publications related to nature-inspired design. In 2012, the United States and China accounted for 25% and 23% of the articles published in the field, respectively. Nevertheless, five of the top ten universities represented in bioinspired research papers were Chinese, against only two from the USA. In the same year, Asia accounted for 37% of the research, followed by Europe (29%) and USA (26%). After three years, Asia had increased its share up to 41%, followed by Europe with 33%, and USA with only 17%. These facts are an indicator on how developing countries like China and India are aiming to counter the consequences of their dramatic development with investment in research, innovation, and funding for programs which explore new sustainable methods from materials to infrastructures.

11 Rapier, Robert. "China Emits More Carbon Dioxide Than The U.S. and EU Combined." Forbes. July 01, 2018. Accessed December 06, 2018. https://www.forbes.com/sites/rrapier/2018/07/01/china-emits-more-carbon-dioxide-than-the-u-s-and-eu-combined/#7d437c29628c.
12 "The Da Vinci Index & Biomimicry." Point Loma Nazarene University, www.pointloma.edu/centers-institutes/fermanian-business-economic-institute/da-vinci-index-biomimicry.

In the case of China, in addition to these efforts, as far as spatial design disciplines such as architecture and urbanism are concerned, nature-inspired solutions are already an important part of the government's development program. The awareness of rapid urbanization being a main source for China's present environmental challenges has triggered nation-wide initiatives such as the generic eco-city program, and the more specific "Sponge City" program, which focuses on efficient water management and flood risk mitigation.



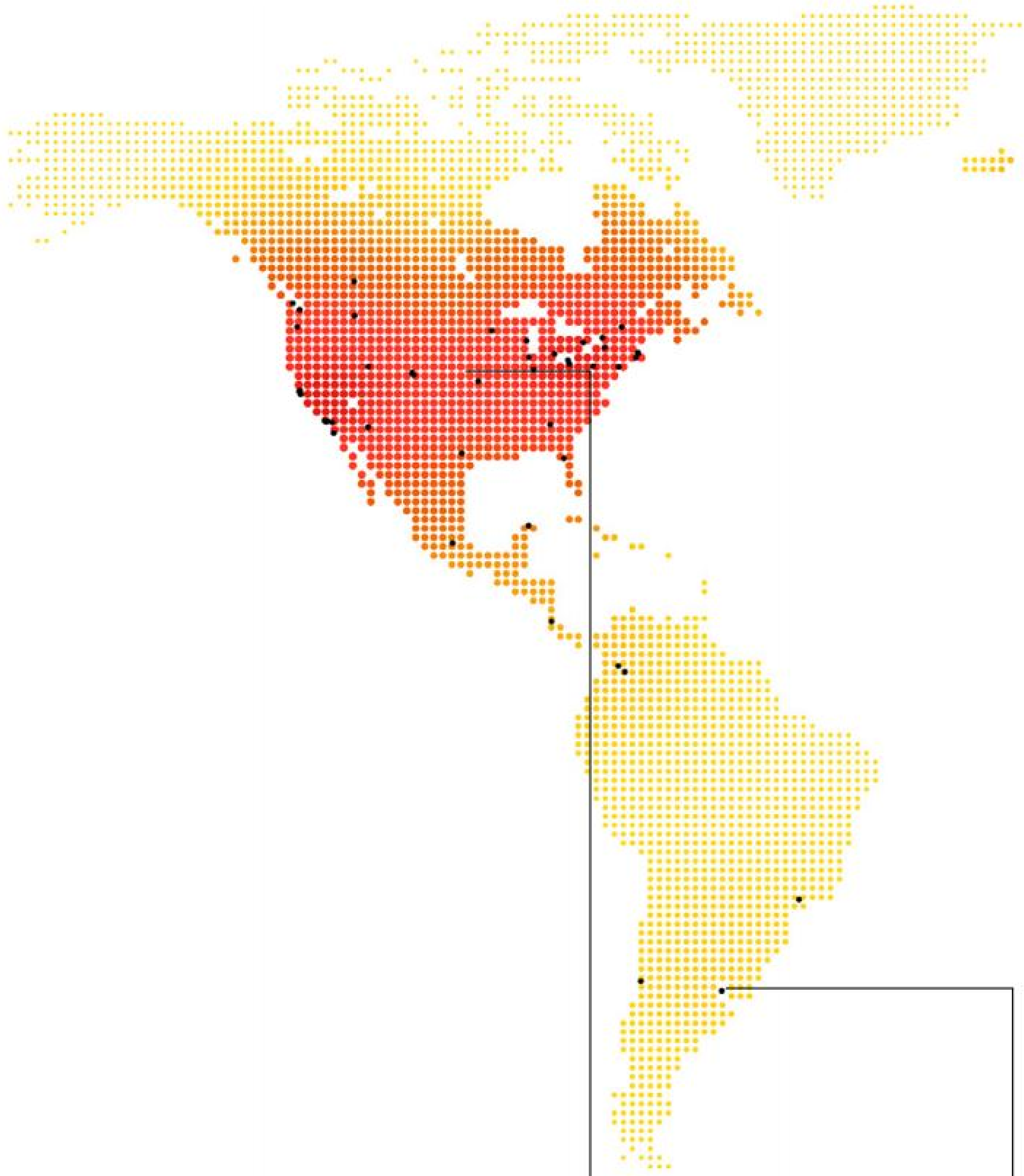


CO_2 & Bioinspiration

Top chart showing CO2 emissions in billion metric tons from 1965 - 2015.[11]

Lower chart, percent of bioinspiration scholarly articles. in 2012 and 2015.[12, 13]

13 "The Da Vinci Index & Biomimicry." Point Loma Nazarene University. Accessed December 06, 2018. https://www.pointloma.edu/centers-institutes/fermanian-business-economic-institute/da-vinci-index-biomimicry.

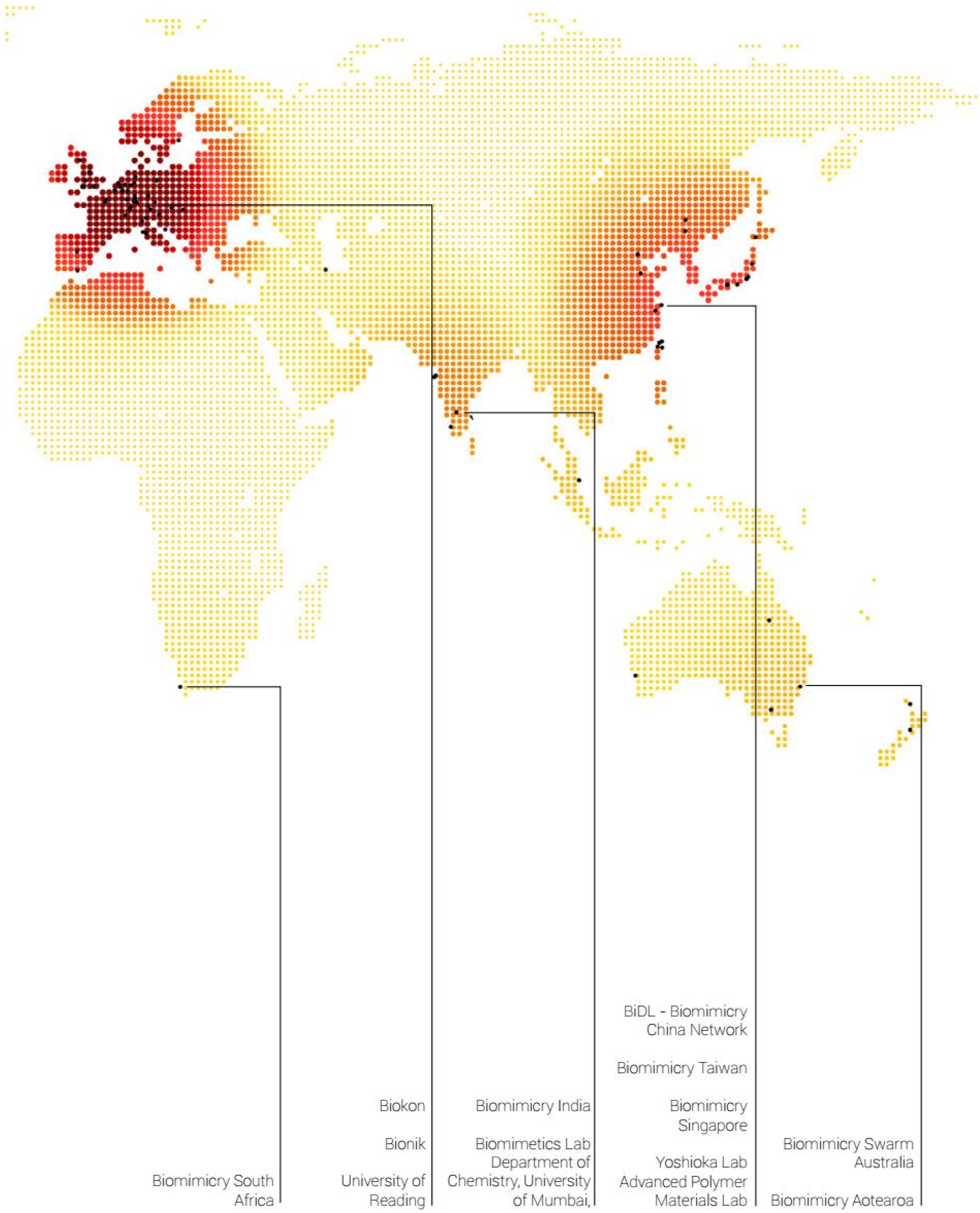


Bio Labs Map

Concentration intensities of biomimetic and biomimicry related labs. Bio labs are polarized between US, Europe and East Asia. It will be interesting to see the evolution of more isolated labs, namely those in South America and Africa. Map is for illustrative purposes only. For full list of labs, see appendix.

Lab Concentration

High *Low*



Biomimicry South Africa
Biokon
Bionik
University of Reading
Biomimicry India
Biomimetics Lab Department of Chemistry, University of Mumbai,
BiDL - Biomimicry China Network
Biomimicry Taiwan
Biomimicry Singapore
Yoshioka Lab Advanced Polymer Materials Lab
Biomimicry Swarm Australia
Biomimicry Aotearoa

Interviews

The line between the different nature-inspired fields is sometimes blurry. To explore the nuances within these approaches, the BiDL lab conducted a series of interviews with biological design experts with previous or current academic and professional experience in China. With a global background from Switzerland, United States, United Kingdom, and China, these experts' backgrounds range from natural or social sciences to design and engineering. We asked each interviewee to answer 10 questions covering their professional experiences and address what this means for current and future practices in China. The questions aim to showcase the range of implementations in which biomimicry and biomimetics are explored in education and professional practice.

Leaf Tendrils

Detail view of florets tendrils

Pius Leuba

Pius Leuba is an architect and founder of the biomimetic design lab (BiDL) at Tongji University. During this time he developed the regional Biomimicry China Network (BCN), which has been admitted into the Biomimicry Global Network. He contributed to the development of a culture assessment tool with BEE and GIGA that allows for the deduction of place-specific design strategies in locally adapted design. He currently teaches Climate Change for the Built Environment at the University of Liechtenstein.

Marie Dariel

Marie Dariel is the principal of Dariel Studio, an interior design company based in Shanghai and the UK. She founded IDEA Design Lab at Tongji University, a non-profit incubator promoting cross-disciplinary and forward-thinking approaches in China. This practice uses biomimicry and human wellness as drivers for change. She is the co-founder of the BCN with Pius and in partnership with the Biomimicry Institute.

Sherry Ritter

Sherry Ritter is a certified Biomimicry professional. After a career as a wildlife biologist, she started working with Biomimicry 3.8 in 2003 as part of the core team. Her research was seminal to the development of biomimicry in collaboration with businesses. She contributed to research which laid the foundation for the Biomimicry Institute and its educational materials which are used extensively.

Camille Fong

Cammille Fong is a Biomimicry Associate at Biomimicry Switzerland. Her work has been presented at the "Thoughts for Food" Summit in Zurich and at "Economy, People and Planet" in Copenhagen in 2016. She is currently studying international relations focused on the Cleantech sector and driving impactful collaborations throughout the globe.

Dengteng Ge

Dengteng Ge is a Professor at the Institute of Functional Materials at Donghua University, in China. His research is on biomimetic materials with dynamic properties from photonic ink to optical smart membranes derived from Cephalopods. The work of his lab has focused on functional materials and dynamic artificial microstructures for applications of wettability, smart windows, sensors and energy storage.

Yongmei Zheng

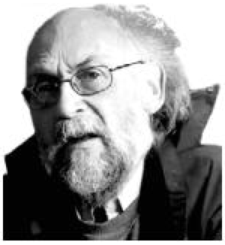
Yongmei Zheng, is a professor at the School of Chemistry at Beihang University. Her research interests are focused on bioinspired surfaces with gradient micro- and nanostructures. She has published more than 90 SCI papers including significant journals such as Nature. She is a senior member of Chinese Composite Materials Society (CSCM), member of Chinese Chemistry Society (CCS), American Chemistry Society (ACS), Fellow member of NANOSMAT Society, International Society of Bionic Engineering (ISBE), and International Association of Advanced Materials (IAAM). She is a member of the editorial board of scientific reports in Nature.

George Jeronimidis

George Jeronimidis is a Professor (Emeritus) for the Composite Materials Engineering, School of Construction Management and Engineering at the University of Reading, UK. In 2009 he became Co-Director of the Emergent Technologies and Design program at the Architectural Association School of Architecture. George was elected president of the BIOKON International, in 2009. He became a fellow of the International Academy of Wood Science (IAWS) in 2005. He served as chairman from 2005-2013 as member of the Scientific Advisory Board of the Max Planck Institute on Colloids and Interfaces, Golm, Germany. He is currently on the Editorial Board of the new international journal Virtual and Physical Prototyping, Wood Science and Technology and Biomimetics & Bioinspiration.

Evan Greenberg

Evan Greenberg is an educator, designer and researcher. Since 2008-2017 he was appointed Studio Master of the Emergent Technologies and Design program at the Architectural Association School of Architecture. Evan is a Teaching Fellow at the Bartlett School of Architecture, UCL, where he led a postgraduate Unit 14 with Dirk Krolikowski. Evan has contributed to many international conferences and publications including the Association of Architectural Educators (2016), the Architectural Humanities Research Association (2015), the International Association for Shell and Spatial Structures (2015), eCAADe (2014) and Architectural Design (2013).



Julian F. Vincent

Julian F. Vincent is a zoologist. In 1968 he started his career at the University of Reading. In 2000 he was invited to the University of Bath, as a Professor of Mechanical Engineering. He was a part-time lecturer at the Royal College of Art & Design and Imperial College London until 2010. He is and has been, a member of numerous scientific and advisory boards. He co-founded the Center of Biomimetics in Reading and Bath and is president of the International Society for Bionic Engineering. He is an Adjunct Professor in Engineering and Materials at Clemson University, USA. He has published extensively on biomimetics including Structural Biomaterials, Biomimetics: Its Practice and Theory, and Biomechanics-Materials: A Practical Approach.

Sherry Ritter

Could you give your own definition of biomimicry?

Biomimicry is learning how to improve human designs by learning from nature. In my "elevator speech", I always jump right into examples, like the lotus plant inspiring roof tiles that self-clean when it rains and spider webs that incorporate UV-reflectant silk strands that have been emulated in glass for commercial building windows to reduce bird collisions.

How did you get involved with biomimicry? When and how did you start learning about biomimicry?

I've always been fascinated by plant and animal adaptations, that is, what strategies they have for surviving in their environments. I have a Master of Science in Wildlife Ecology and worked for many years for state wildlife management agencies. I often gave talks to school children and took them on field trips, usually focusing on adaptations. When I moved to Montana, I met Janine Benyus and heard about her book. In 2003 when I was less than a full-time employee, I asked her if she had any work I could do on a part-time basis, and she and Dayna Baumeister made an arrangement for me to collect biomimetic case studies. A few years later, I was hired as part of the Biomimicry Guild (now Biomimicry 3.8). I also worked for the Biomimicry Institute.

Considering your background, which field(s) are you applying biomimicry principles to (energy, structures, design, science, education)?

I've done a lot of projects with for-profit and non-profit sides of Biomimicry 3.8. I should say that I don't have any design background. Whether I was doing consulting, working on AskNature, or teaching workshops, my primary focus was on the natural side—helping clients and others learn from nature and how to apply what they learn to their designs. I also taught biomimicry methodology in workshops.

Throughout your work, were any of the projects realized?

One of the issues we always had was that we would work with clients, but we didn't always know what they did with the information. They might have come up with something, but we often didn't know what they developed. Recently Biomimicry 3.8 put out information that revealed some of the products that came out of consulting with them, however I'm not certain on which tasks I helped that directly translated into these products.

The largest report that was made public was the one we did for HOK which can be found online as the *Genius of Biome* (the link which can be found in the resources index). It seems that HOK did take some of those ideas further; I know they went into designs. Tom McKeag of HOK, who came over to the first public lecture in Shanghai at the beginning of the time I was there at the D&I and he gave some examples of things they were developing. For example, we talked about beaver dams—one of the strategies in the Genius of Biome—that hold water on the landscape, which helps to reduce floods but also helps provide ecosystem services like replenishing groundwater and keeping water cool. The design strategy that came from the biological strategy came down to using a series of leaky structures to slow down water. Tom suggested a concept of a series of rooftop structures, and even install things on the sides of buildings. These structures would reduce the amount of runoff going into the city water systems and decrease the number of pollutants reaching rivers, lakes, and the ocean.

Another example comes from before my time, but when Dayna and Janine were working with the Interface, and the result was the entropy carpet tile that emulated the organized chaos on a forest floor.

To help designers and for use in workshops and our professional courses, we developed the *Biomimicry Resource Handbook* (the link which can be found in the resources index). We did a lot of on line instructional materials for the biomimicry design challenges for the Biomimicry Institute, which was mostly put together by Megan Schuknecht, Gretchen Hooker and myself. The whole idea for the design challenge was not only to generate great designs around these significant issues but also help students learn the process of doing biomimicry while they did it. Not everybody who wanted to do the challenge was located where someone taught biomimicry. The idea was for them to get up to speed on their own.

What are you working on or researching right now?

I retired in 2013, then continued doing contract work for two years which again involved doing research for client projects, teaching workshops, working on AskNature, and helping with biomimicry design challenges. Currently, I'm enjoying retirement and getting involved in local riparian restoration projects, conducting bird surveys, and leading student field trips to learn about wildlife.

What are your educational experiences with biomimicry?

I'm a Certified Biomimicry Professional, which I earned mainly through work and teaching experience with the Biomimicry Guild and Institute. I've taught biomimicry design methodology in workshops in Mexico on three occasions, Costa Rica, China, and France, and taught two cohorts of the Biomimicry Specialist program, which were 9-month long courses taught on line and in-person sessions.

Can you expand upon what you taught in these international settings, how you dealt with language, concepts and give a general introduction?

The workshops in Mexico mostly included Mexicans, but also some Costa Ricans, Puerto Ricans, Colombians, Canadians, and Americans. The difficulty in Mexico for me was to some extent the language, as I wasn't well-versed in Spanish. We taught in English, and then when the students got into smaller teams, they would talk in Spanish unless there was a student from the States in their group. I tried to stay out of group conversations unless I felt a need to jump in and guide them, but with everyone chatting in Spanish,

Natural Artifacts

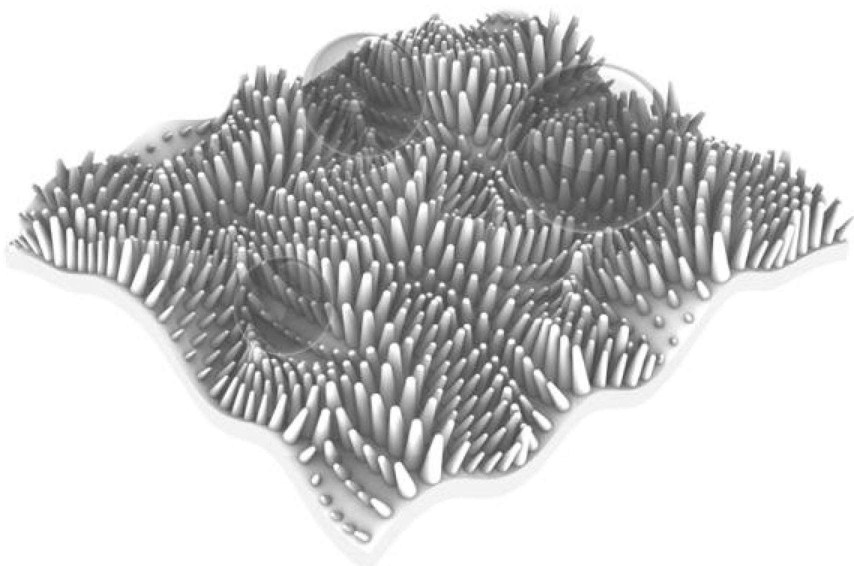
In biomimetics, there are several topics that researchers typically reference or build upon within their work. These include attributes, material properties, organization principles or shapes found in nature that recurrently inspire designers and scholars, eventually leading to applications in highly diverse fields. As a preface to the presentation of the labs' projects, this chapter introduces some of these concepts and links them to their most representative sources in nature.

Ribbed & Veined

Close up view of vein pattern on plant leaf


Hydrophobic
Surfaces that shed water due to micro scaled surface bumps

Hydrophobic & Hydrophilic



Hydrophobic:
Lacking an affinity for water; insoluble in water; repelling water.[1] Commonly found in plants surfaces used to assist in water directional transport and water shedding to clean surfaces.

Associated Terms: *Lotus Effect, Superhydrophobic, Ultrahydrophobic*

Hydrophilic:
Having an affinity for water; capable of interacting with water through hydrogen bonding.[2] Almost the opposite of hydrophobic. Commonly found in aquatic plants that are adapted to living in submerged conditions.

Associated Terms: *Oleophilic, Superhydrophilic, Ultrahydrophillic*

1 "Hydrophobic." Biology Online. Accessed November 22, 2018. https://www.biology-online.org/dictionary/Hydrophobic.
2 "Hydrophilic." Biology Online. Accessed November 22, 2018. https://www.biology-online.org/dictionary/Hydrophilic.

Special Surfaces

Opposite Page: Grass blades with water droplets depicting hydrophobic conditions.

Current Page : Diagram of a hydrophobic surface with water droplets

Biological Prototypes

As a showcase of the current bio-inspired research going on in China, four renowned university labs were selected to introduce their work in this book: The Key Laboratory of Bionic Engineering at Jilin University, the Key Laboratory of Bioinspired Smart Interfacial Science and Technology at Beihang University, the Dynamic Technology Lab for Bionic Materials and Structures at Donghua University, and the Biomimetic Design Lab (BiDL), at Tongji University in Shanghai. The chosen projects cover research and applications ranging from material science to mechanical engineering and environmental design. All the projects are explained following an established methodology: a natural element is selected, some of its properties are highlighted and studied, real applications are explored and proposed, and eventually a final prototype is built and evaluated.

Plant Patterns

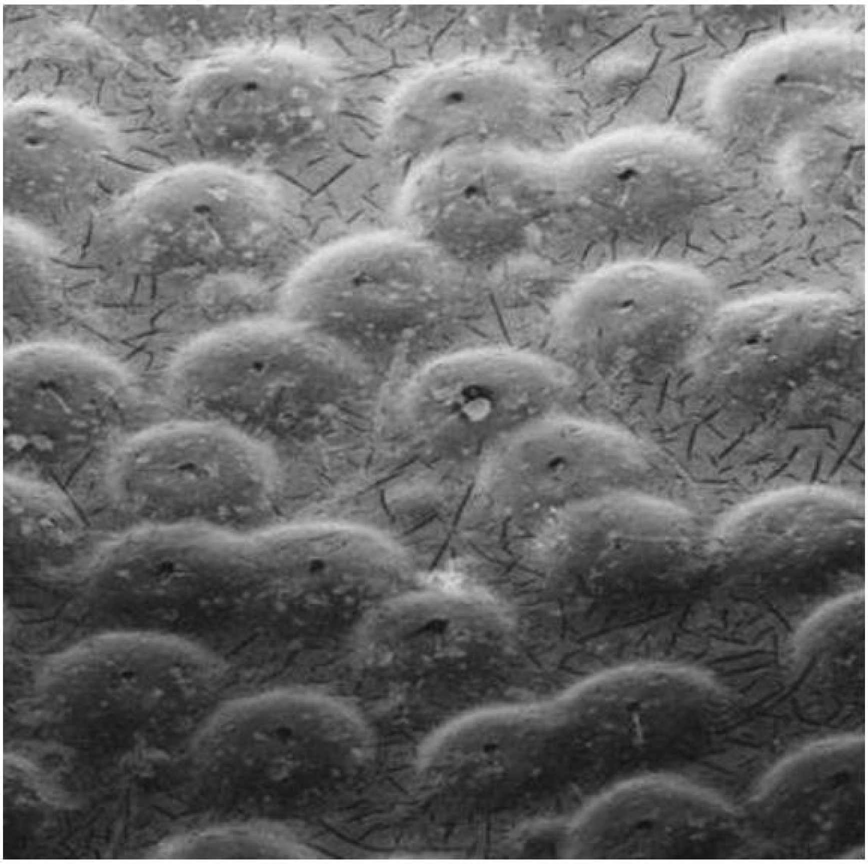
Small leaves arrayed on a plant


Convex Domes

Dung Beetle

The dung beetle is typically a soil-burrowing animal and has adaptive features to fit their environment. They have a function of anti-adhesion and soil resistance which is attributed to the raised microstructures on their body surface.

The head of dung beetles is typically a surface covered with small convex domes. Through the use of a scanning electron microscope (SEM), we observed and analyzed the surfaces of several dung beetles. From these observations, we found that the raised domes on the surface are random in size, with a quantity that appears to be densely packed and uniformly distributed. Through abstraction of these relationships, we aimed to develop surfaces for machinery that would support anti-adhesion of the soil using similar properties.



Dung Beetle Domes

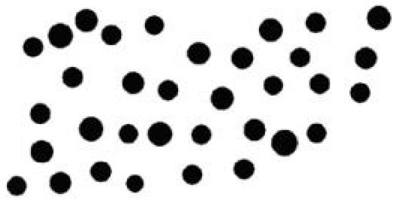
Opposite Page:
Image of Dung Beetle

Current Page:
SEM image of Dung Beetle shell surface displaying the convex dome surface conditions.

Surface Design

Diagrams showing patterning options of convex circles intended to be applied to agricultural equipment surfaces. Images vary in slight size to explore surface friction conditions.

1



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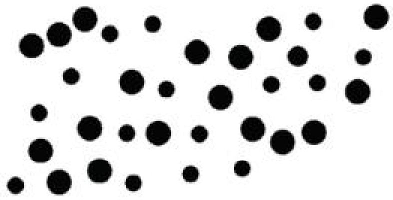

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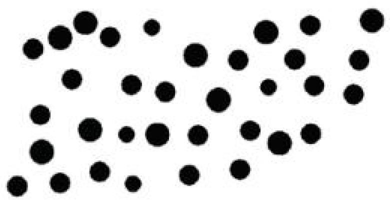

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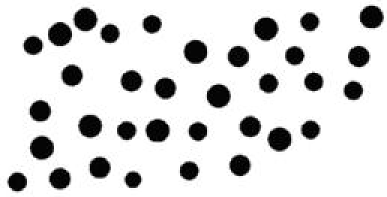

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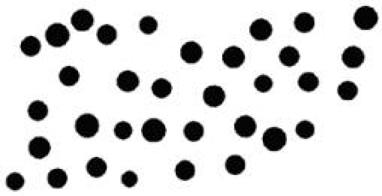
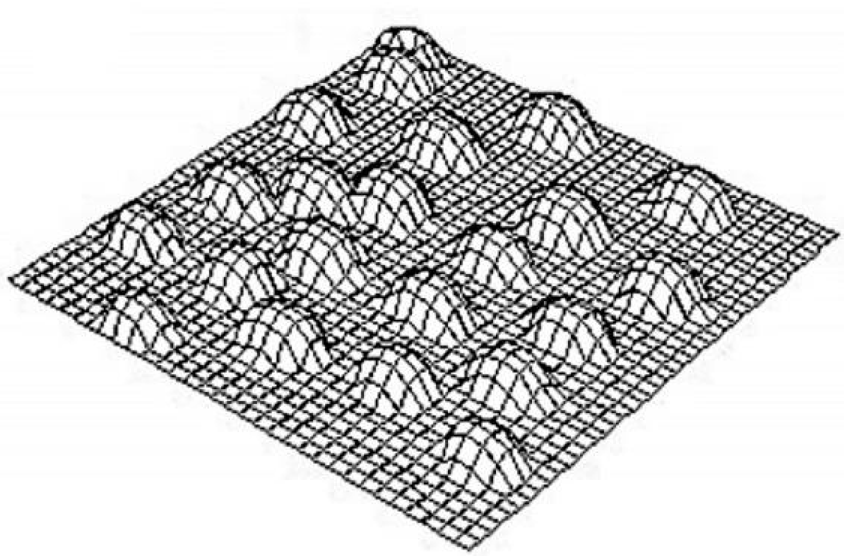


Surface Design

Computer generated surface showing raised convex pattern in 3D.



Through computer simulation and mapping of similar surface proportions through mathematical analysis, a biomimetic non-smooth surface was developed. The size of non-smooth units was simplified within manufacturing capabilities to adapt to the industrial production.

The application was for a plow moldboard which is a typical farming component in agricultural machinery. The biggest problem with the traditional plow moldboard is severe soil adhesion. Soil adhesion and friction on the surface usually generates a draft force where energy consumption and abrasion increase, which leads to the reduction in the production efficiency.

The parameters of the convex domes on the covered surface were at 7 mm in height, 25 mm in base diameter and 45 count. In the best case studied, the results showed that the machinery's resistance was reduced by 18.09% as compared to that of the conventional smooth blade.

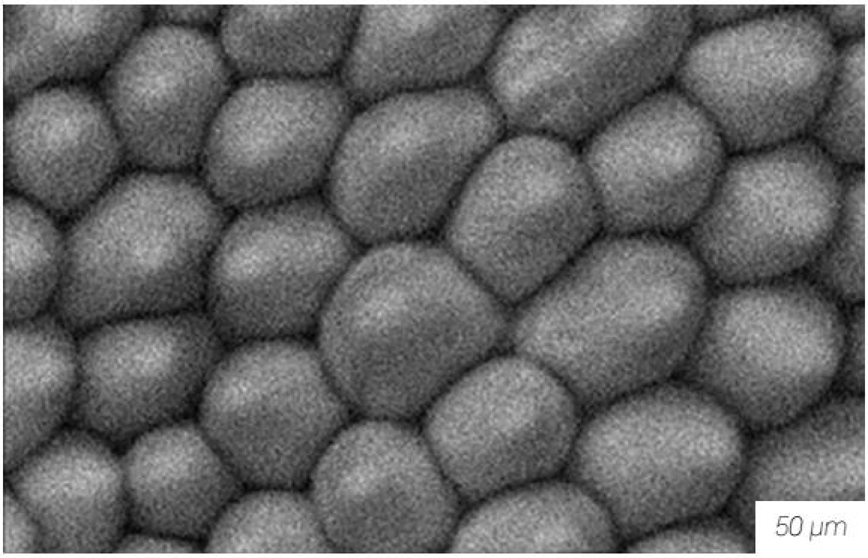
From this testing results, we believe that the explored biomimetic method is one of the most effective means to reduce soil adhesion and resistance. The issue of anti-soil adhesion has been well developed in dung beetles and other soil-burrowing species (ant, pangolin, earthworm, ground beetle, mole cricket, roach, earwig, locust, millipede, and centipede) which all live in moist, soil-rich environments. These are all worth exploring due to the distinct non-smooth morphology of their body surfaces.


Microscale Papilla

Rose Petals

Rose petals are unique as they exhibit superhydrophobicity as well as high adhesion. The surface of a rose petal has a hierarchical structure consisting of microscale papillae with each papilla having nanoscale folds that contribute to these features. In the image below, both surface structures observed (micron-sized bumps, and submicron-sized folds) that increase the solid-liquid contact area.

To develop surfaces with similar properties, we established a process which combines graphene, copper and stainless steel into a panel. The process to produce this composite panel was explored by growing graphene on a copper substrate where the copper grains were clearly visible. Micro/nano structures were etched by laser and combined onto the graphene film. The end result showed similar properties to rose petal structures.



Microscale Papilla

Opposite Page:
Image of rose petals with water droplets collected on the surface, an example of the petal's superhydrophobicity.

Current Page:
Microscale view of rose petal surface with papillae that contribute to the petal's superhydrophobic and high adhesion features.

Donghua University

The Dynamic Technology Lab for Bionic Materials and Structures (DT-Lab) was created in 2015 by Professor Dengteng Ge, as part of the Institute of Functional Materials at Donghua University. The lab has received grants from the National Natural Science Foundation of China (NNSFC), and by the Natural Science Foundation and the Science and Technology Innovation Program of Shanghai. Currently, the team consists of 12 people, with ongoing collaborations with universities in China and the USA. The lab's primary focus of study includes artificial microstructures, their deformation control, the manufacturing of colloids, and polymer-based functional composites.

Water Crystals

Opposite Page:
Ice formed packing pattern

Carystoides Escalantei Butterfly

Top Image:
Female *Carystoides escalantei*.
Photo taken at vertical direction with flash light.

Middle Image:
Male *Carystoides escalantei*.
Photo taken at vertical direction with flash light.

Lower Image:
Male *Carystoides escalantei*.
Photo taken at low angle with flash light.

Extraordinary Whiteness

Whiteness is frequently appears on the wings, legs, and bodies of many species of moths and butterflies. While "white" may often be simply one more color among many within a larger complex pattern, there are times when the whiteness itself appears to be a key signal.

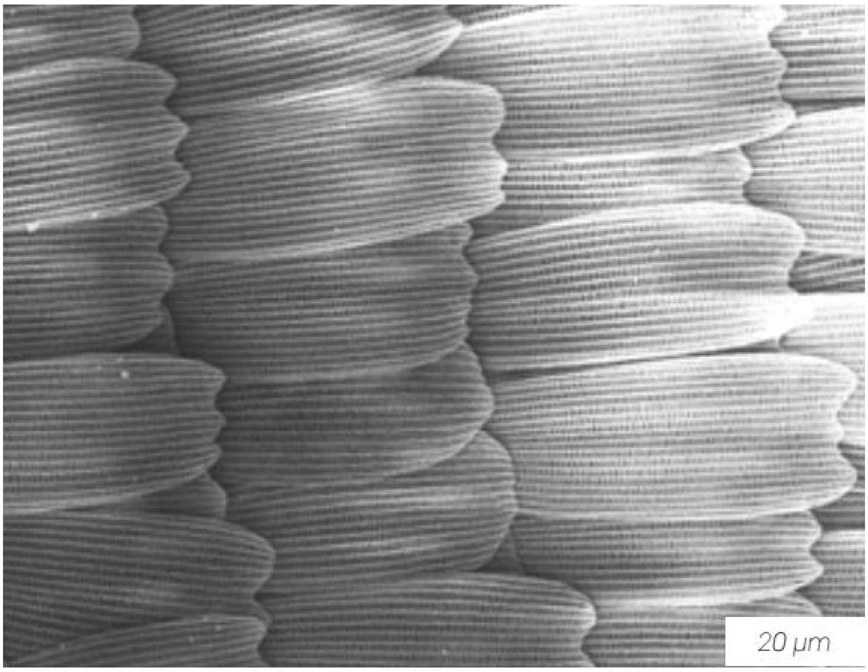
Natural whiteness is often attributed to the scattering or diffusion of light from (sub)micron-sized textures including ribs, ridges, and pores. Species, such as *Pieris brassicae* and *Delias nigrina,* have randomly packed beads in between ribs and cross-ribs, which enhance their appearance of whiteness. Metallic to silvery whiteness occurs on some butterfly wings as the result of mixing structure colors for the purpose of communication.

Here, we investigate the nano and microstructures of white spots on the wings of *Carystoides escalantei*, a dusk-active and shade-inhabiting Costa Rican rain forest butterfly (*Hesperiidae*).

On both males and females, two types of whiteness occur: angle-dependent and angle-independent. Interestingly enough, some spots on the male wings are absent from the female wings.

Carystoides Escalantei

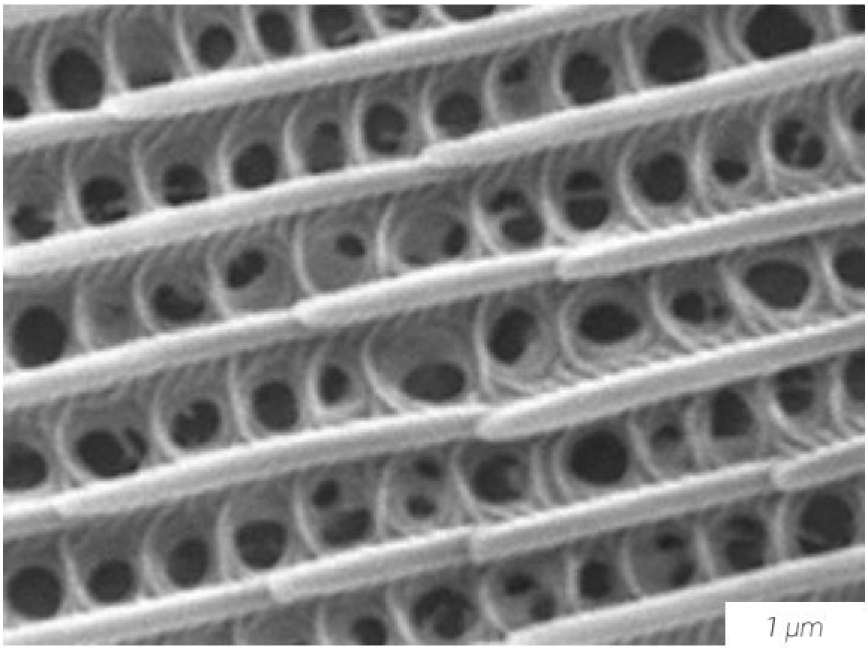
Male *Carystoides escalantei* with white on antennae, middle body region and tips of wings.

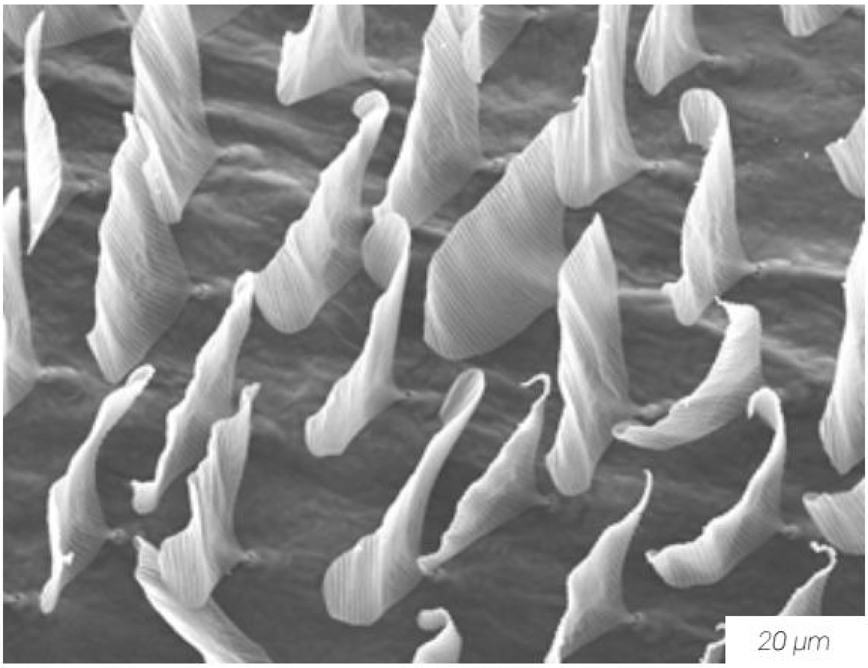


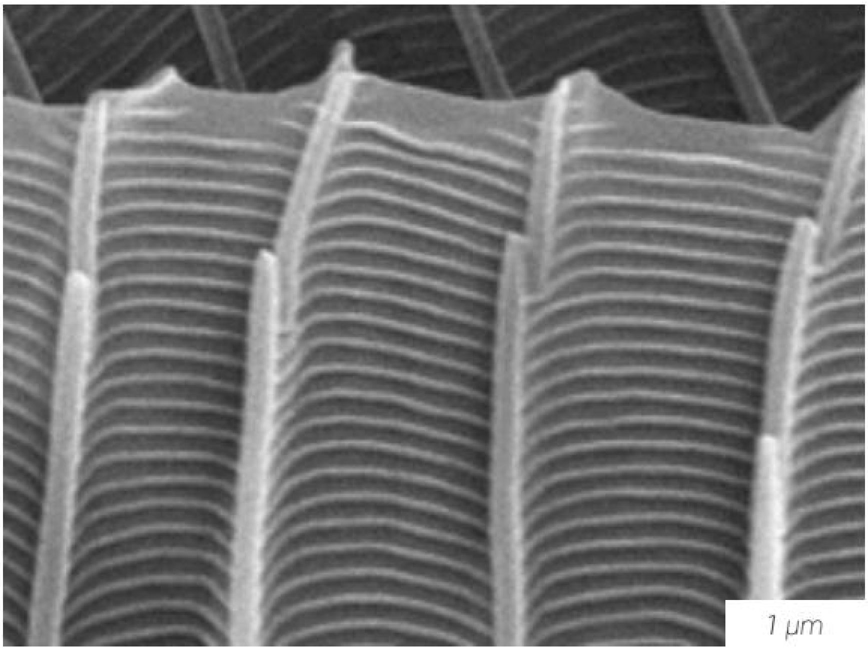
Angle Independent Structure

SEM Photos of the white spots at the antenna.

The angle-independent areas at the antenna and wing tips have white spots, which differ in the microstructure, orientation, and associated properties of their scales. The angle-dependent whiteness can be bright or dull depending on the observation directions.







Angle Dependent Structure

SEM Photos of the white spots in the middle of front wing

Angle-dependent areas are the middle region of the wings.
The angle-dependent scales show enhanced retro-reflection.

Heliotropism

The construction industry represents a high amount of energy consumption due to its systems such as heating, cooling, ventilation, as well as lighting and other household appliances. In response to this, energy savings strategies are increasingly becoming a focus to reduce consumption by increasing efficiency.

This research explores prototypes using locally accessible materials, to improve thermal comfort while reducing the reliance on systems that require energy to alter environments.

The movement of plants informed the exploration of this work. In general, plants are in a fixed position, therefore to increase the chance of exposure to the sun they have solar tracking mechanisms. This movement includes phototropism and heliotropism. Phototropism is a growth-mediated movement in response to unilateral light. Heliotropism is a dynamic and oscillatory form of plant movement, which is, distinguished from phototropism, as a reversible, rapid and not involved in the growth periods of plants. Both allow plant organs to remain close to optimize conditions for growing (e.g. energy obtaining an optimal temperature).

Early on the projects intended to have mechanisms which would have the ability to articulate movement in response to a stimuli. This movement needed to alter the thermal or environmental conditions of a space.

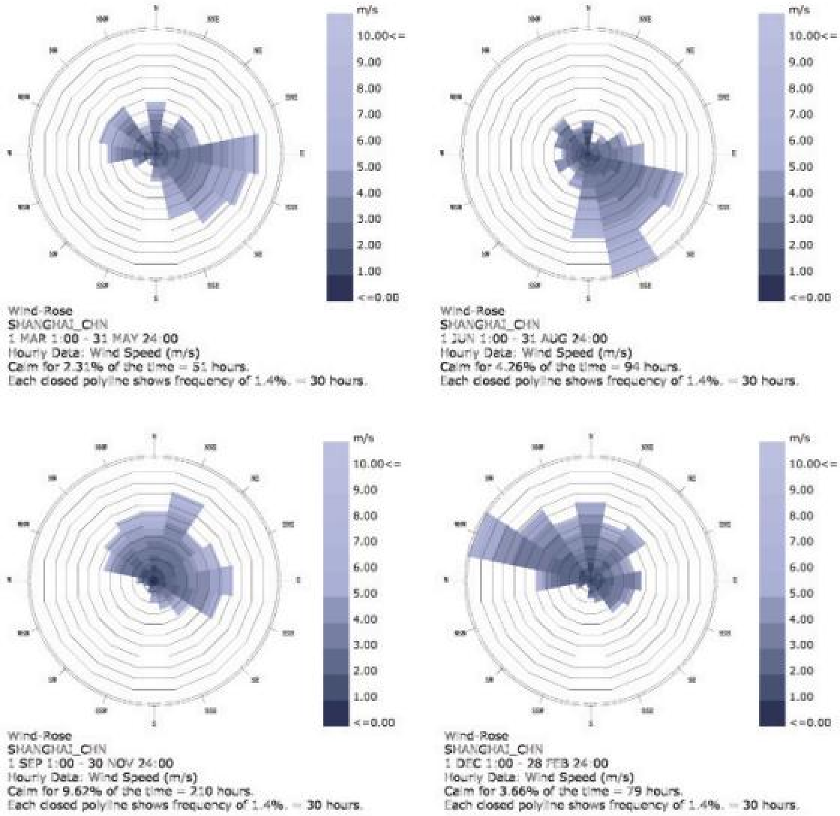
The following work represents two projects which address this goal. The first "Microclimate Regulation System Based on Plants Adaptability" by Cunyi Liu and the second, "Responsive Kinetic Structures Based on the Tropic and Kinetic Movement of Plants" by Jiarui Tan.

Panel Prototype

Image of modular panel system final model.

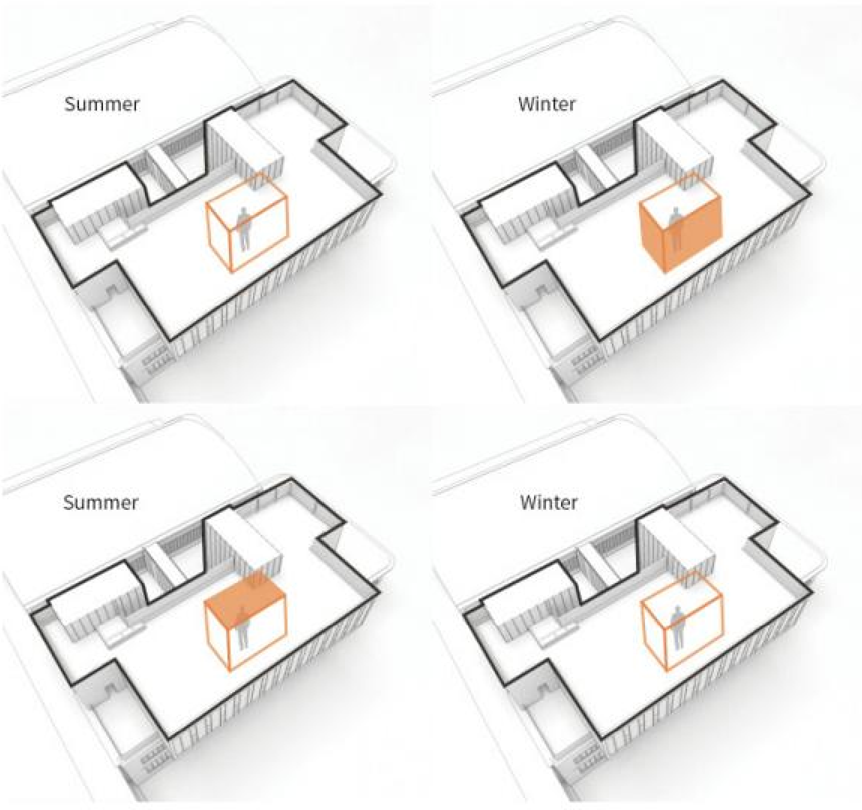
Site Conditions

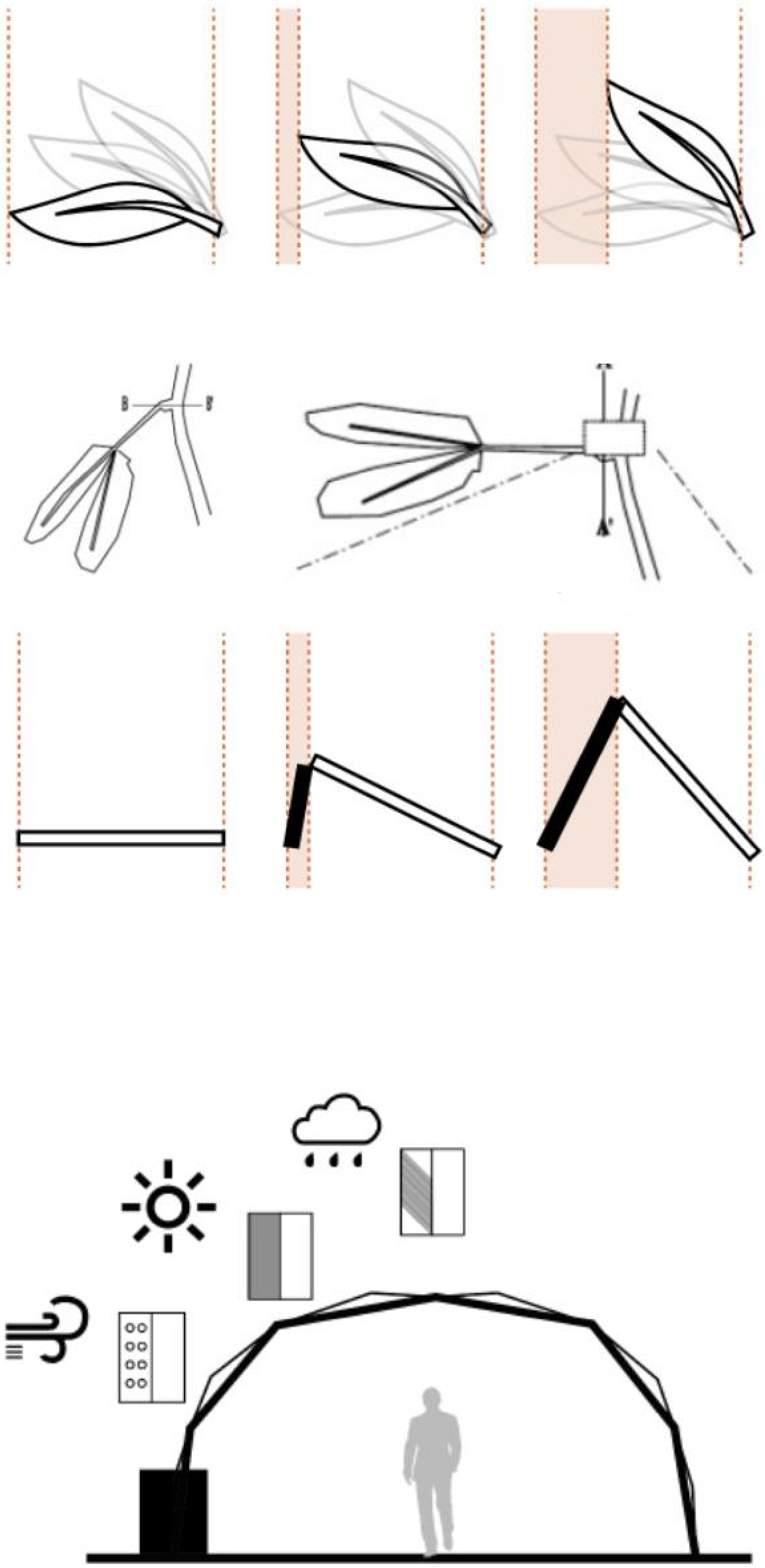
Wind Rose Diagrams



Site Conditions

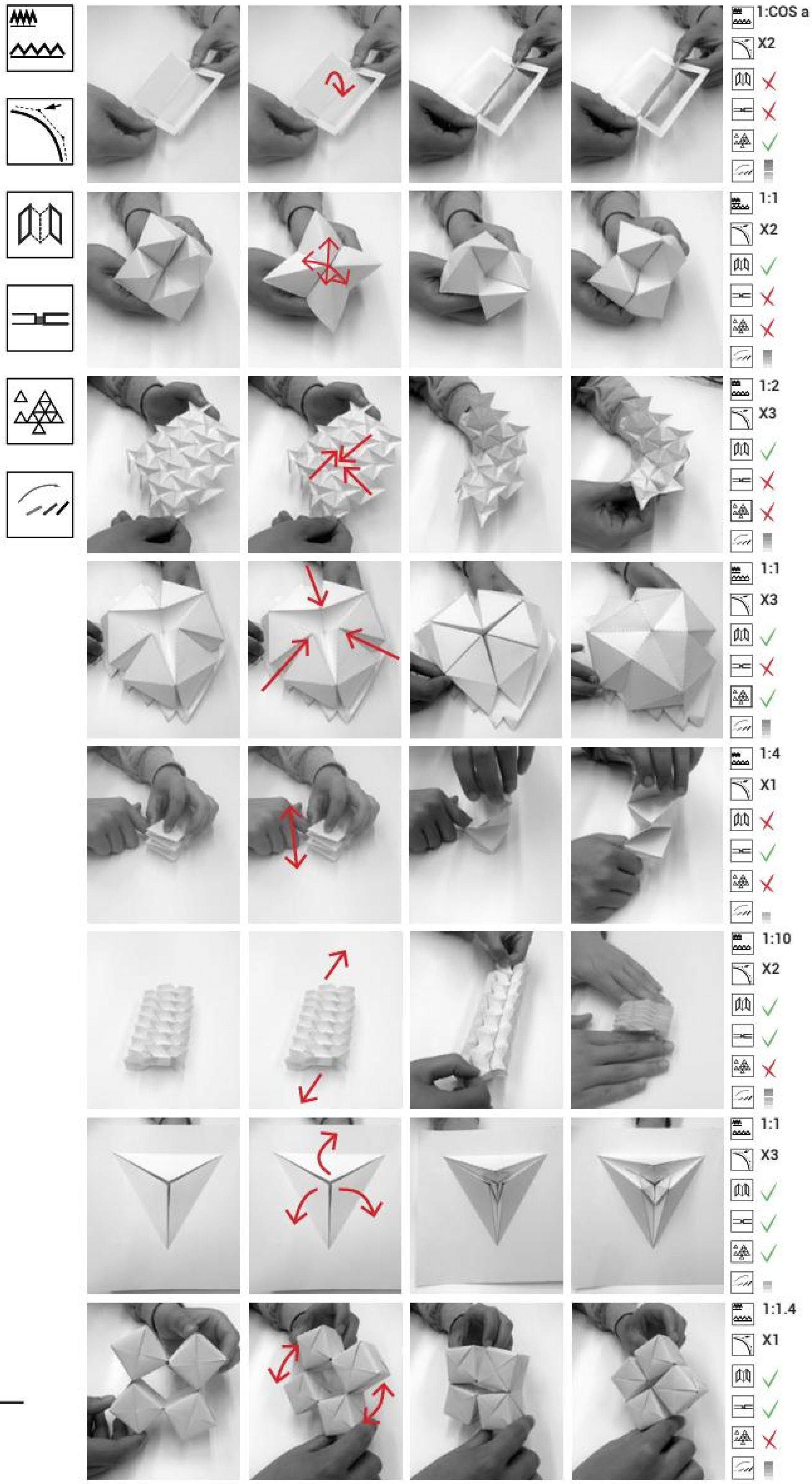
Lower Images:
Massing surface areas of protection throughout the year





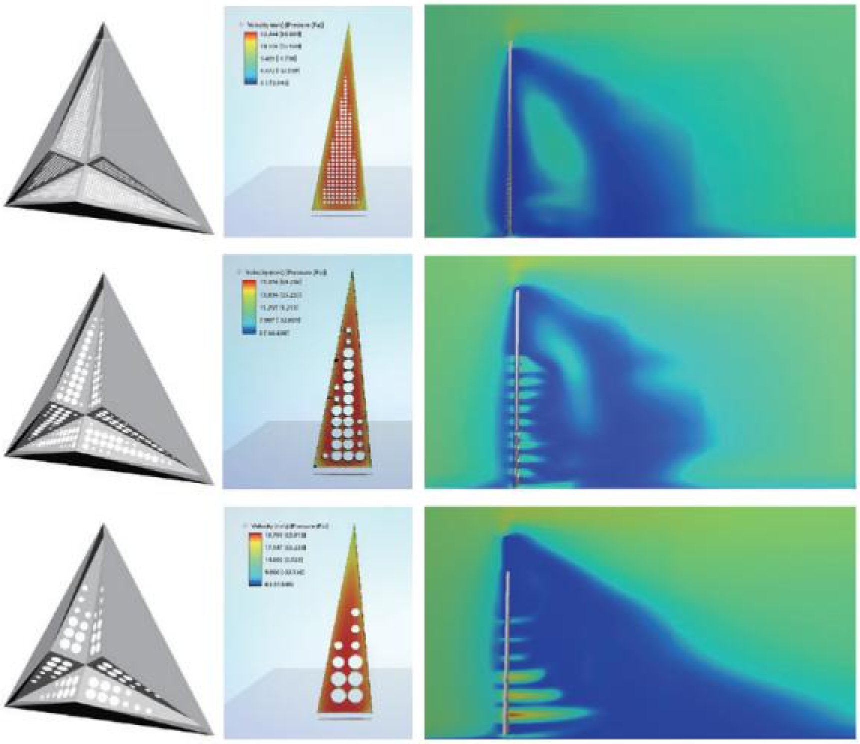
Movements Diagrams

Leaf movement concepts translated into shading systems



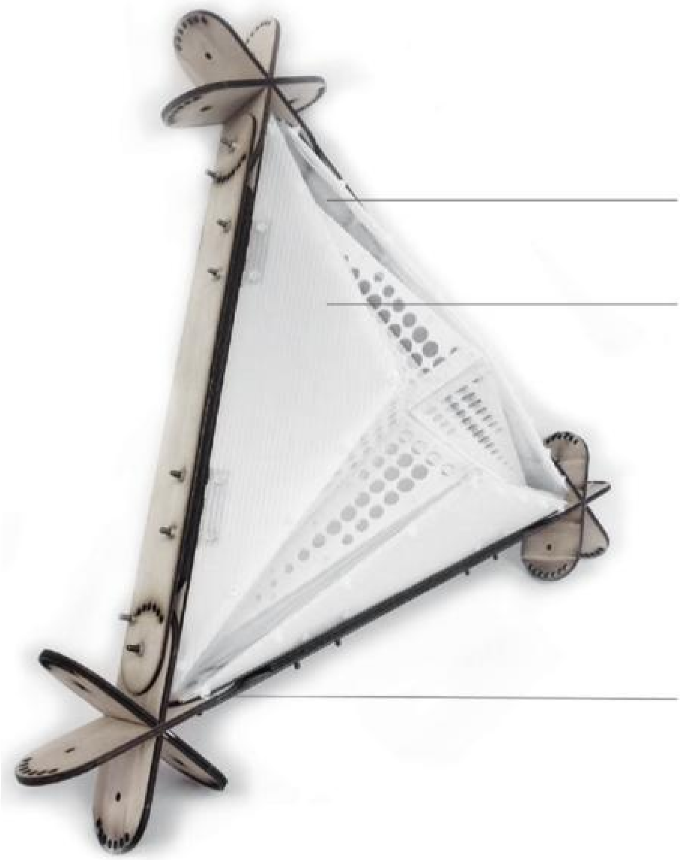
Model Studies

Paper Folding
Movement Studies



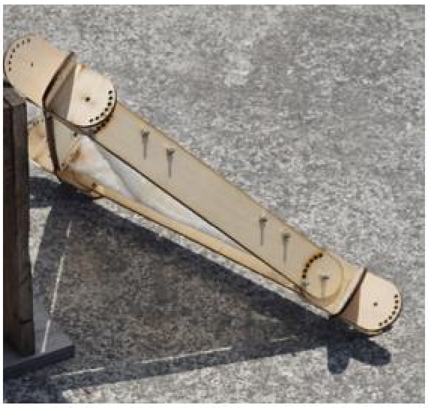
Module Studies

Wind studies through opening patterns in modules



Physical Model

Physical Model with Perforation

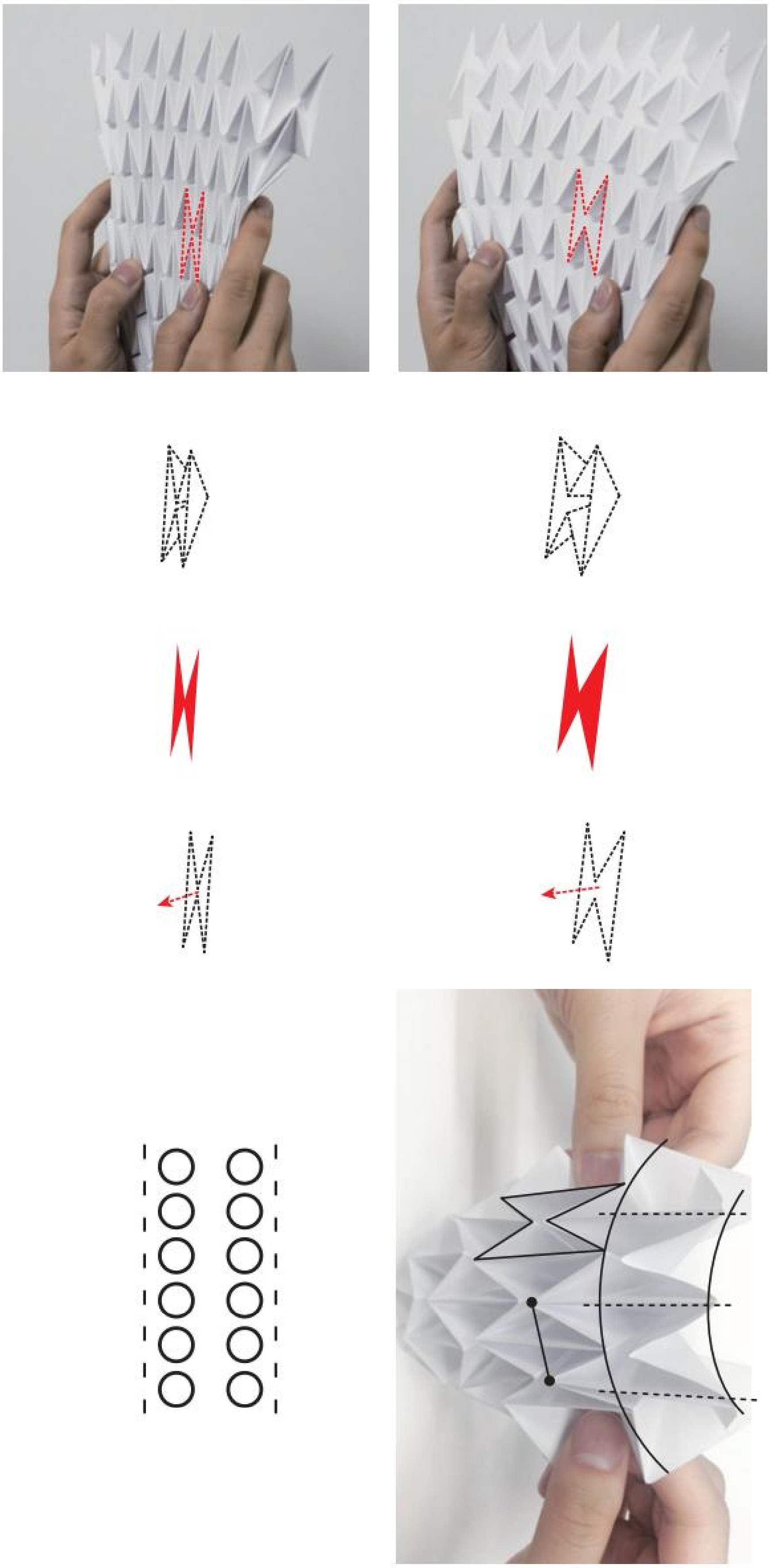


Models

Physical Model

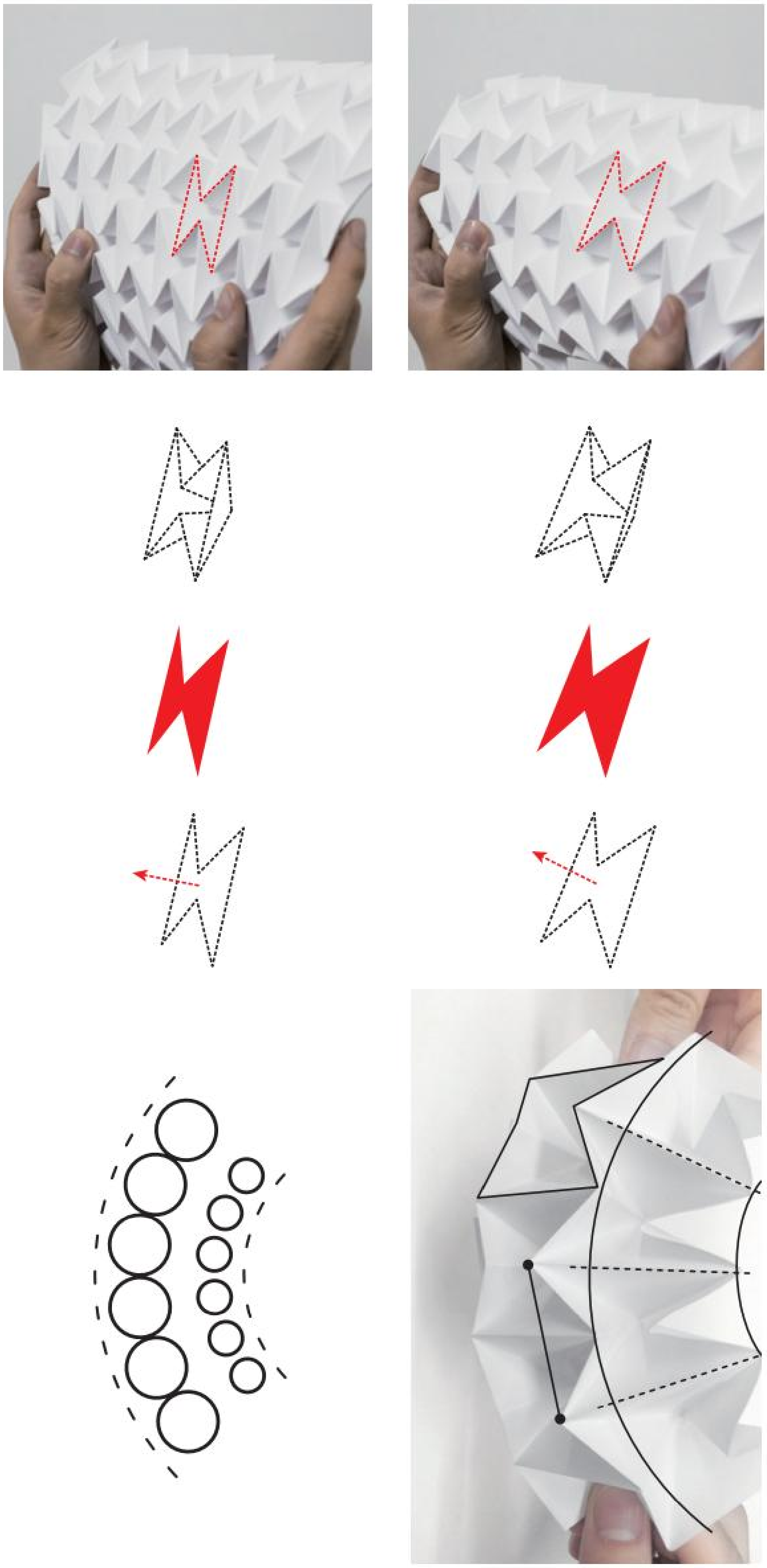
Models

Physical Model

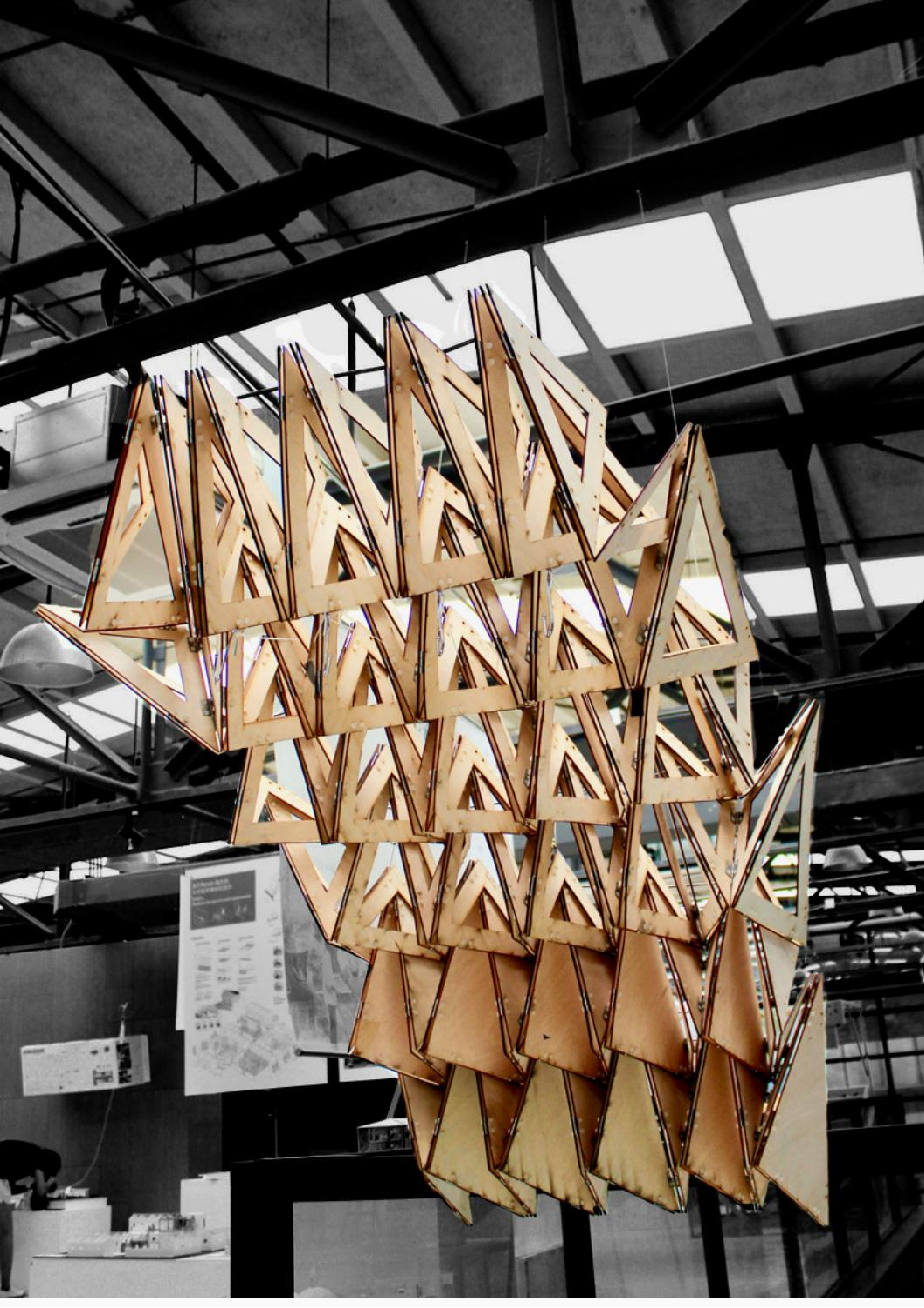


Patterns Isolated

Reduced paper model studies to explore a single modules movement





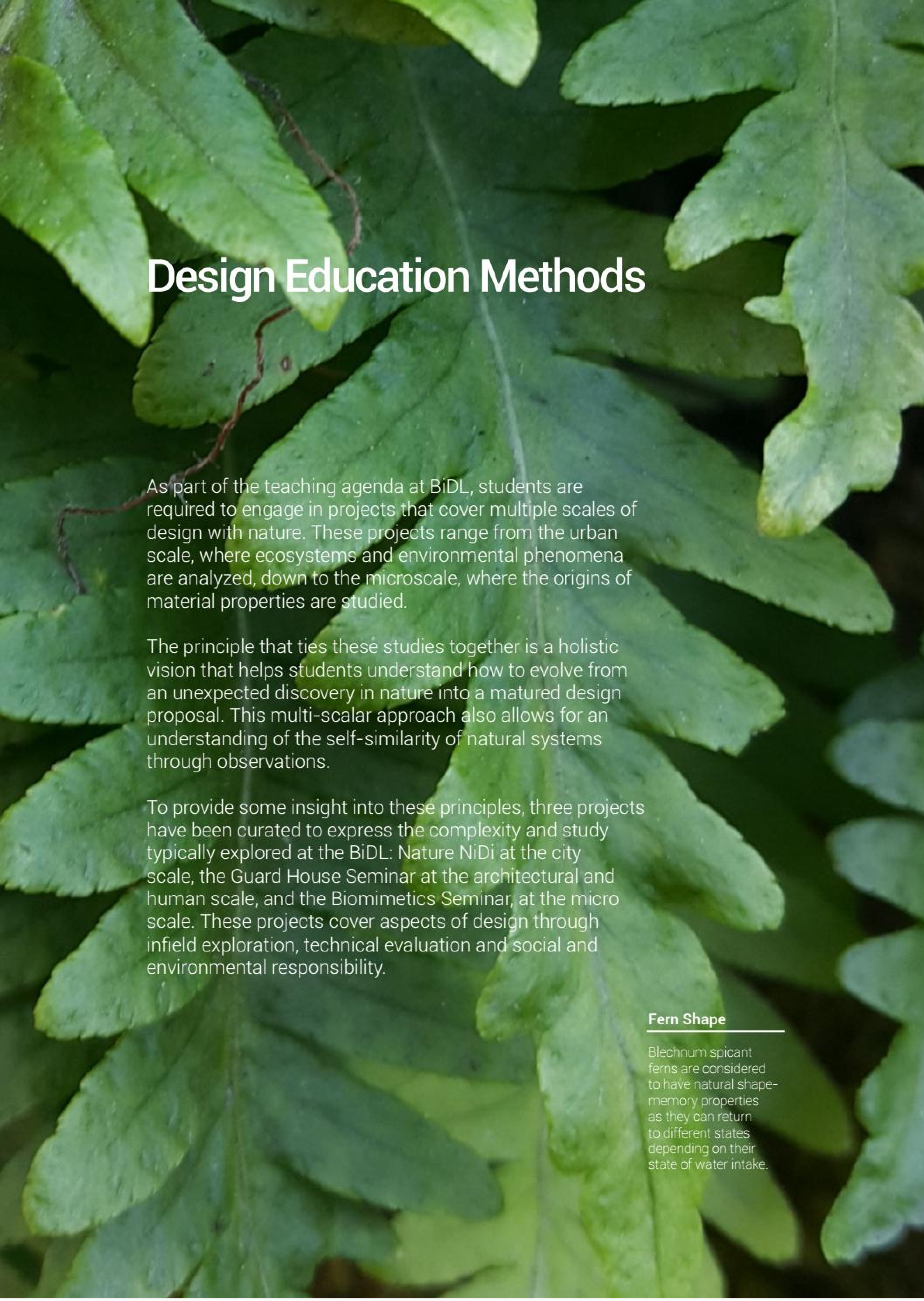



Design Education Methods

As part of the teaching agenda at BiDL, students are required to engage in projects that cover multiple scales of design with nature. These projects range from the urban scale, where ecosystems and environmental phenomena are analyzed, down to the microscale, where the origins of material properties are studied.

The principle that ties these studies together is a holistic vision that helps students understand how to evolve from an unexpected discovery in nature into a matured design proposal. This multi-scalar approach also allows for an understanding of the self-similarity of natural systems through observations.

To provide some insight into these principles, three projects have been curated to express the complexity and study typically explored at the BiDL: Nature NiDi at the city scale, the Guard House Seminar at the architectural and human scale, and the Biomimetics Seminar, at the micro scale. These projects cover aspects of design through infield exploration, technical evaluation and social and environmental responsibility.



Fern Shape

Blechnum spicant ferns are considered to have natural shape-memory properties as they can return to different states depending on their state of water intake.

Luxun Park

Luxun Park is an authentic Shanghai park which serves adjacent residential neighborhoods in an area near Hongkou Stadium. Historically, the park was an old British shooting range which was converted into a local park and dedicated to the Chinese writer Lu Xun as he lived in the nearby area.[1]

The park provides key features of allées for strolling, a boating area, mahjong, dancing and tai chi areas. The parks connection to nature is curated through a typical urban landscape, however, there are areas of lush overgrown shade and understory foliage that has developed since 1896. In terms of connecting visitors with the landscape, this park is successful as it provides an area of reprieve and respite in the city. The park has been selected as part of the NiDi mapping list, as it provides connection to the concept of biophilia and need for nature within the city.

Although there are limited areas to observe ecological processes, the age of the park has allowed the green space to act as a landmark for visitors. Many birds, insects and fish have inhabited the park. This suggests that even in parks where the landscape is cultivated, natural relationships can survive to benefit the adjacent urban context.

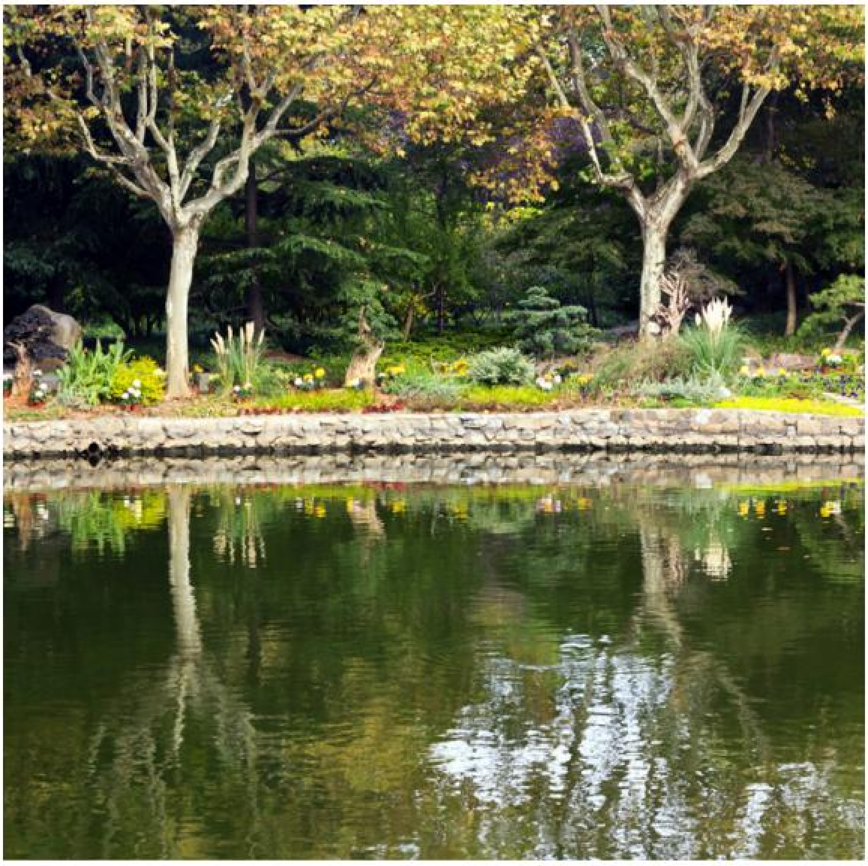
Luxun Park

Man stretching on tree in Luxun Park Shanghai China

1 "Lu Xun Park." Beijing Visitor - China Travel Guide. December 13, 2017.

Luxun Park

The park features many landscape amenities such as calligraphy space, river seating next to the large lotus and meandering paths to enjoy the water.



Human Scale Design

In the Guard House Seminar, techniques were introduced which explored how to use environmental conditions for designing habitats. There are many resources and tools that facilitate the study of climate and often times students must develop technical information to prepare a design. As an example, when considering aspects of humidity and temperature control, intensities of either factor can vary the outcome of a habitable or inhabitable space.

The project aimed to address issues of environmental comfort found throughout the guard houses at Tongji University. A guard houses provides shelter for the staff which monitor the entries to the campus throughout the day. Typically, these enclosures provide basic shelter from wind and rain but don't include thermal comfort or amenities such as water and restrooms. The main issue associated with these spaces was how to control the climate on the interior with minimal intervention and reliance on systems that would require additional energetic support. This problem is relevant throughout all of Shanghai, as many facilities, institutions and corporations have guard houses with the same limited amenities.

The site selected was the guard house located at the main gate in the southeast area of the campus. It is adjacent to Siping Road, the main road of access to the university and where human traffic is consistently high on a daily basis.

The students developed their projects following three phases. The first phase focused on data collection and framing the issues to guide the design. Students interviewed and frequently visited the house to establish relationships with the staff and understand the needs from an in depth perspective. The second phase required students to research biological systems and source a potential solution. Students worked through a series of concepts to reach a final design that worked for the site, scale and needs of the staff. In the last phase, students developed full applications for the guard house and were asked to articulate them as an architectural intervention.

Guard House

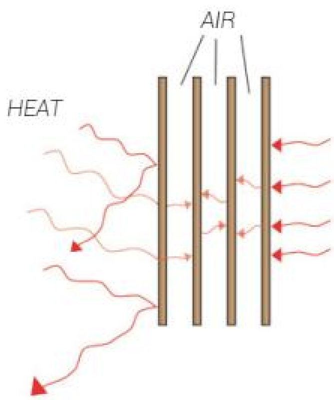
A Tongji University guard house on the north side of the main entrance gate at Siping Campus

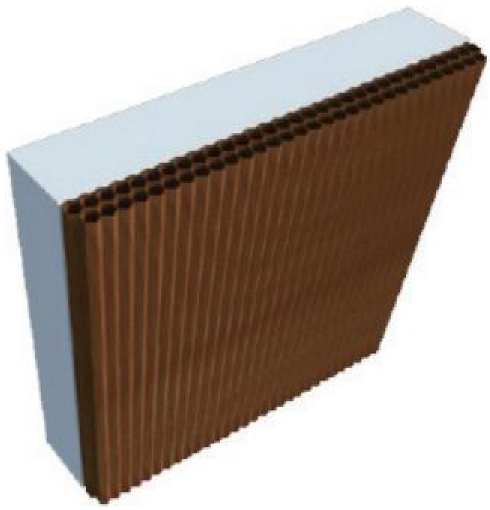

Self Shading

Tree Bark

"The Bark of trees keeps its surfaces cool by minimizing absorption of solar light and maximizing thermal emission."[1] Bark is a critical feature that helps to protect and mitigate heat gain and loss. Tree bark displays a paper-like structure and these layers are highly insulating, as they allow for trapped air to occupy spaces in-between. Trees with more of a rough surface, have been studied to show that these surfaces produce a lot of shadows which stimulate the convection of air, that moves heat away from the surface. In addition to this, the form of trunks, minimizes the surface with respect to the volume. For this reason, comparatively little solar heat can come in from the outside.

Inspired by these functions, we developed wall systems that through their layers and pockets, could direct air flow and promote heat absorption. The areas of application could be to the existing exterior walls to reduce the heat gain through mass during the summer months. In addition to this, convection was considered to occur through the cool side through internal cells, to allow for constant air flow on the interior spaces.





Bark Studies

Opposite Page:
Tree Bark Photo

Current Page
Top Image:
Concept Diagram of a bark inspired wall system

Axon views of wall system showing cells for air build up

Student Team
Sheng He , Kan Liu, Junying Li

1 Henrion, Wolfgang, and Helmut Tributsch. "Optical Solar Energy Adaptations and Radiative Temperature Control of Green Leaves and Tree Barks." *Solar Energy Materials and Solar Cells* 93, no. 1 (2009): 98-107. doi:10.1016/j.solmat.2008.08.009.

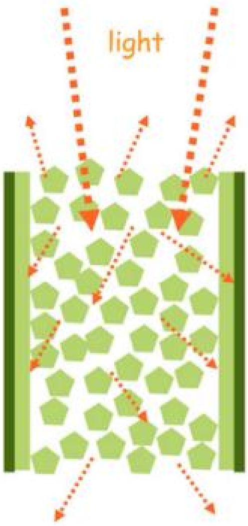

Light Filtration

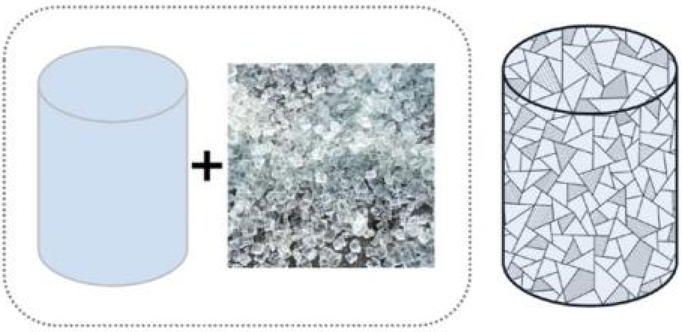
Succulents

Succulents typically can be found in climates where there are extremes in temperatures which requires them to maximize energy absorption and store this energy for long periods of time. Shown here in the *Fenestraria aurantiaca* plant, there is a distinct light filtration mechanism developed for this purpose. The top morphology of the plants' skin is more transparent than the rest of the plant to support light filtration.

Sunlight enters the tops of the plant through a series of oxalic acid crystals. This light is diffused and reflected internally such that the sunlight reaches the grains of chlorophyll that are distributed around the sides and the bottom of the leaf.

The design inspiration from this feature explores a roof system that would use light as an energy resource and diffuse heat gain.





Succulent Studies

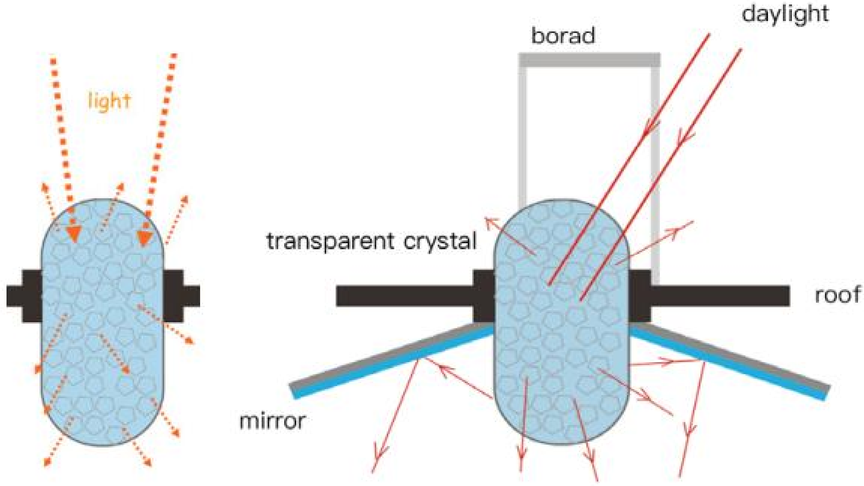
Opposite Page:
Image of *Fenestraria aurantiaca* or "Baby Toes" or "Window Plant"

Current Page
Top Image:
Concept diagram of sunlight absorption in walls

Lower Images:
Material concept diagram for *Fenestraria aurantiaca* inspired ceiling system

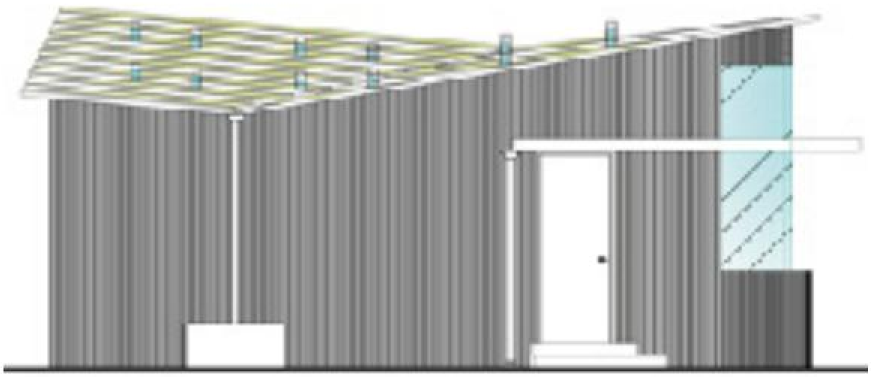
Light Pillars

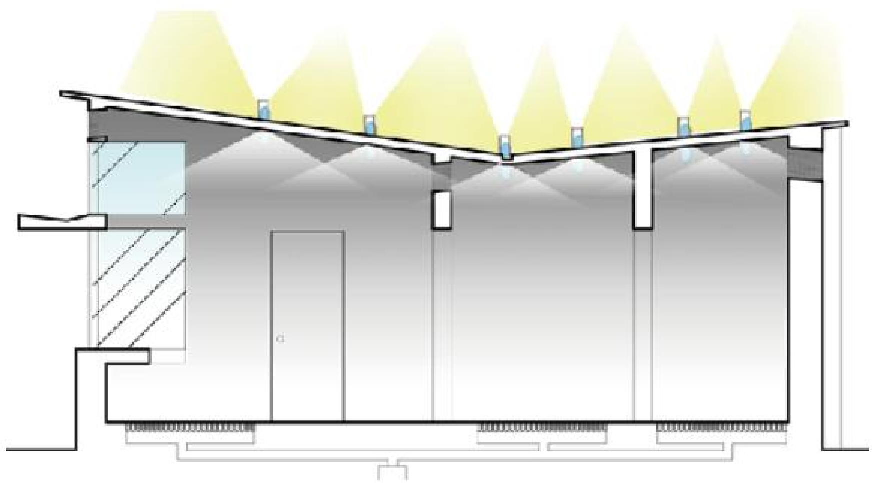
Succulent skylight concept



Roof Application

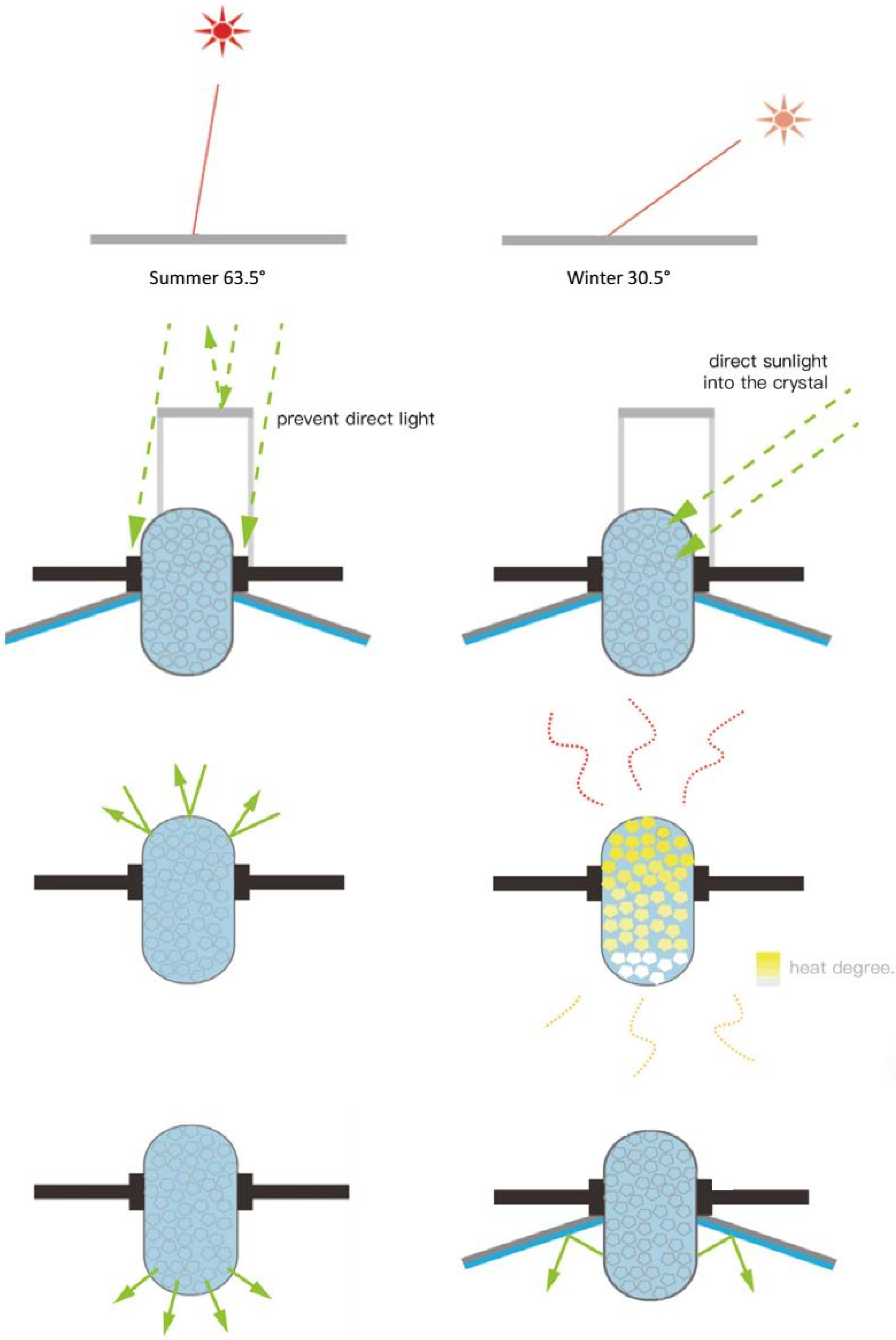
Guardhouse's elevation and section showing skylight concept





Light Concepts

Opposite Page: Images of light refraction and absorption during different times of the year.


Summer 63.5°
Winter 30.5°
prevent direct light
direct sunlight
into the crystal
heat degree.

Microscale Design

In this chapter, the projects looked at nature in detail, at the microscale to understand functions from a new perspective. As at the microscale much of the composition is about fiber orientation, this led the analysis to be concentrated on understanding hierarchies and how change in function occurs at different scales. Rather than select the primary biomimetic organisms such as the lotus leaf, students were tasked with picking any artifact that they were interested in exploring in detail.

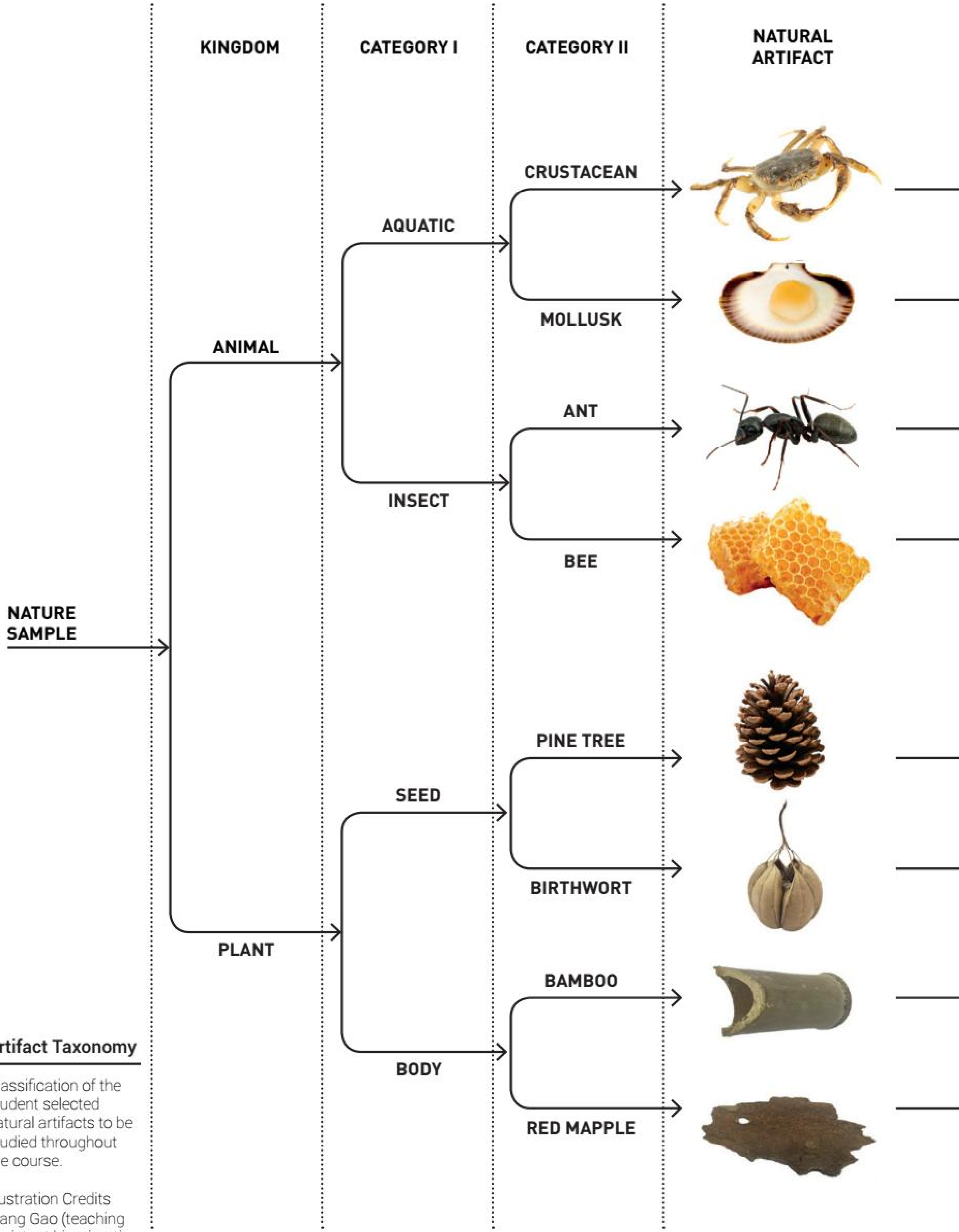
Through a series of classes which progressed from studies on form, movement, materiality, and scale, students were asked to develop their work through physical testing, modeling and digital exploration. The outcomes were required to be physically prototyped, which directed the design to tend to be at the industrial design or architectural scale.

The class worked in collaboration with the Department of Molecular and Cell Biology School of Life Science and Technology at Tongji University to help the students develop SEM (Scanning Electron Microscope) images of their artifacts. Professors at this college invited students to use their microscope which used a process of gold coating to allow for magnification. A gold coating was applied to the objects to assist the microscope's electron beam in illuminating the artifacts. This process to study the outcomes directly with the scientists was a unique and one that many times designers don't get to enjoy, as a connection with the sciences can be limited.

The final designs range from proposals for new materials to joints and to systems that provide alternatives to conventional methods such as new concepts for lifting. As the course was open to all students of the university, the composition of students was comprised of undergraduate to graduate from a range of backgrounds such as industrial design, service design, environmental and communication designers. For many, it was their first course in biomimetics and studying nature to inform abstraction for design.

Seed Dispersal

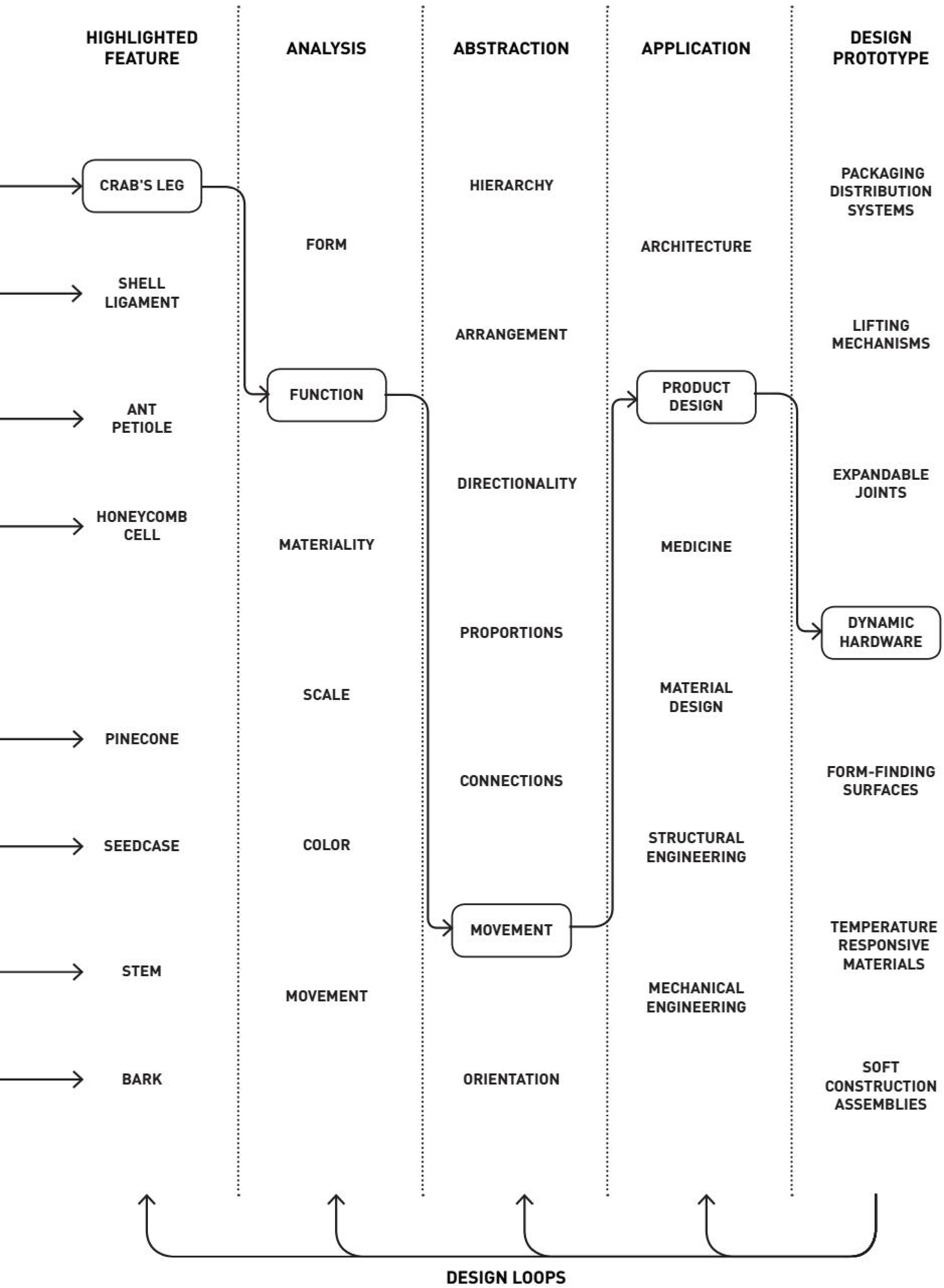
Opposite Page: Photograph of *Aesculus hippocastanum*, Sapindaceae or commonly called a Horse-chestnut tree or conker tree showing flowering inflorescence in early spring



Artifact Taxonomy

Classification of the student selected natural artifacts to be studied throughout the course.

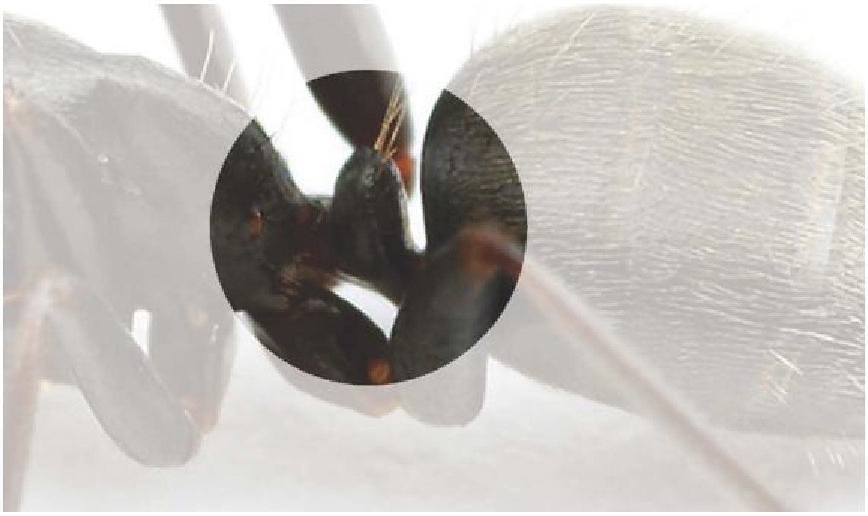
Illustration Credits Xiang Gao (teaching assistant biomimetic design)


HIGHLIGHTED FEATURE
ANALYSIS
ABSTRACTION
APPLICATION
DESIGN PROTOTYPE
CRAB'S LEG
SHELL LIGAMENT
ANT PETIOLE
HONEYCOMB CELL
PINECONE
SEEDCASE
STEM
BARK
FORM
FUNCTION
MATERIALITY
SCALE
COLOR
MOVEMENT
HIERARCHY
ARRANGEMENT
DIRECTIONALITY
PROPORTIONS
CONNECTIONS
MOVEMENT
ORIENTATION
ARCHITECTURE
PRODUCT DESIGN
MEDICINE
MATERIAL DESIGN
STRUCTURAL ENGINEERING
MECHANICAL ENGINEERING
PACKAGING DISTRIBUTION SYSTEMS
LIFTING MECHANISMS
EXPANDABLE JOINTS
DYNAMIC HARDWARE
FORM-FINDING SURFACES
TEMPERATURE RESPONSIVE MATERIALS
SOFT CONSTRUCTION ASSEMBLIES
DESIGN LOOPS

Ant Petiole

The main focus of this analysis was on the section between the two body volumes, the head and the abdomen of the ant. Between these areas and the connecting thorax, joints enable the ant to rotate these features almost freely. Although it appears to be a paradox, these areas which need to manage the rotation for such a large volume of the outer body compartments, are within the thinnest points in the ant's anatomy.

The petiole differentiates the ant from other insects. "The petiole (and post-petiole, when present) provides a flexible junction, allowing the ant to bend its gaster forward to sting or spray."[1] The petiole is the physical joint of the whole ant body. Even though it constitutes the thinnest area between the several body compartments, its function requires high flexibility while being stable enough to lift the weight of the attached voluminous body parts. The following design principles were derived from this observation investigating the change between flexible and rigid or stable states and conditions. The developed object can be used in several industries to provide a stable and flexible linear joint. This could be useful in architecture or buildings where flexibility and stability are required at the same time.



Joint Concepts

Opposite Page
Photograph of carpenter ant

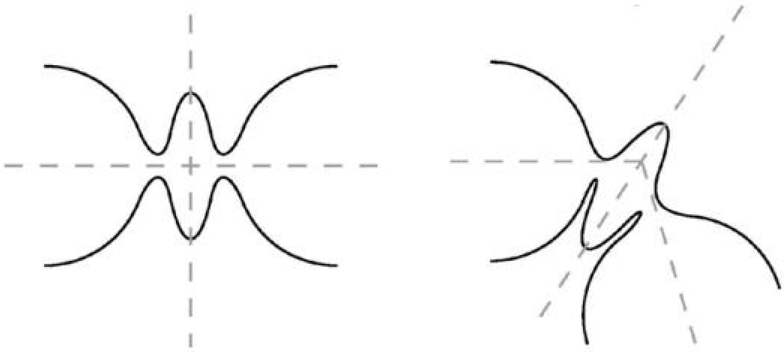
Current Page:
Photograph with isolation around the petiole

Project by
Fabian Kragenings

1 "Face to Face with an Ant Seeing Red." Scribol.com. May 18, 2018.

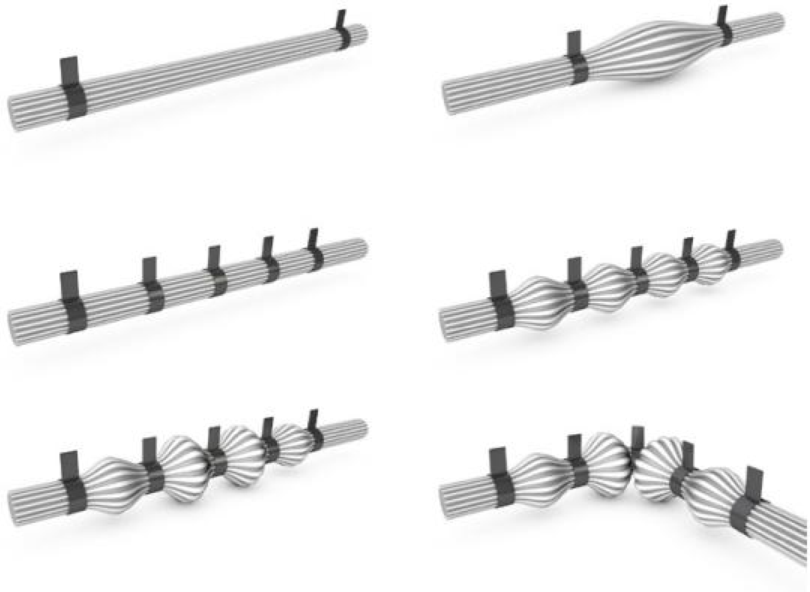
Abstracted Joints

The diagrammed mechanism shows the possibility of controlling the angle between two compartments to maintain the flexibility of the joint.



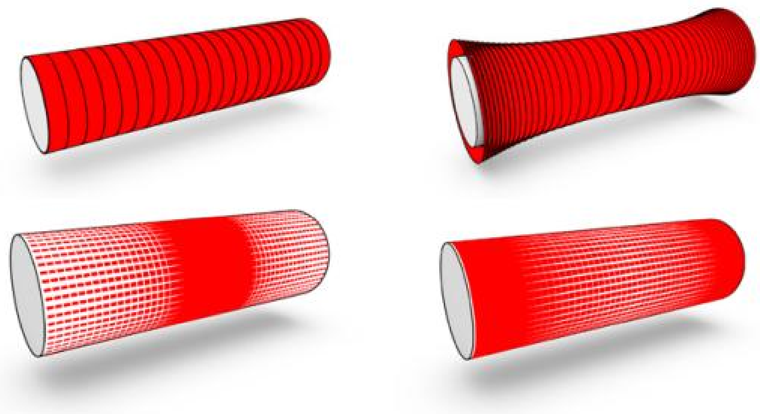
Bending Concepts 1

The abstraction of the mechanism considers the restriction of the angle by the petiole. As shown in the series, there is a gap between the outer volumes and the connecting petiole. This gap defines the rotational range of the compartments.



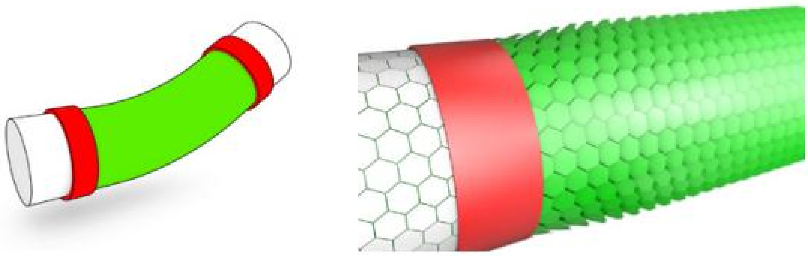
Bending Concepts 2

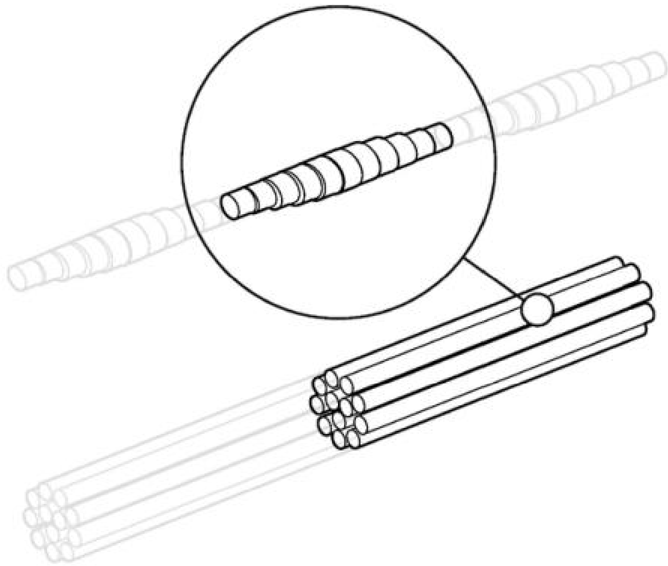
The concepts to the right explores skin alternating techniques to achieve flexibility and rotation.



Bending Concepts 3

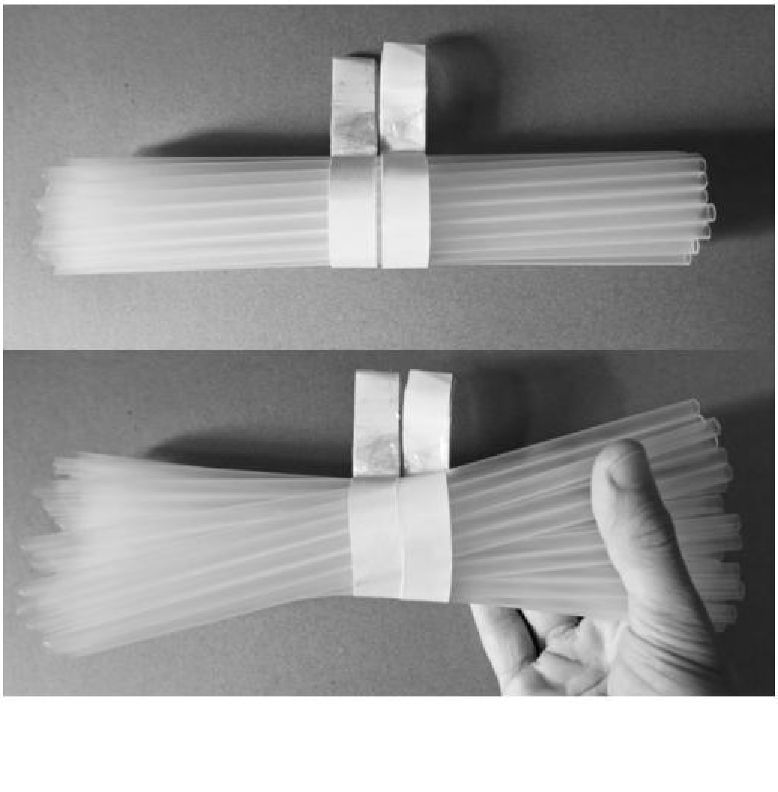
These studies explore paneling systems that could react to curvature through angled scales to increase or decrease rigidity,





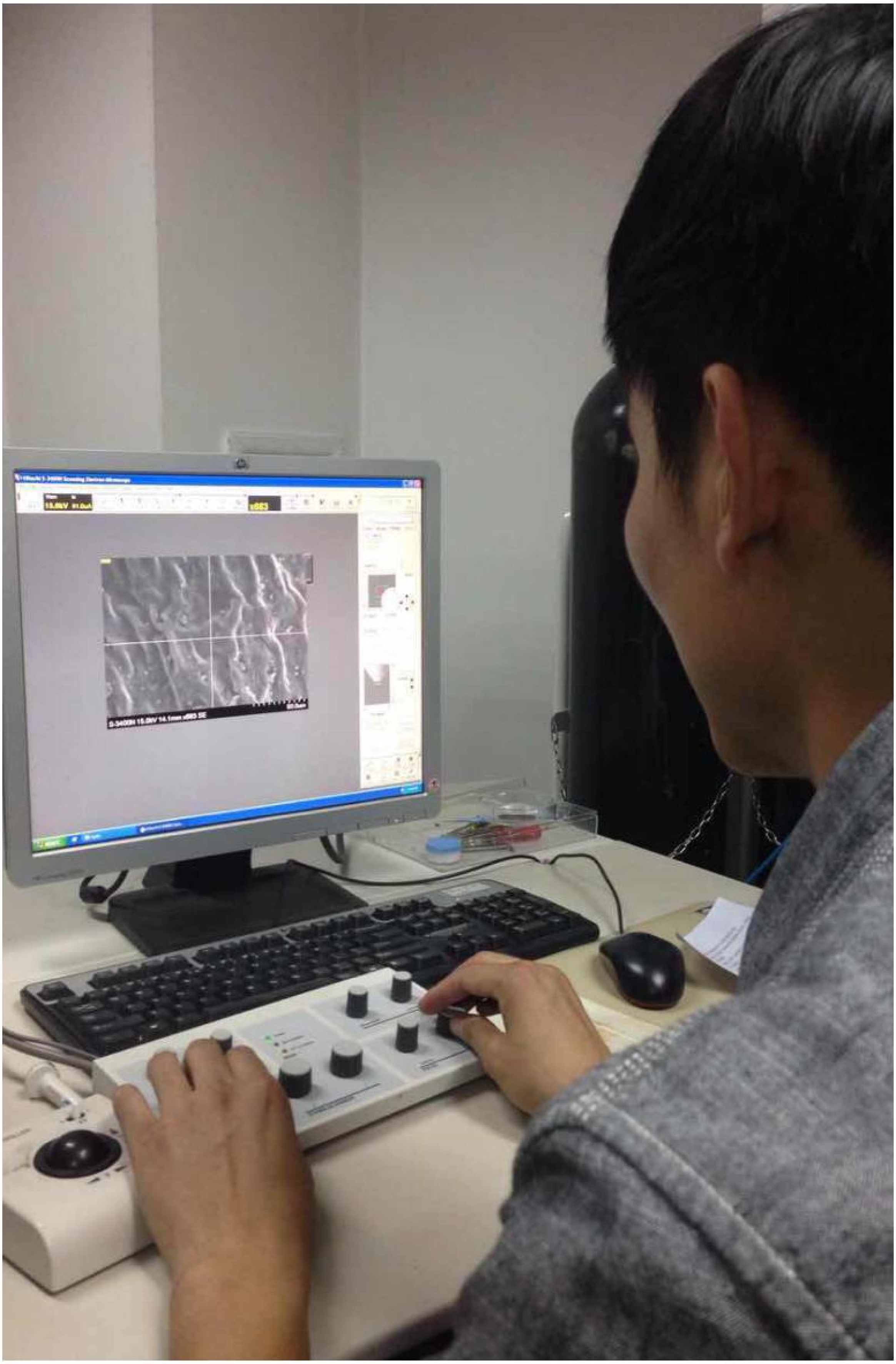
Joint Prototypes

Bundling joint diagram shown at two scales, object and materiality



Physical Prototypes

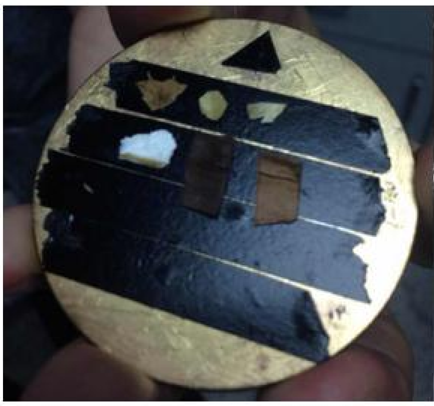
Fiber twisting, due to the holder positioned in the center of the bundle, the individual straws had the ability to move in a radius. By twisting the bundle the overall surface on the outer areas enlarges, which could provide connection points for other objects.



SEM
(Scanning Electron Microscope)

For study at the micron level, students worked with the lab in the Department of Molecular and Cell Biology School of Life Science and Technology at Tongji University to develop imagery exploring the structures. The team in the lab consisted of professor Jian Zhu, Dr Xiling Du and professor Liu Zhu who graciously assisted students in preparing their samples, discussing how to view them to obtain the best results and how to understand the imagery capture. While this process might be standard in the science field, for the design students, it was a rarity to be able to prepare artifacts for scanning and work one on one with the lab.

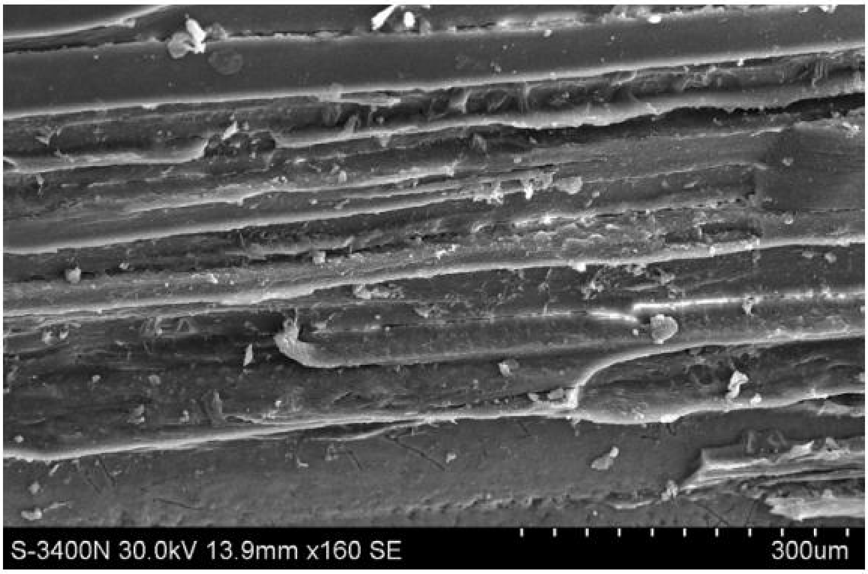
When we discuss micro and detailed levels of exploration, we are at the scale of a micron (symbol μ) pronounced "mu" and is understood to be 10^{-6}, one-millionth of a meter. A micron is also known to be indicated as a micrometer (μm) which is the same scale and can be represented as *(*um*)*. On many of the students' images, the *um* denotation is indicated for reference. Many of the projects from other labs in this book worked at this scale, as it is where biology and materials begin to show details of their organizational structures. To provide a point of reference, a human hair is about 50 μm in diameter. For measurements below a micron, we commonly use nanometer (nm), which is 10^{-9} one-billionth of a meter.

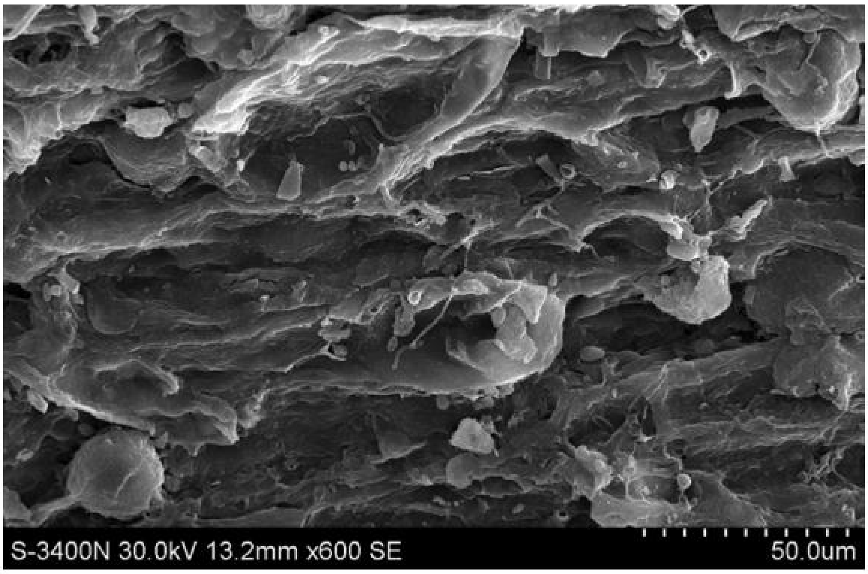


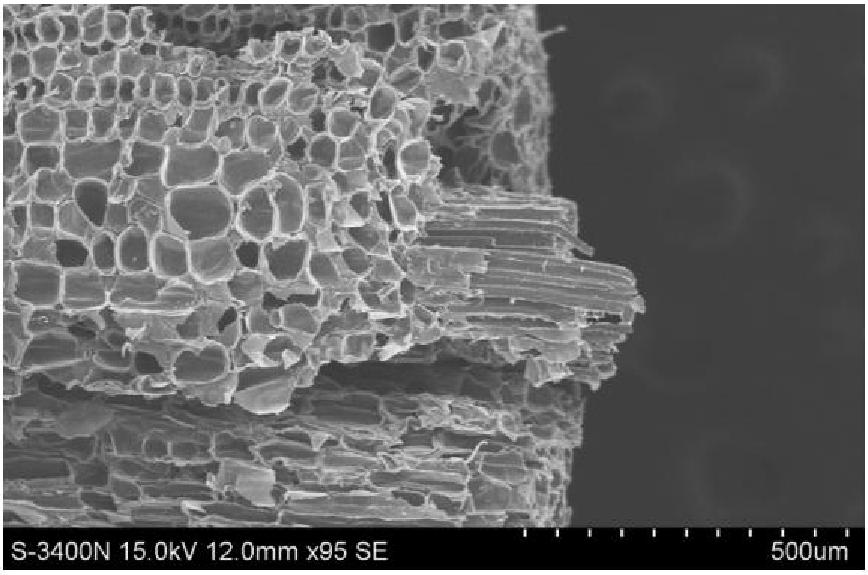
SEM

Opposite Page: Professor Zhi Liu assisting students with scanning in the Department of Molecular and Cell Biology School of Life Science and Technology. The electron microscope is useful to view smaller details on the surface of objects as it uses accelerated electrons to illuminate details.

Current Page: Image left shows a prepared sample before scanning with artifacts cut down and on adhesive tape. Image right shows samples after gold plating has occurred.





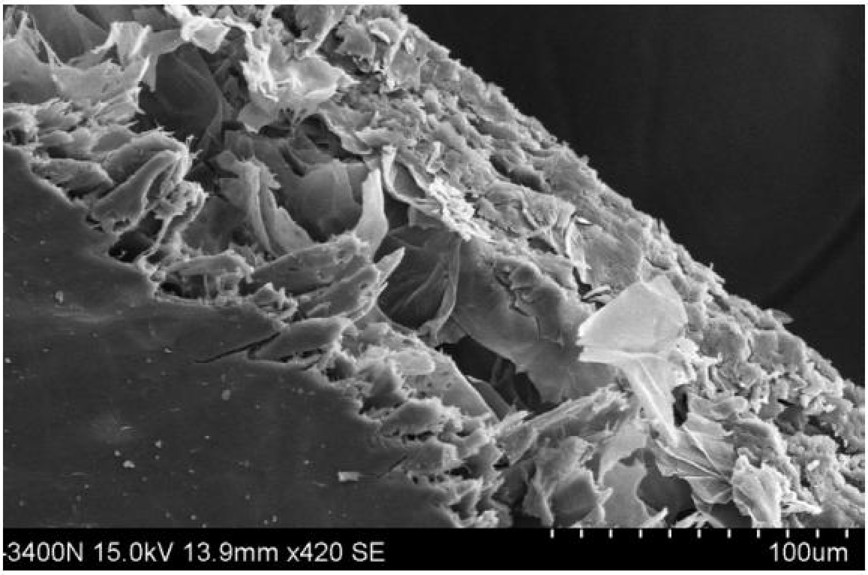


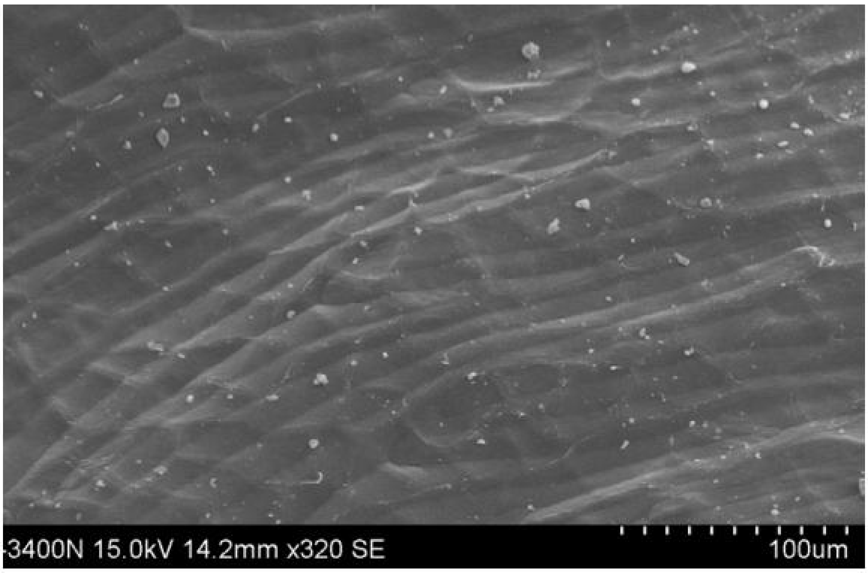
Artifact Scans

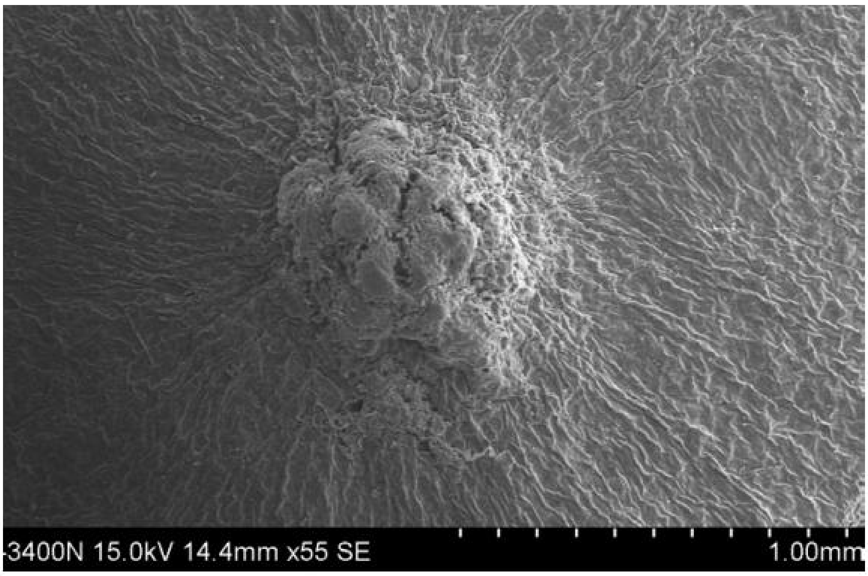
Image Top:
Shell outer surface

Image Middle:
Pine cone scale outer surface

Lower Image:
Bamboo end after being broken off







Birthwort Scans

Image Top:
Break in seed case

Image Middle:
Inner surface of seed case

Lower Image:
Main connection of all seedcase shells. Connection was located on the bottom exterior of the seed case.

Conclusion

Tendrils

Fern tendril in early spring

Bioinspired design is both simple and complex.

Simple as it provides an easy reference to discuss ideas through a means we all can relate and feel inspired by – *the natural world*. Nature easily engages those from a wide range of backgrounds, from environmental enthusiasts to professional designers and scientists, as well as the general public. Complexity arises when the metaphor is not enough and we need to understand beyond what we see. At many levels, we are still trying to comprehend how natural systems are interrelated and how we can start mapping these connections.

Bioinspiration is a broad field that encompasses many facets of biology, engineering and design. The research and development of materials, systems and techniques based on natural phenomena is considered one of the main contributors for innovation in applied sciences, and a critical driver for future advances in sustainability. However, the extent to which bioinspiration can influence our daily lives through its different ramifications is still relatively unknown. In that sense, this book aims to serve as an introduction to the umbrella term of bioinspired design, and explain the similarities and dissimilarities between its different specializations, from biomimetics to biomimicry.

To provide insight into the process that merges nature and design, bio labs founded by some of the top universities in China were invited to exhibit their work for this book, namely the Key Laboratory of Bionic Engineering from Jilin University, the Key Laboratory of Bioinspired Smart Interfacial Science and Technology from Beihang University, the Dynamic Technology Lab for Bionic Materials and Structures from Donghua University, and the Biomimetic Design Lab (BiDL), from Tongji University in Shanghai.

Additionally included are interviews with international researchers that began their careers when the discipline was just starting to establish itself. These biodesign experts include biologists, zoologists, architects, engineers and chemists, and their answers aim to showcase the different ways nature-driven methodologies are explored in education and professional practice.

"The Rise of Biodesign" offers a unique perspective into the current state of biomimetics and biomimicry in a challenging but exciting moment for bioinspired fields. Through professional research and students projects, this collection of work shines light on educational methods currently being explored in Chinese institutions, as part of a national environmental agenda that is critical, not only for the future of the country, but for our entire planet.