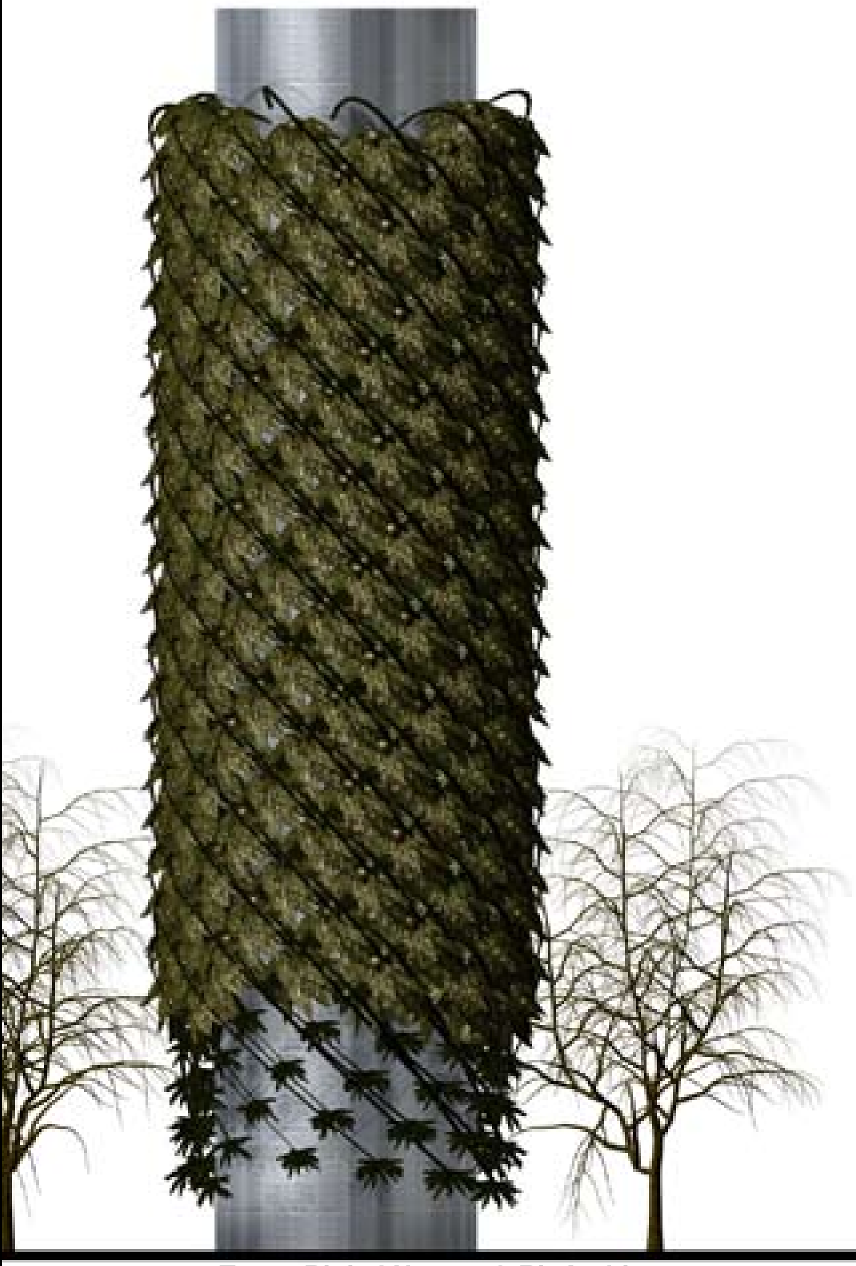
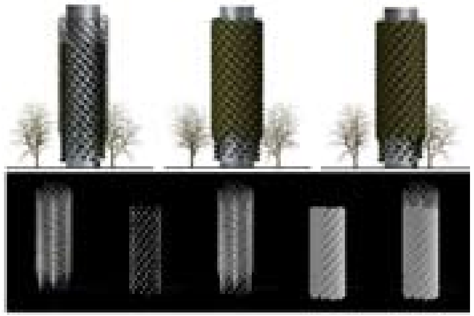
D-BA^2

Digital-Botanic Architecture 2 • eBook



eTrees, Digital Nature, & BioArchitecture

Dennis Dollens



Cover: BioTower. 2009. Dennis Dollens. Digitally grown tree, branches, leaves, and flowers programmed as an experiment dealing with environmentally active functions in order to create biomechanical, living, achitecture. Generated in Xfrog, edited in Rhino, and rendered in 3DS MAX.
See 28-35.

Back Cover: Dennis Dollens. Xfrog grown eTree & BioTower generative leaf surface.

eBook edition ISBN: 978-0-930829-69-8

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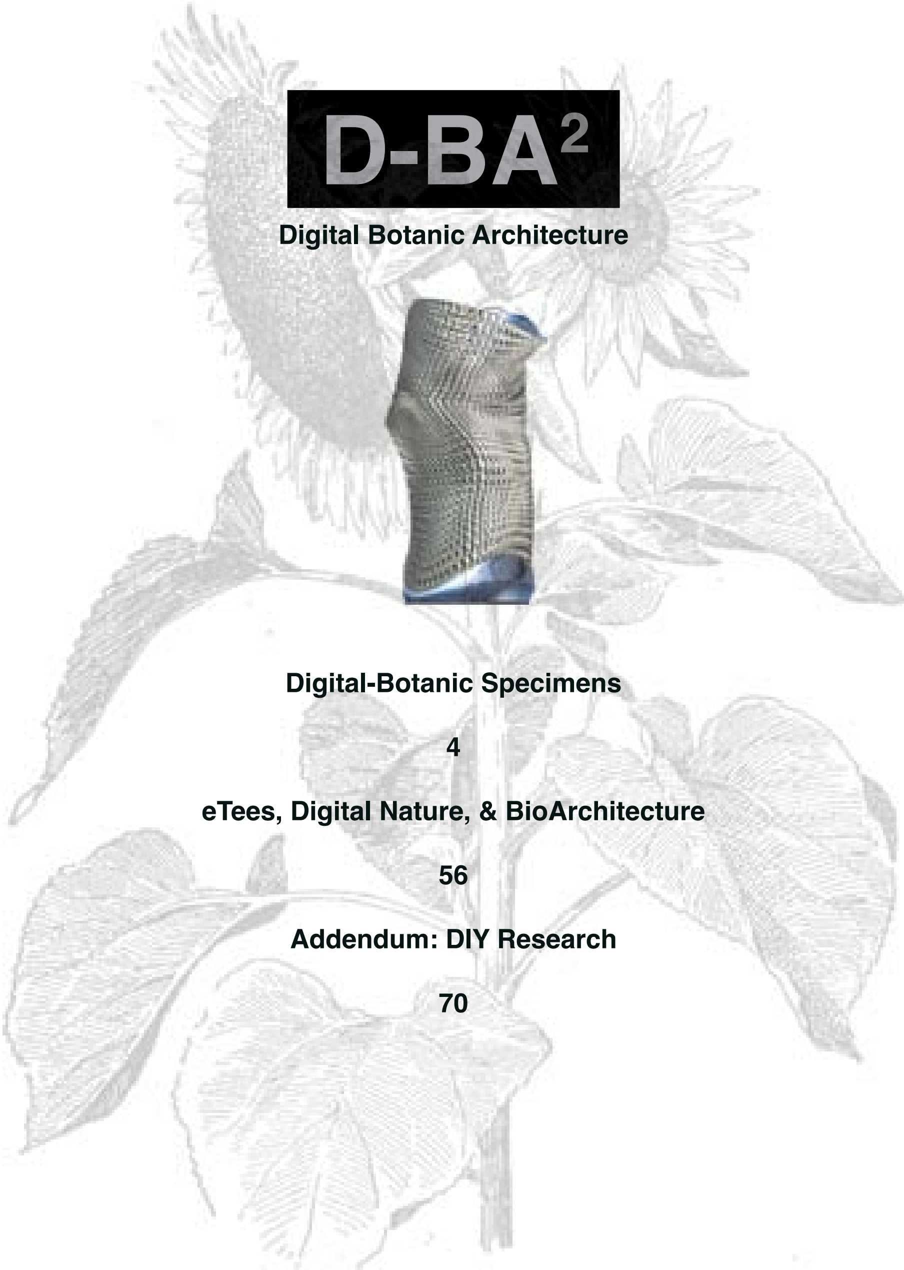
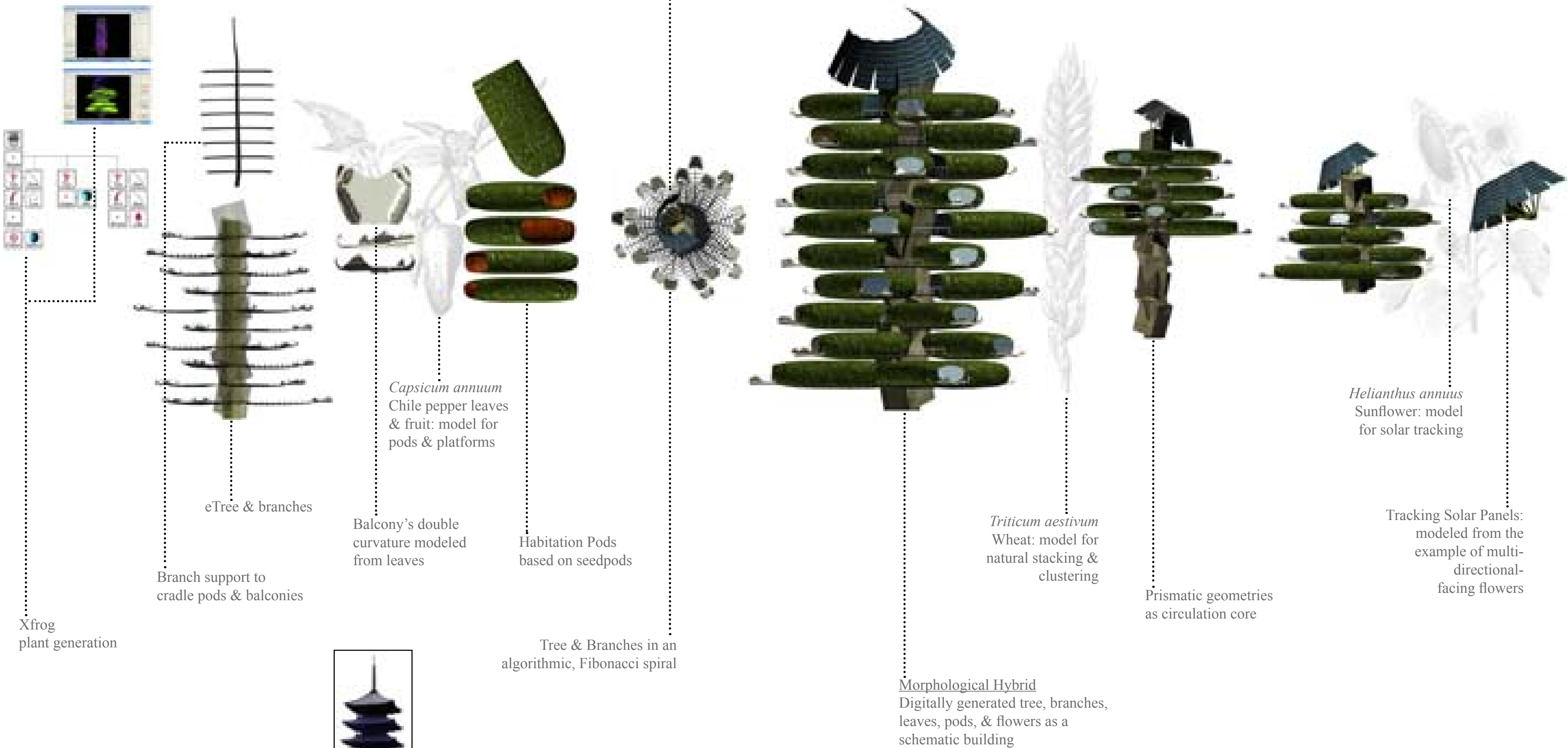


D-BA²

Digital Botanic Architecture

eTree Anatomy & Morphology

DBA² • Digital Botanic Architecture II
This series of experiments with simulated digital trees, hybridized into architectural elements, illustrates botanic forms and their morphological and mathematical attributes applied to design systems and structures. Using this generative process demonstrates how the transference of some biological properties, held in algorithmic notation, such as phyllotaxy, allometry, and phototropism, may be inherited by architectural and design elements derived from plant simulations and their corresponding biological maths.



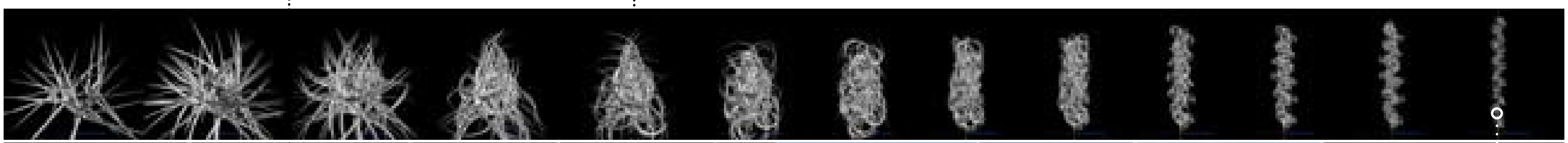
DIY
•
Trees as Architecture

exodesic.org

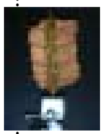
eTree Branch & Tendril Morphology

STL & SLS eTree models. 1999-2009
Branch and tendril development evolving as multi-directional, flexing structural trusses that gradually erase the digital tree trunks. Simultaneously, the branches sprout secondary growths based on flowers, leaves, tendrils, and pods that are eventually reprogrammed as living or mechanical spaces for prototype buildings.

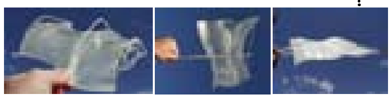
STL Truss #10. 2009
Generative sequence from Xfrog animation.



STL Two Branch Column. 1999
The project's starting-point based on a tree & then machine fabricated



STL Truss #1. 2000-2003
Tendrils & structurally intersecting branches.
Above: STL with adobe-pulp skin.
Below. STL eTrees with membrane surfaces



STL Truss #2. Intersecting and self-reinforcing branches grown to reinforce the column's center

STL Truss #3.
Gravitropic, intersecting branches grown to link and structurally pierce and graft with/ into lower branches

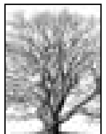
STL Truss #4. Central trunk model with spiraling, interlinking branches for structural reinforcement

STL Truss #9. The first design to eliminate the eTree's central trunk and therefore become a flexible structure of interlinking, spiraling branches with nodes for connecting joints, stems, and tendrils

STL Truss #10.
Sharing many of the attributes of #9, this structure departs, having greater branch asymmetry and flex while also acquiring greater strength

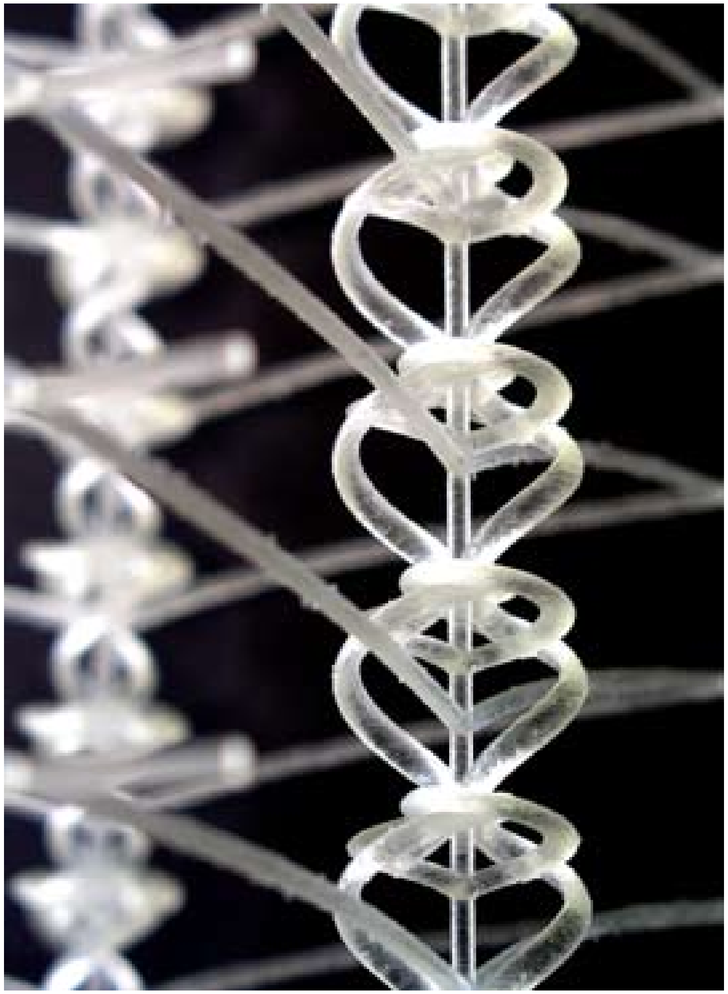
STL Truss 11.
No central trunk supports this structure. Its strength comes from asymmetrically reprogramming one of the branche's 3D coordinates in order to extend it, elongated in only one direction

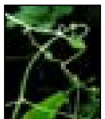
STL Truss #7.
This model is of the ArizonaTower. It is a collection of trees linked by branches—each of which sprouts both pods programmed for circulation stairways and pods reprogrammed as elongated cubes for habitation



DIY Looking
•
Recursive
Branching

http://algorithmicbotany.org/

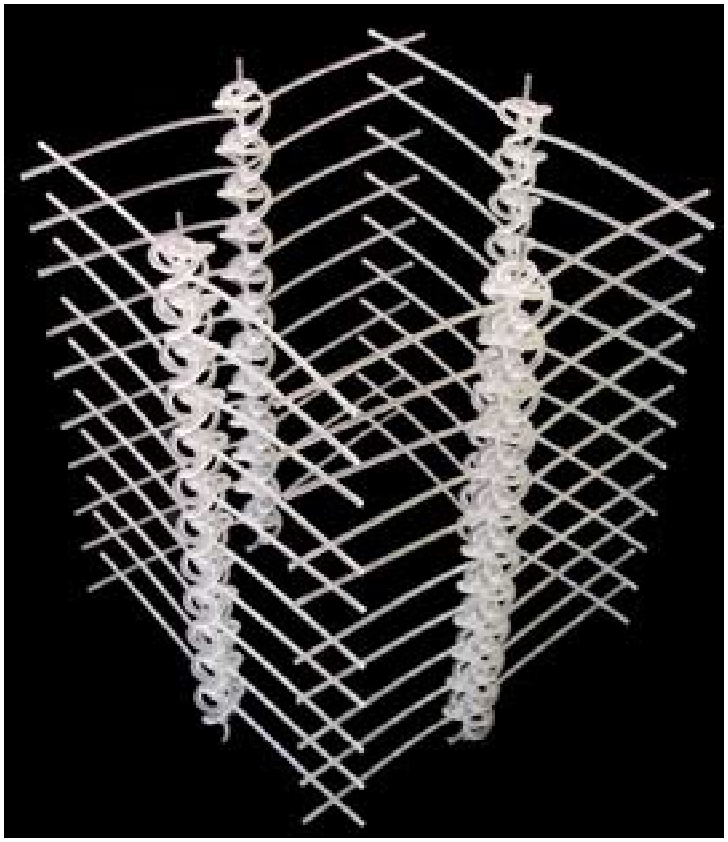




DIY • Botany
• Tendrils
• Knotting
• Connectors

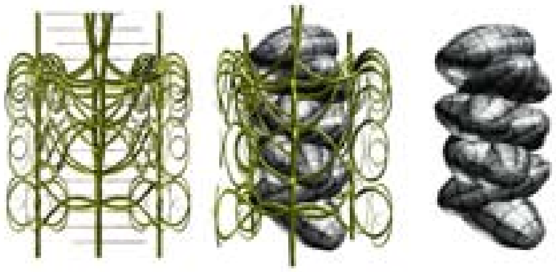
www.xfrog.com

Four eTrees, One Frame

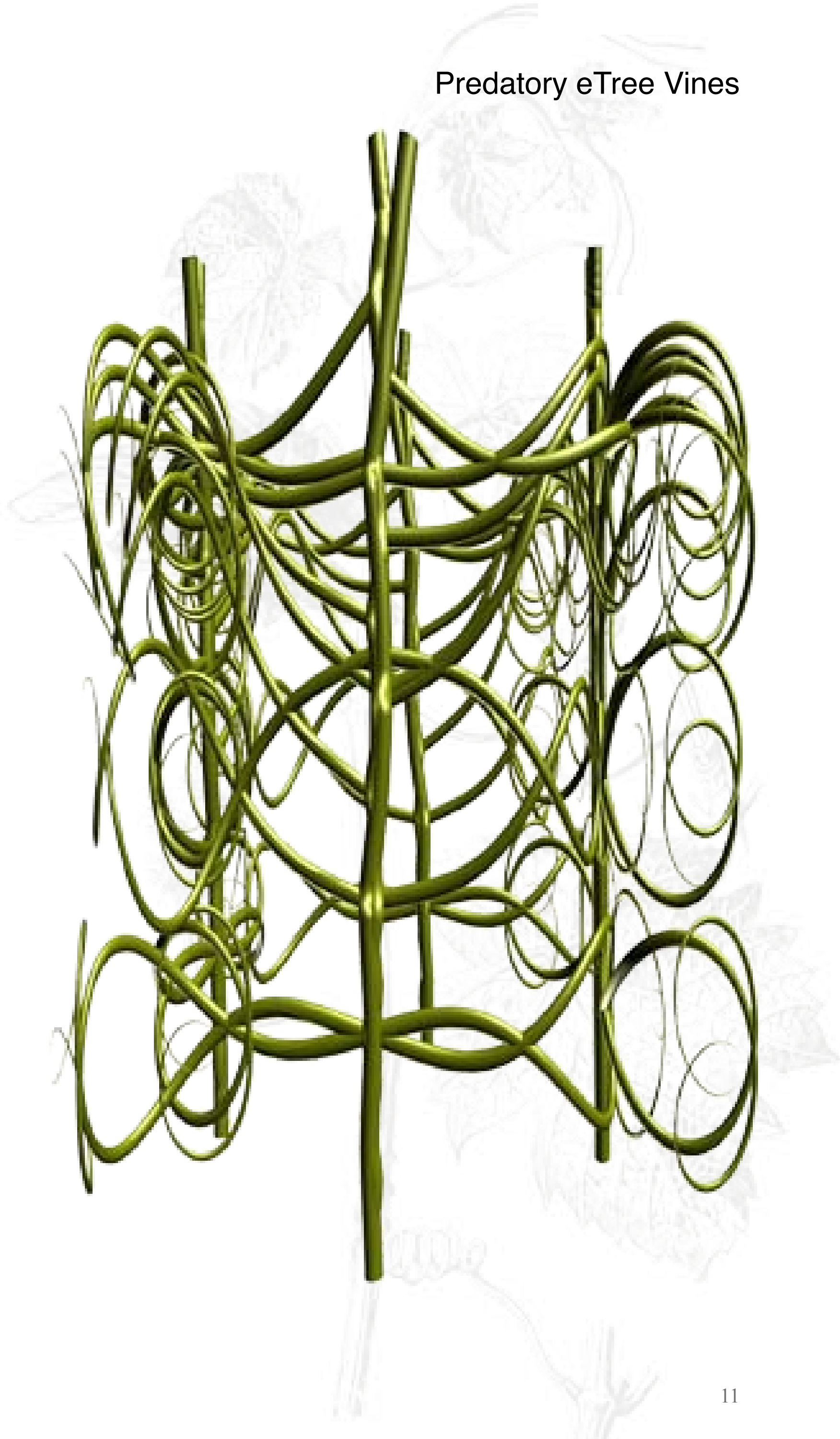


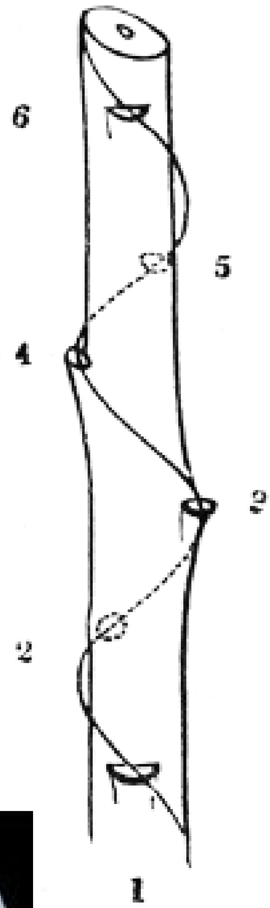
STL eTree models. 2000-2003
These four eTrees with equally proportioned trunks and branches were digitally simulated. Half of the branches were programmed to loop and intersect, thus reinforcing each of the four central trunks (detail, left), while the other branches were grown straight, intersecting at the corners of the building cage.

Predatory Frame. 2005
Above and right page 11: Predatory Structure—four eTrees with vine and tendril branches grown as framing structures with tendrils ready to reach out and anchor the building. Below: pod clusters stacked and held within the vine and tendril frame. Bottom: Earlier, related growth strategy for prototype canopies, Paris metro, 2001-2002.



Predatory eTree Vines





Phyllotaxy & Algorithmic Growth from Digital Software
Plant leaves and flowers (and shells and bones and horns) follow geometric spiraling patterns that can be captured in algorithmic formulas and thus digitally simulated. Above left and right, are19th-century scientific diagrams of botanic, spiraling progression. Right page 13 top, illustrates phyllotaxic branch spiraling overlaying an Xfrog drawing whose branches have been programmed into regular polygons (a basic eTree); the branch tips sprout over-scaled leaves (modeled here as panels) that illustrate the embedded Fibonacci directional flow. Photo inserts, right page 13: spider web with spiraling construction; and, far right spiraling succulent leaves of *Euphorbia myrsinites* (Myrtle Spurge).

eTrees, Nature's Numbers, & Spiral Growth

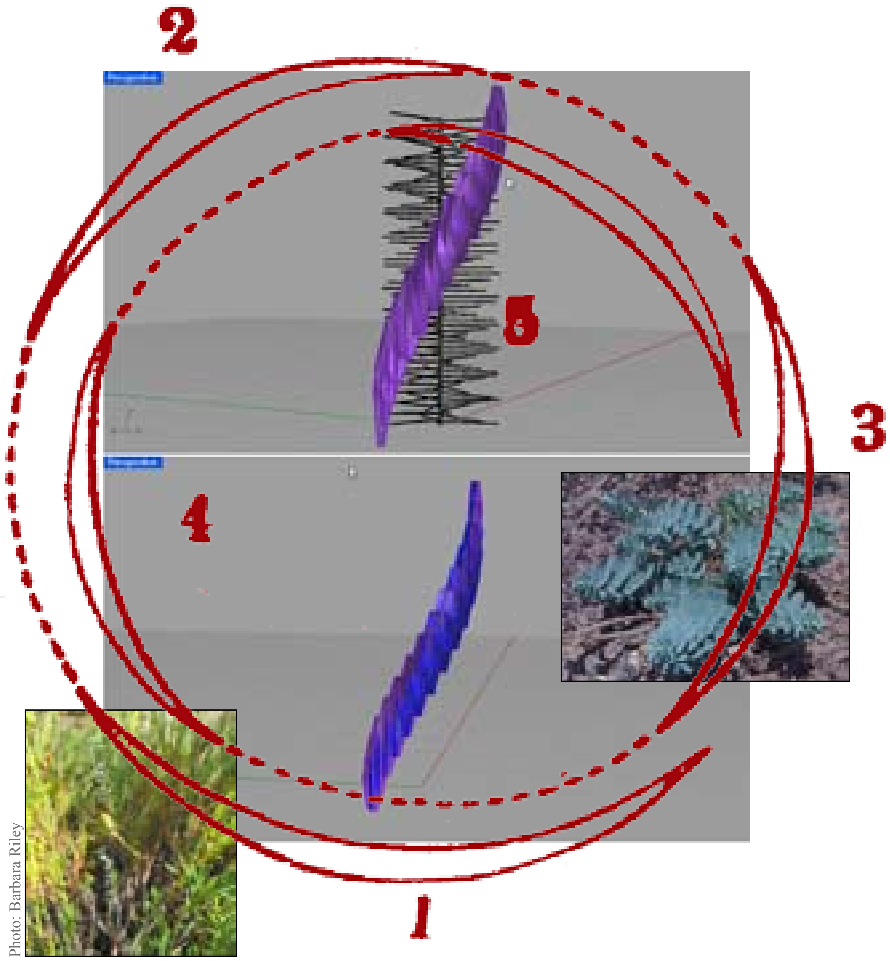
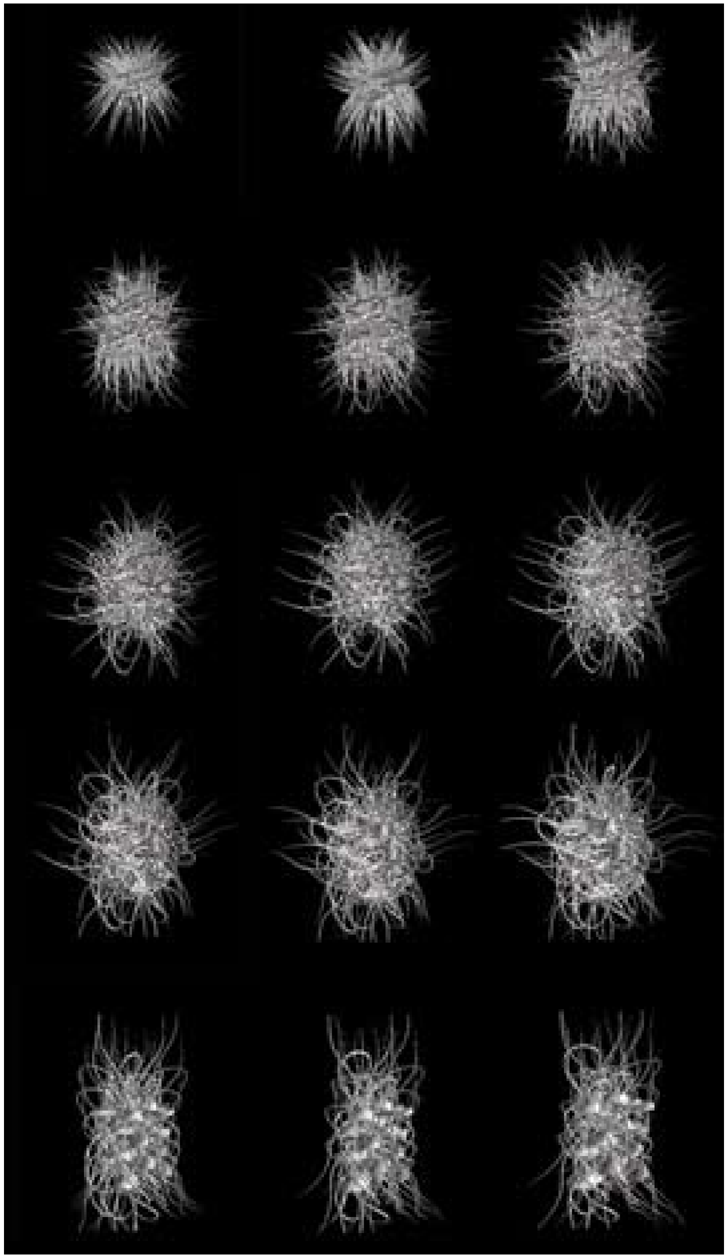


Photo: Barbara Riley

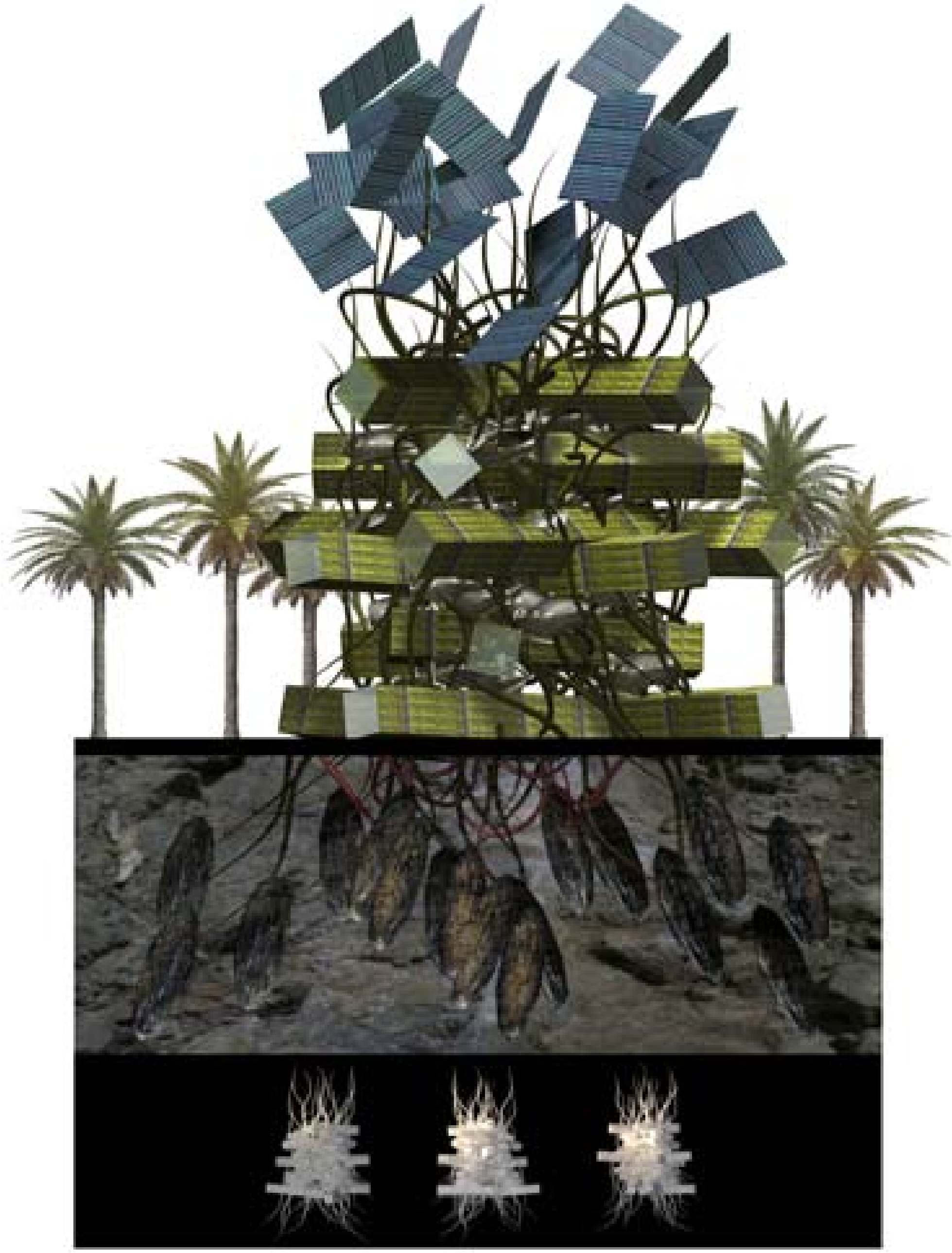
DIY
Botanic
Spiraling
• Phyllotaxy

http://en.wikipedia.org/wiki/Fibonacci_number

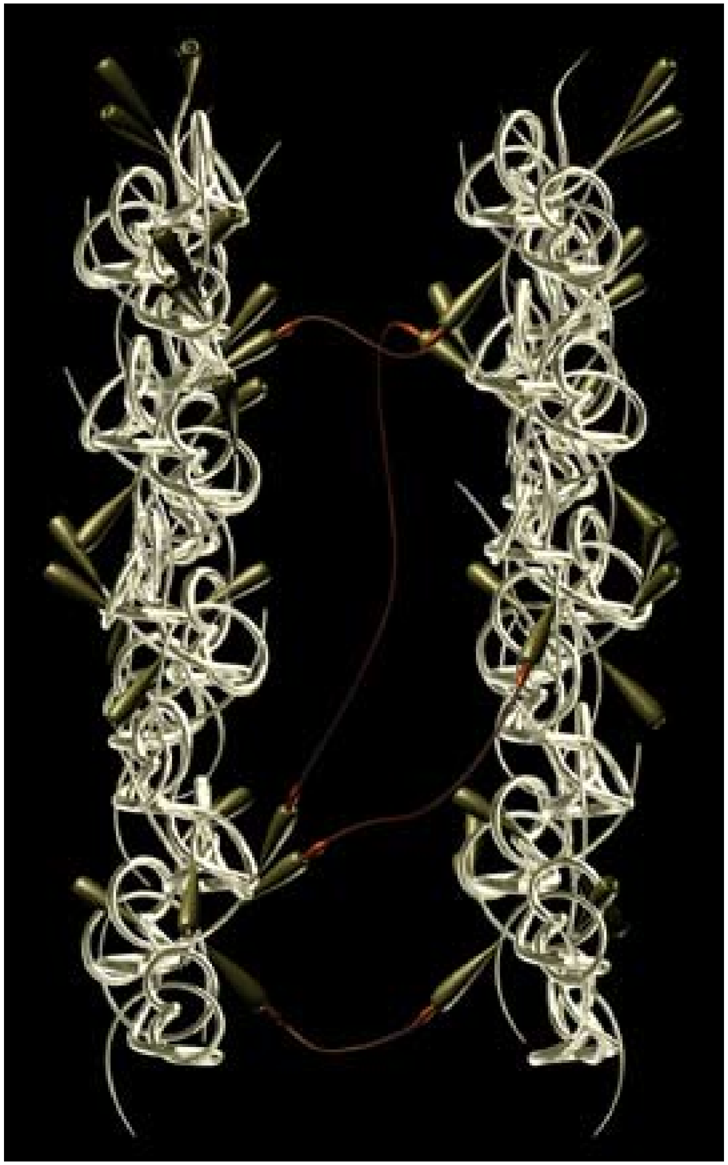
eTree Animation: ArizonaTower



ArizonaTower Xfrog Growth.
Animation sequence illustrating the digital growth of multiple branches and pods.

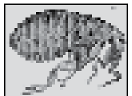


ArizonaTower.
Rendering of the ArizonaTower's pods and branches with solar panels and rooted biodigesters developed from digital leaves. Bottom: ArizonaTower STL models.



SnapPods, Seedpods, Barbs, & Tendrils

SnapPod Connectors. 2008-ongoing
eTrees whose branches link with tendril-like snapping pods.
Xfrog screen (below) shows the generation of the structure and
3DS Max renderings (far left, page 16) show the snapPod connectors and eTrees.
Below middle: Squash tendrils spiral growth reaching and attaching to tree stump.



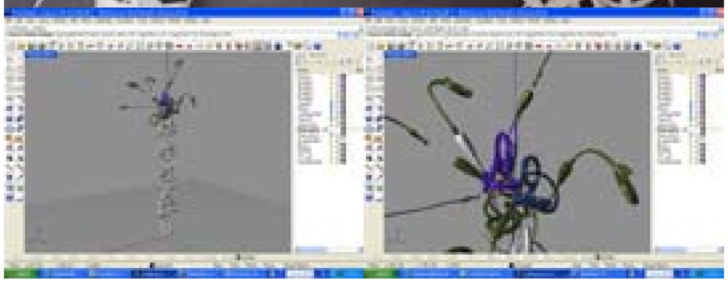
DIY Microscopy
Robert Hooke
Micrographia
1666

http://www.gutenberg.org/etext/15491

SnapPods, Seedpods, Barbs, & Tendrils

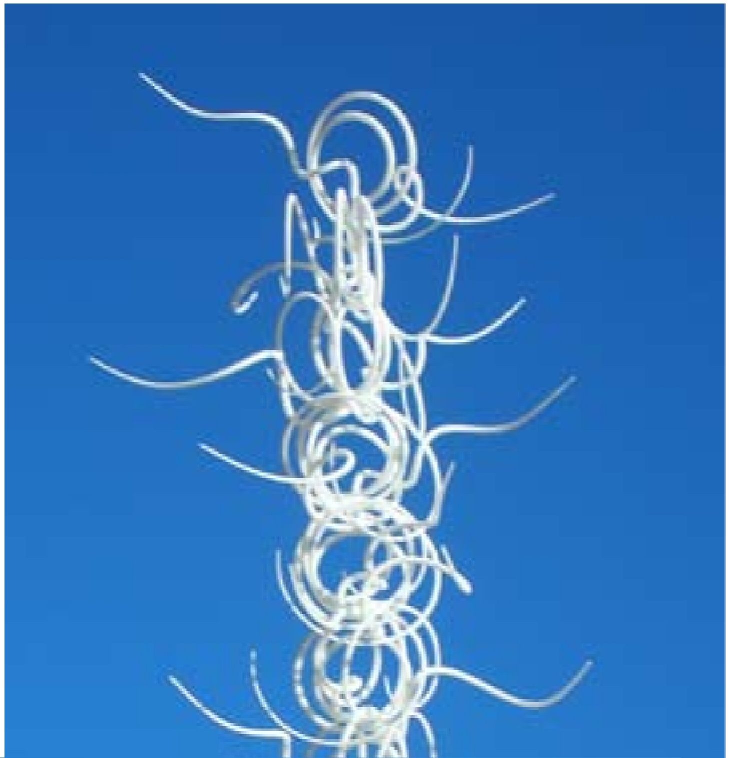
STL snapPods. 2008-ongoing

Below and right page 19: are the first generation of connectors linking the structural eTrees. Below bottom: Rhino screen captures of the snaps derived from flower seedpods, tendrils, barbs, and thorns.



DIY Citizen Science: Toy Digital Microscope

http://www.microscopy-uk.org.uk/primer/index.htm

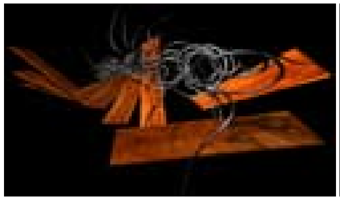


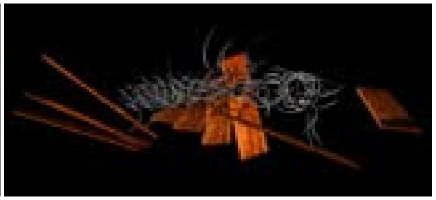
eTree Branches & Tendrils

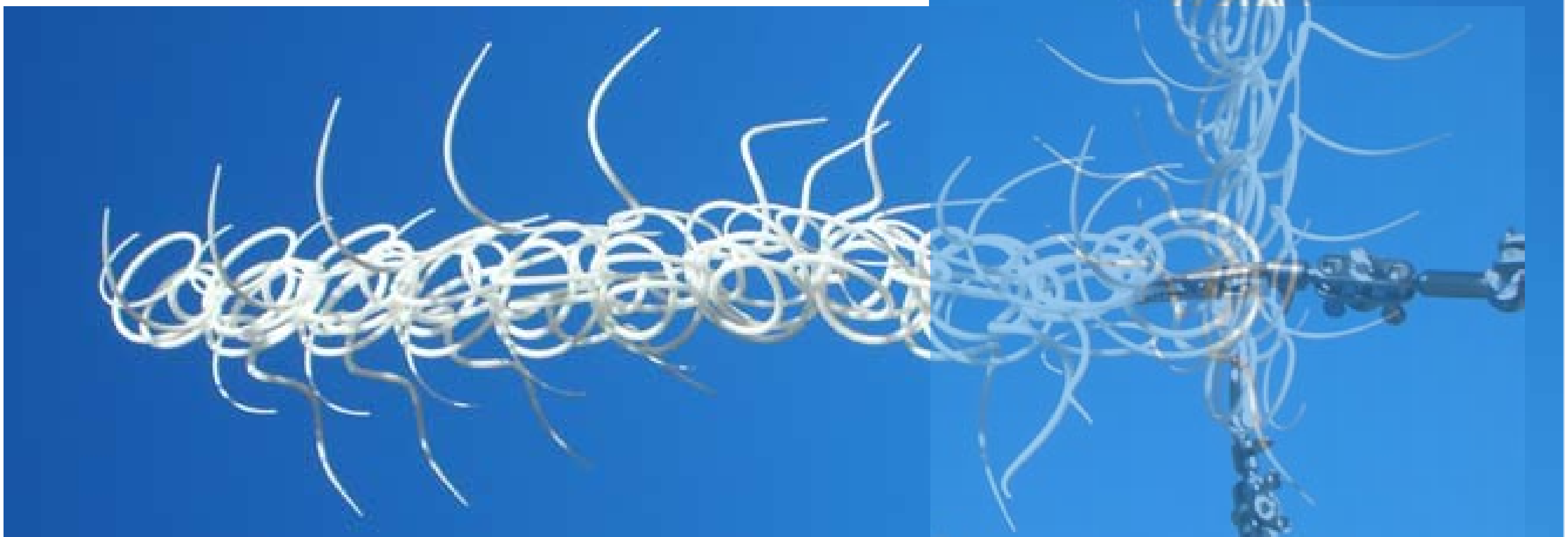
TreeTruss. 2007-ongoing

Developed first as a horizontal, interior ceiling structure for a club, this eTree supported projectors, lights, sensors, and acoustic baffles. Since 2007 the ceiling structure has been revised with additional branching for several projects—most prominently, the cylinderlike body for the Los Angeles Tower (22-29).

Below: renderings of the early versions of the eTree with sound baffles (originally generated as leaves). Middle: eTree with tendrils; STL model seen in horizontal and vertical positions. Bottom: Xfrog stills from an animation of the eTree growth sequence. This multidirectional eTree, whose central trunk has been repressed in the software code, suggests a structural form and system for environmentally flexing column and beam typologies and is a subject of ongoing design research.





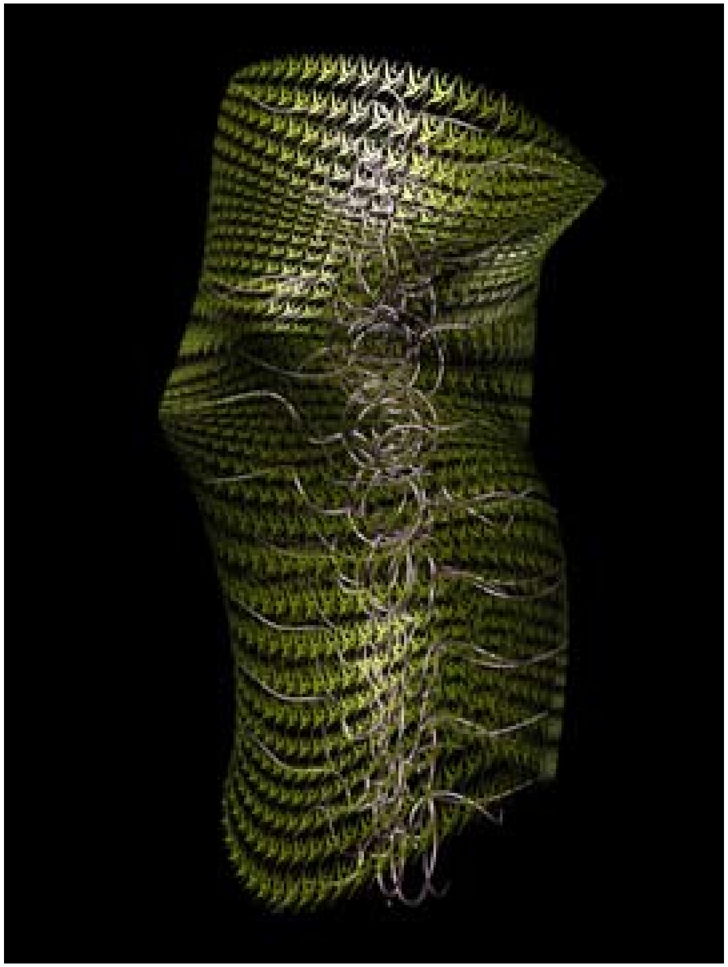


Self-Shading Tower for Los Angeles

2007-ongoing

As already seen (20-21), the eTree generating this tower's cylinder is also a component of other projects—a kind of spine whose structural code lends itself to multiple design paths resulting in different kinds of structural leafing (46-49) and branching forms. While prominent in the developmental stages of the tower's panels, the eTree is eventually repressed in favor of the load-bearing monocoque facade supporting the building and held in compression and tension by the fifteen floor planes.

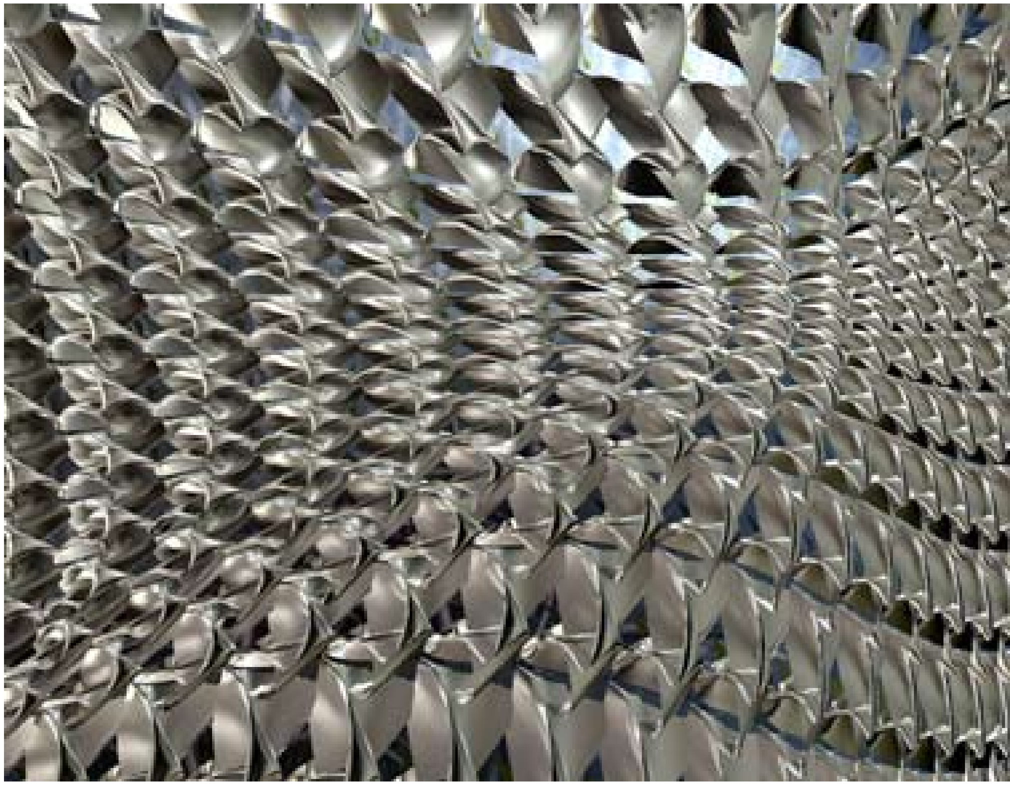
www.paracloud.com



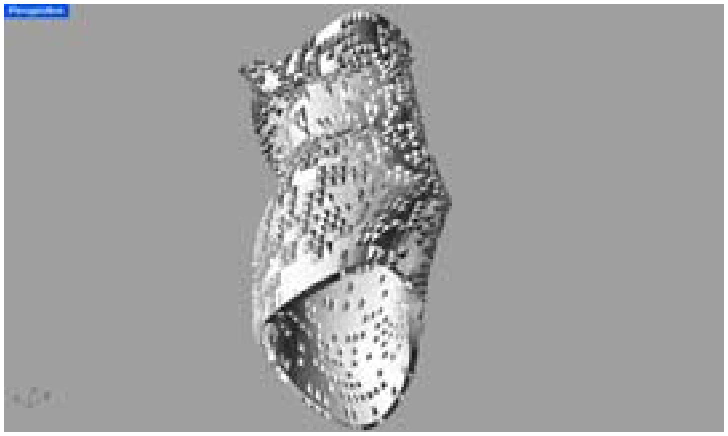
DIY • Botany
• Clusters
• Orientation
• Shape

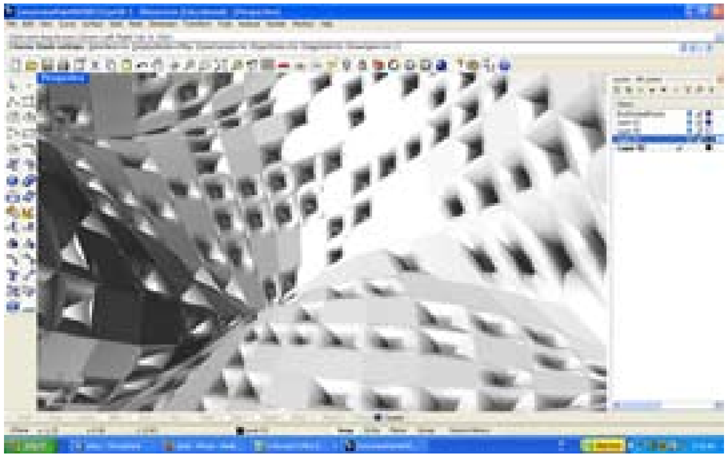
http://en.wikipedia.org/wiki/Monocoque

Self-Shading Tower for Los Angeles



Skin / Monocoque Panels. 2007-ongoing
Left page 24: first parametric expression of leaves populating the cylinderlike volume created from a point cloud determined by the eTree's tendril tips.
Above: Further parametric development of a leaf form (folded as a continuous surface), creating a monocoque facade component generated by ParaCloud. The linking, chainmail-like components are part of an ongoing search for load-bearing panels that can take on environmental performance duties—such as filtering and ventilation—as well as, in other design formulations, housing sensor-embedded monitoring. Additionally, the panel designs adjust easily to produce pockets where plant, algae, or other biological agents may be grown in living facades.



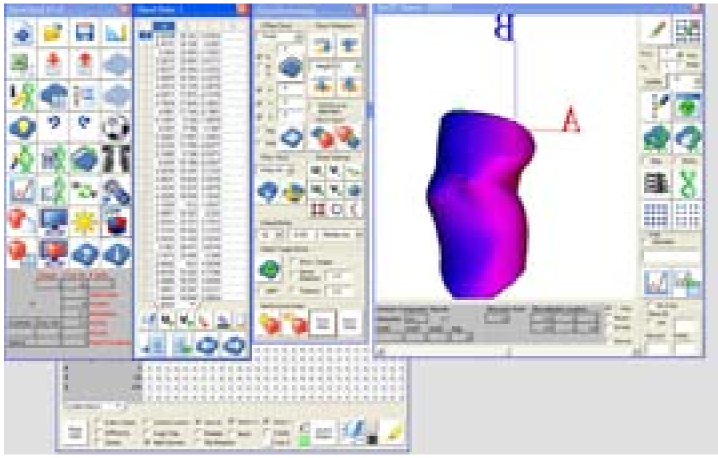


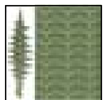
Tower for Los Angeles: Almond Skin

Skin / Monocoque Panels. 2007-ongoing

Left page 26: populated 3D components generated in ParaCloud with individual panels intended to function as load bearing monocoques—inspired by almond shells (bottom left) and mechanically related to the structures of airplanes.

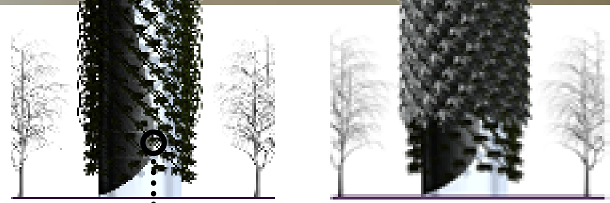
Bottom: screen shot of ParaCloud running a solar calculation for dispersing three different components around the tower's perimeter, each with different environmental sensitivity and controls.





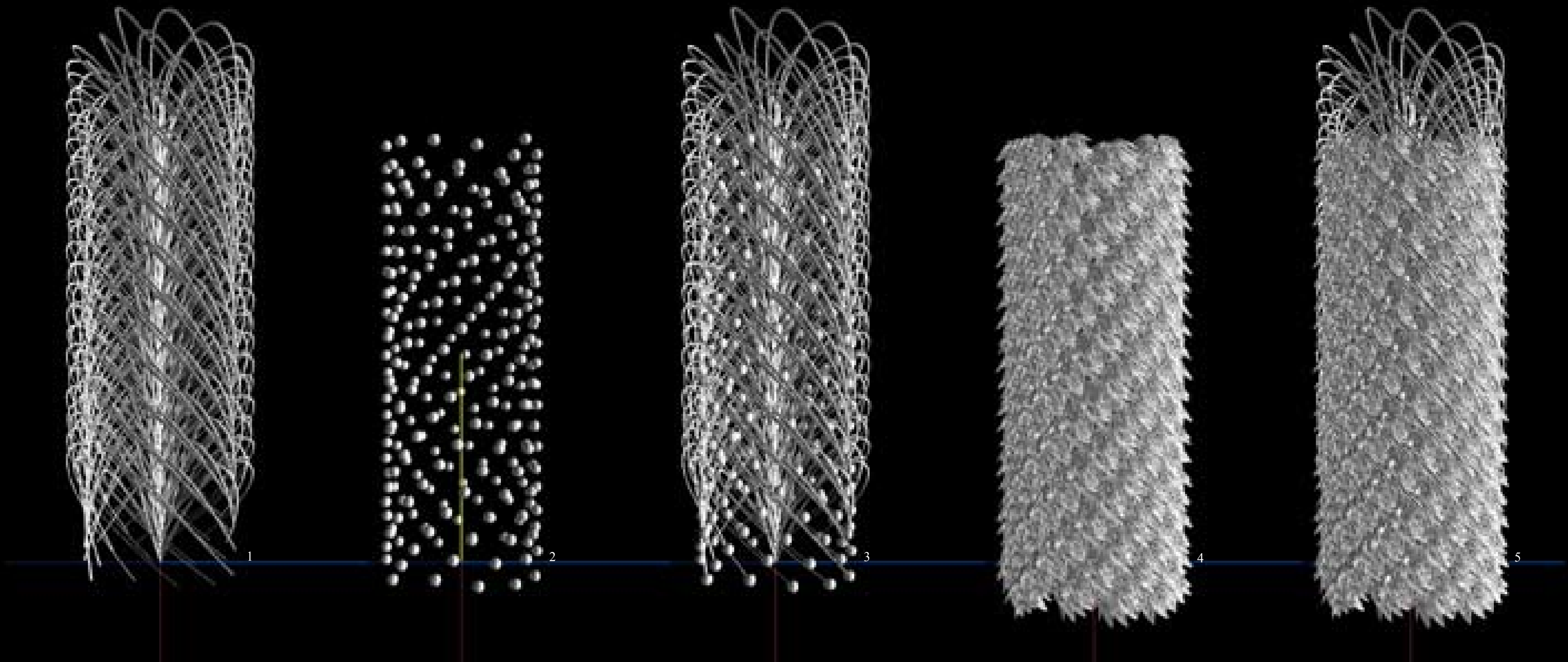
DIY
Design
Research
•
Leaf
Folds

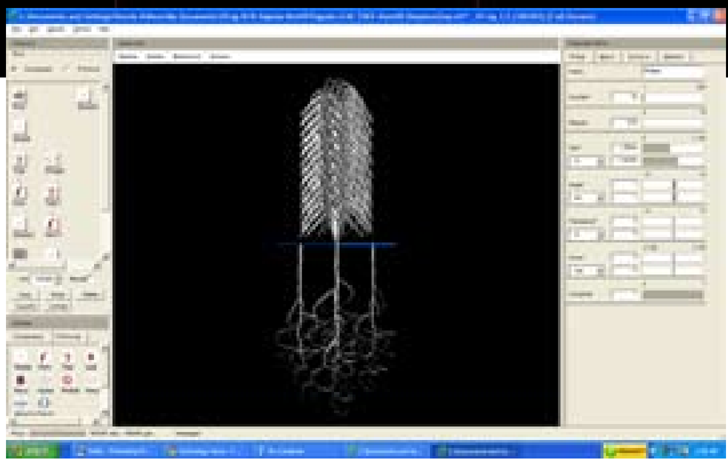
Branch Truss & Yucca Skins

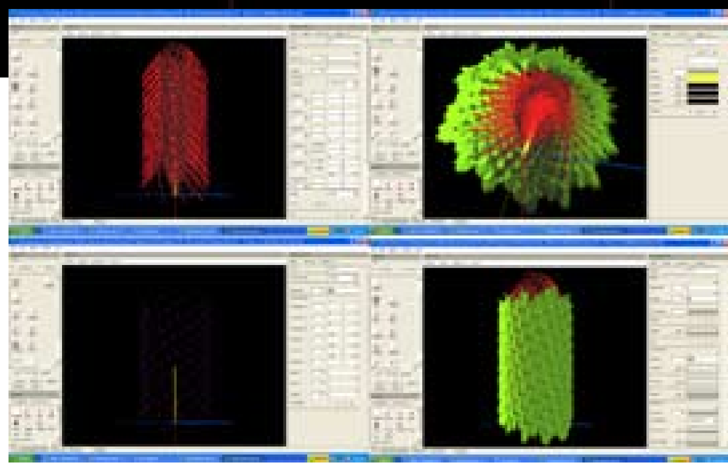


2000-ongoing
Top & Left: Canopies installed at the Santa Fe Art Institute, 2001.
Series of branch structures—asymmetrical trusses—supporting paper membranes hand-made from yucca blades (leaves), demonstrating the idea of clustered skins stabilizing and strengthening branching struts; the Canopy project became the physical prototype for the monocoques and then the hovering leaf clusters later developed for the Los Angles Tower and BioTower (above).

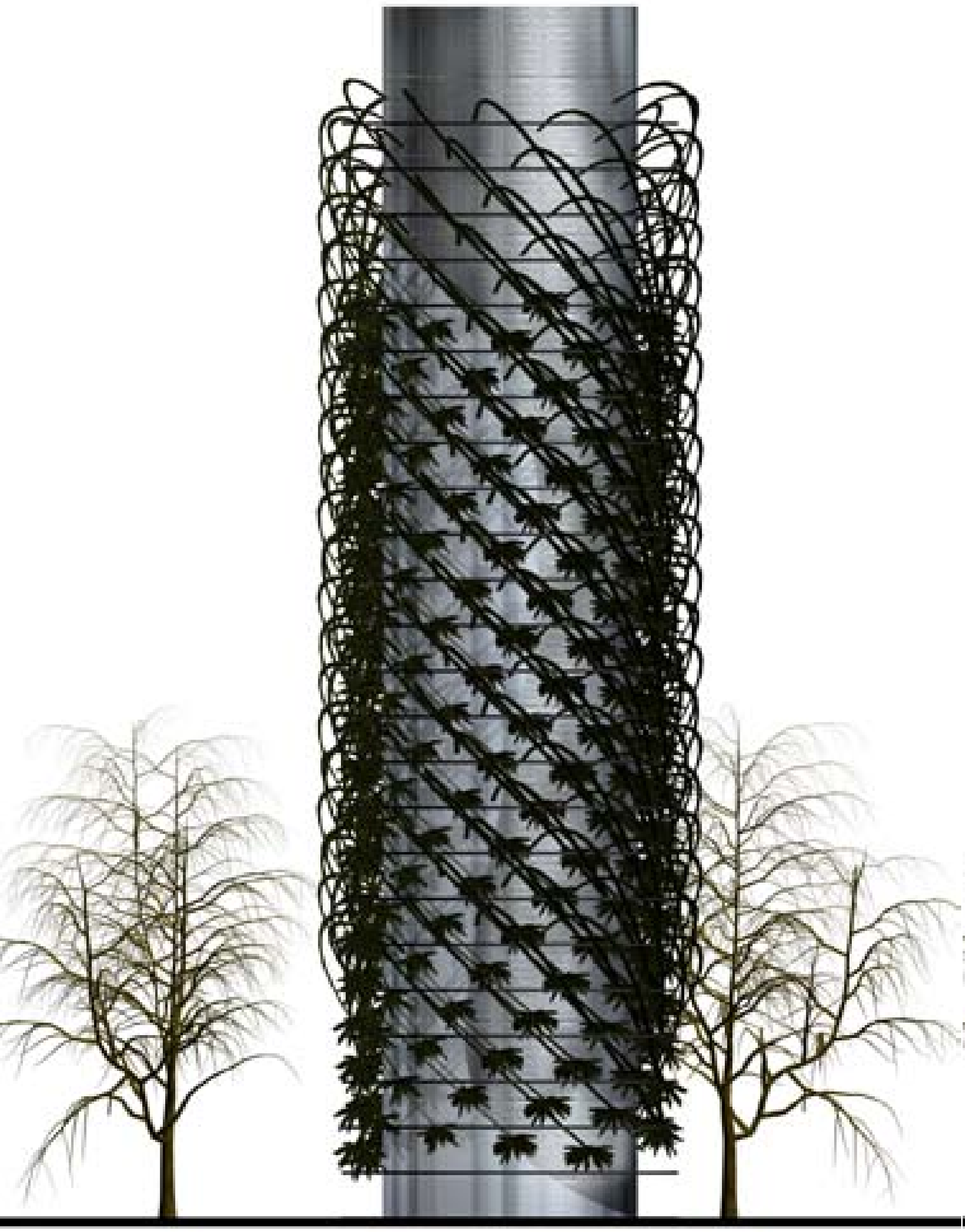
BioTower: Generative Leaf Sequence



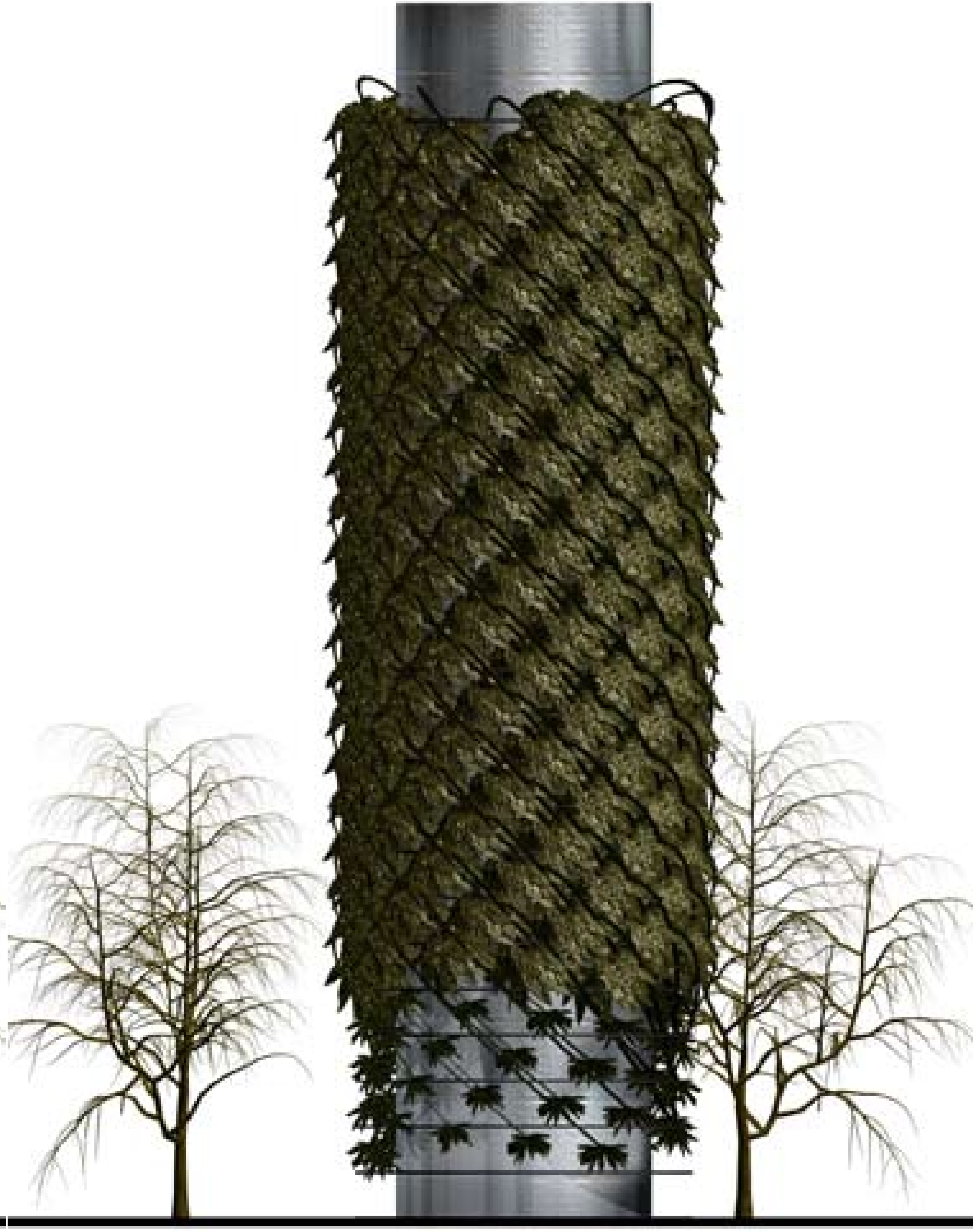




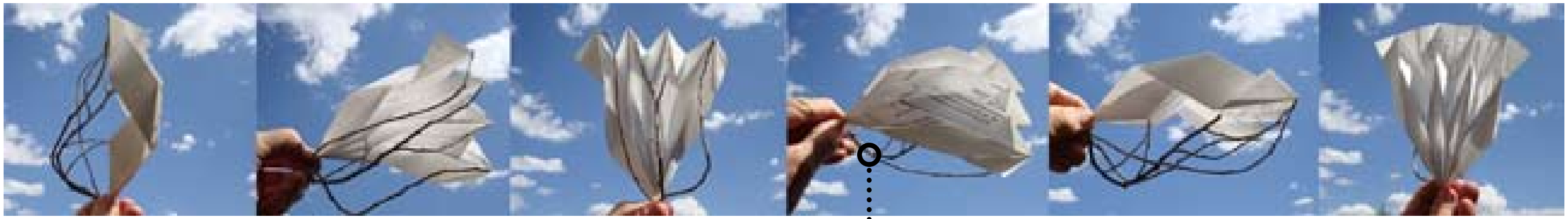
BioTower. 2009-ongoing
Digital growth sequence. Left to right top: 1. eTree branches.
2. Sensor nodes (pods). 3. Branches & nodes. 4. Leaf clusters.
5. Leaf clusters, branches, & sensor nodes. Bottom left & right page 31:
Xfrog screen shots for the BioTower's exterior systems.



BioTower



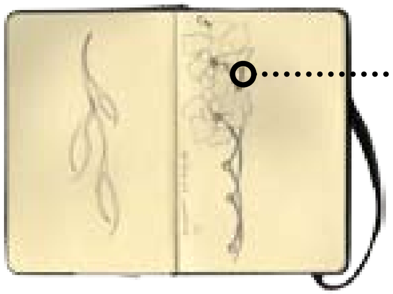
BioTower. 2009-ongoing
Above: BioTower with branch matrix, sensor nodes, & floor planes.
Right page 33: BioTower with leaf-cluster systems for air filtration & ventilation, sound baffling, & heat / light control.

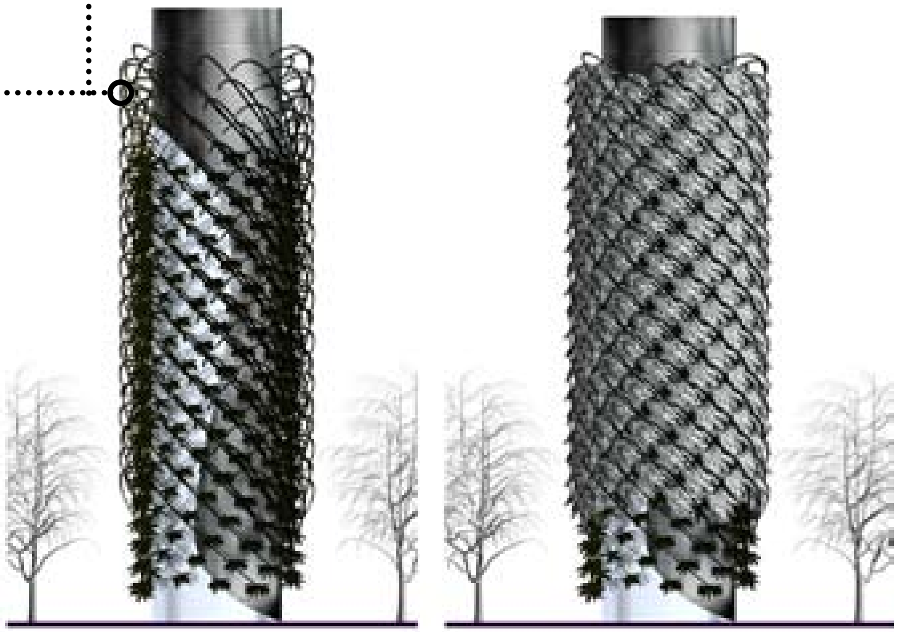


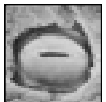
BioTower Facade & BioScreen

2009-ongoing

Top: Series of branch panels with an origamilike folded paper skin modeled from the observation of leaves, as an early study for a hovering screen facade with a faceted surface. Above: Schematic for outer biomechanical sensor-node pods, biological filters, and passive cooling system embodied in digital leaf panels. Right page 35: Inner structural panel and glass study. Below, righthand page: sketch for branches, nodes, and flower petals or leaves.





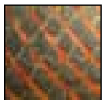


DIY Electron Microscope Stomata

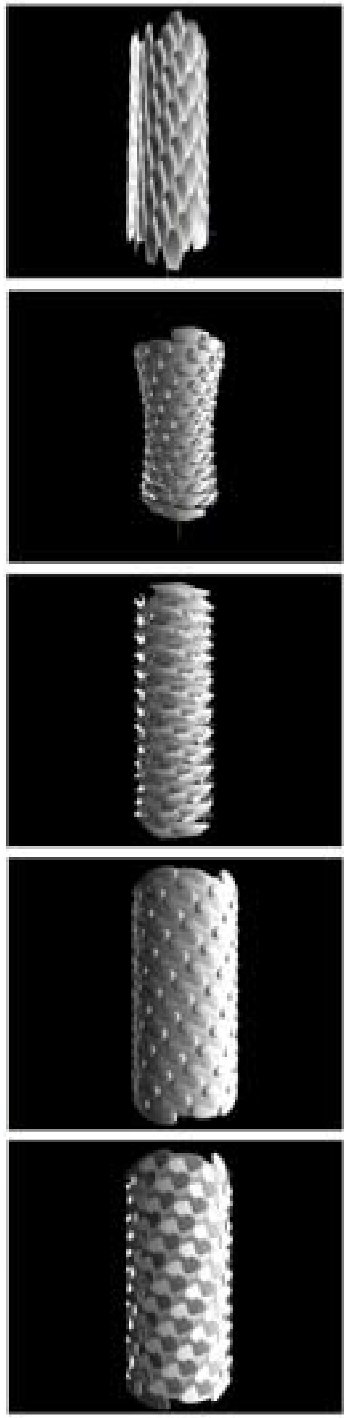
http://www.jstor.org/stable/3066303

e(palm)Tree Column & Skins

Right page 37: Photo collage. Los Angeles. *Washingtonia robusta* (Mexican fan palm) and five Xfrog bark simulations for imbricated, interlinked tiles as prototypes for architectural scales, panels, and interlocking structures. Below: Xfrog digital growths as a stylized palm column.

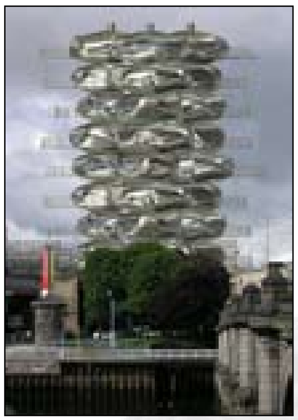


DIY Biological Skins



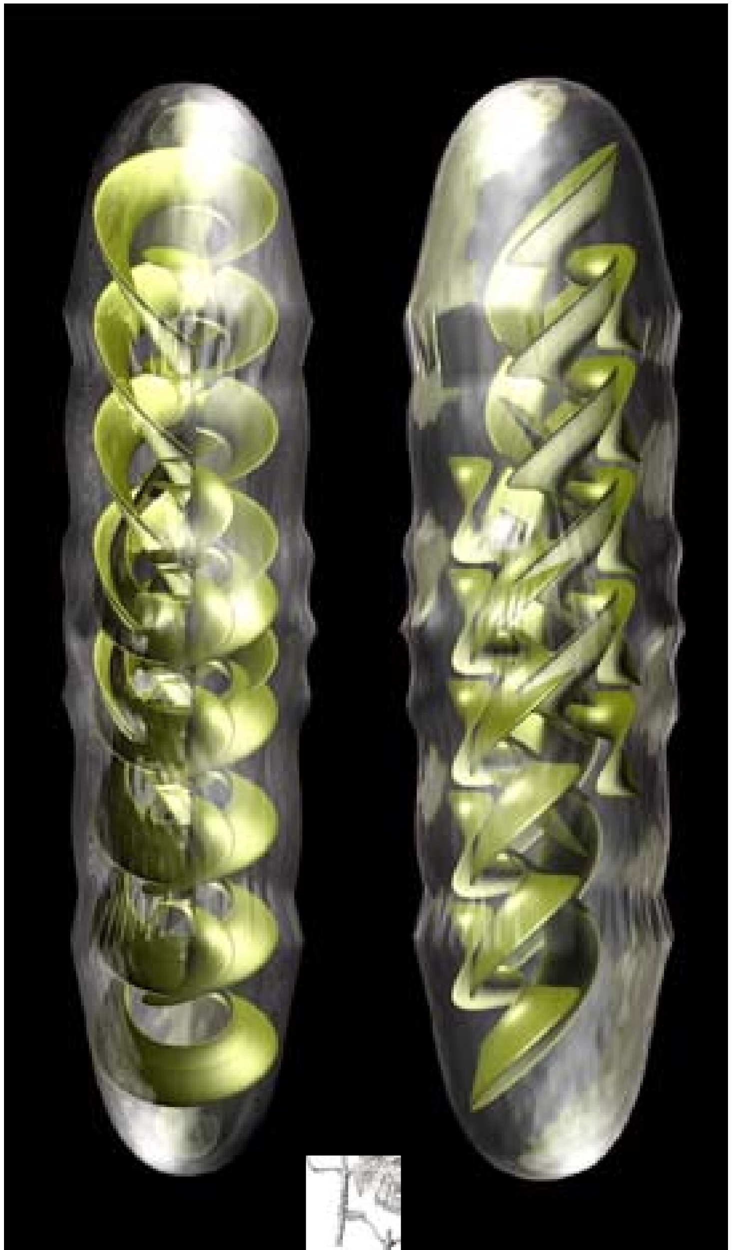
eTree Branches: Braided, Interlaced, & Imbricated Pod Nests (Cradles)

Untitled. 2009. Each structural cluster is comprised of three eTrees with asymmetrically grown branches programmed as imbricated armatures nesting and stacking spherical pods. While weaving in nature may most obviously come from bird nests and spider webs, allied procedures, such as the interlacing of the cane cholla, *Opuntia imbricada* (background) illustrate one of nature's wide ranging structural growths to borrow and extrapolate from.



Right and bottom page 38: Project for an apartment building along Glasgow's Strathcylde River, Scotland, 2005. Stacked and spiraling pods grown on eTree frames as an experiment for pod clustering and orientation.

eTree Branch & Membranes

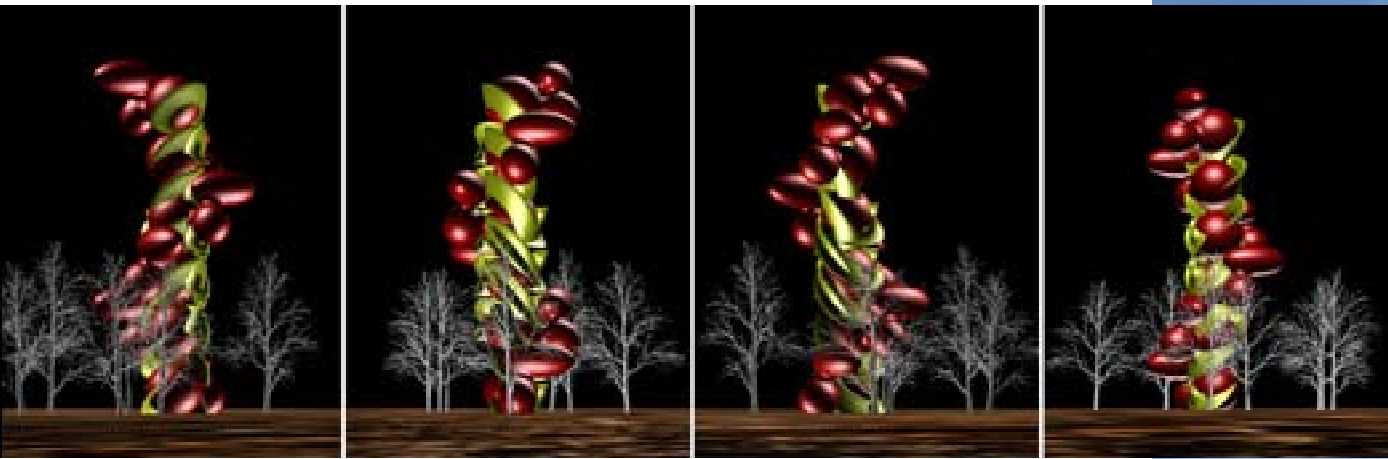


DIY
Spiraling
Tendril
Connections

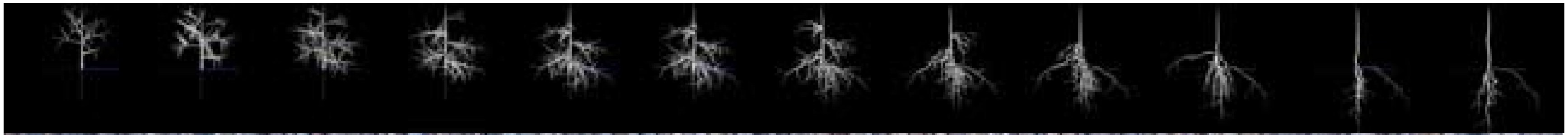
Above & right: Untitled. 2009
Digital sketches using a single eTree from the previous design, encased in a clear membrane for visualizations based on cellular forms, diatoms, and protozoa.

eTree Branches, Stacking Pods, & STL

Untitled. 2009
Below: Study for spiraling and stacking pod clusters.
Right page 43: eTree STL model as branch armature.
Bottom: early outer skin (1996-97) for surfacing pods. Handmade yucca paper tested for fiber alignment, strength, and translucency modeled as a pod section.

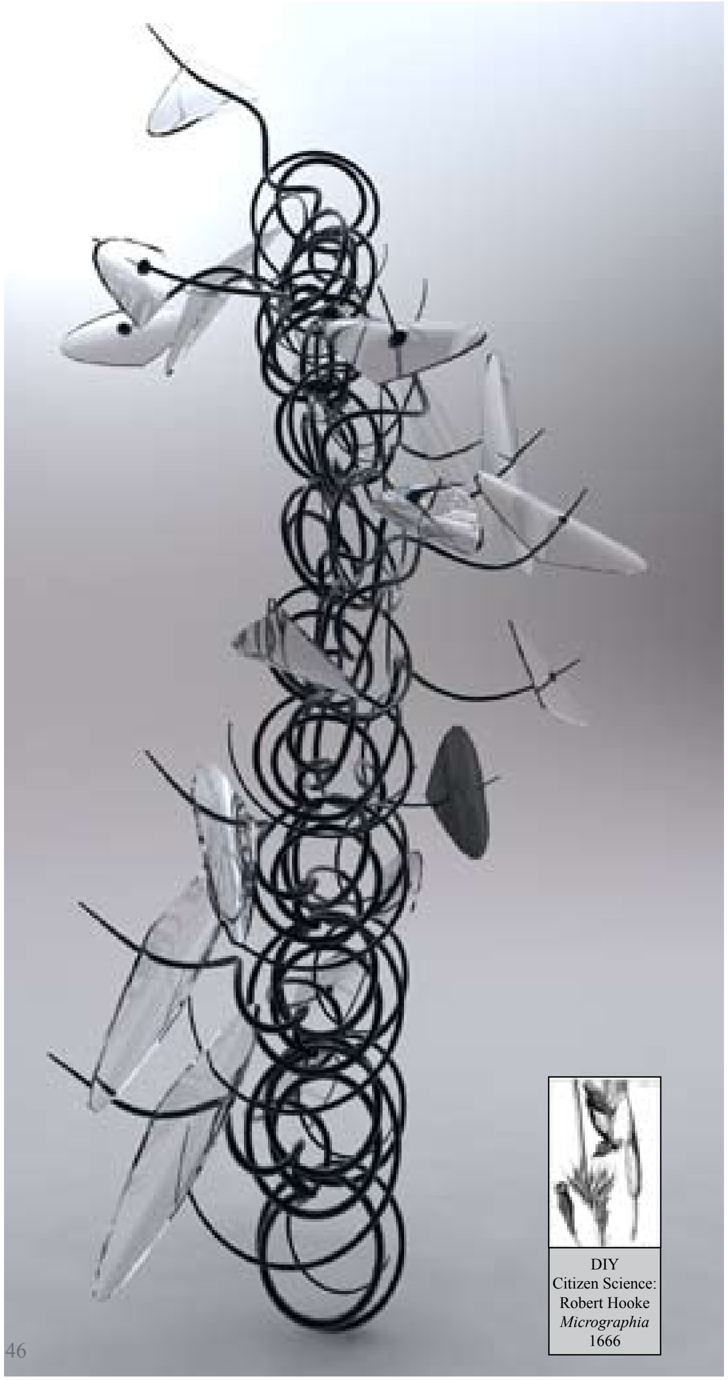


eTree Spinelike Branch STL

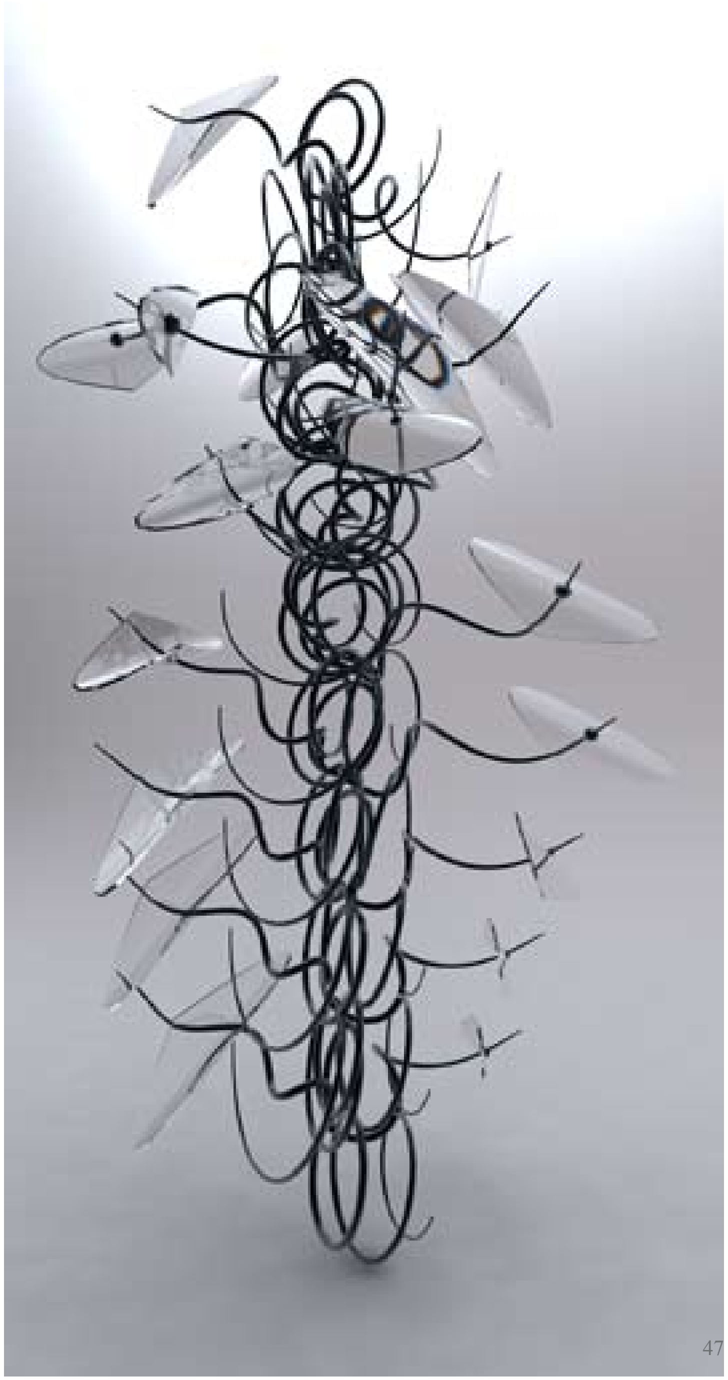


Top: eTree branch-to-root Xfrog animation sequence.
Double eTree branch armatures, STL models.

DIY • Botany
Transforming
• Pods
• Leaves
• Branches

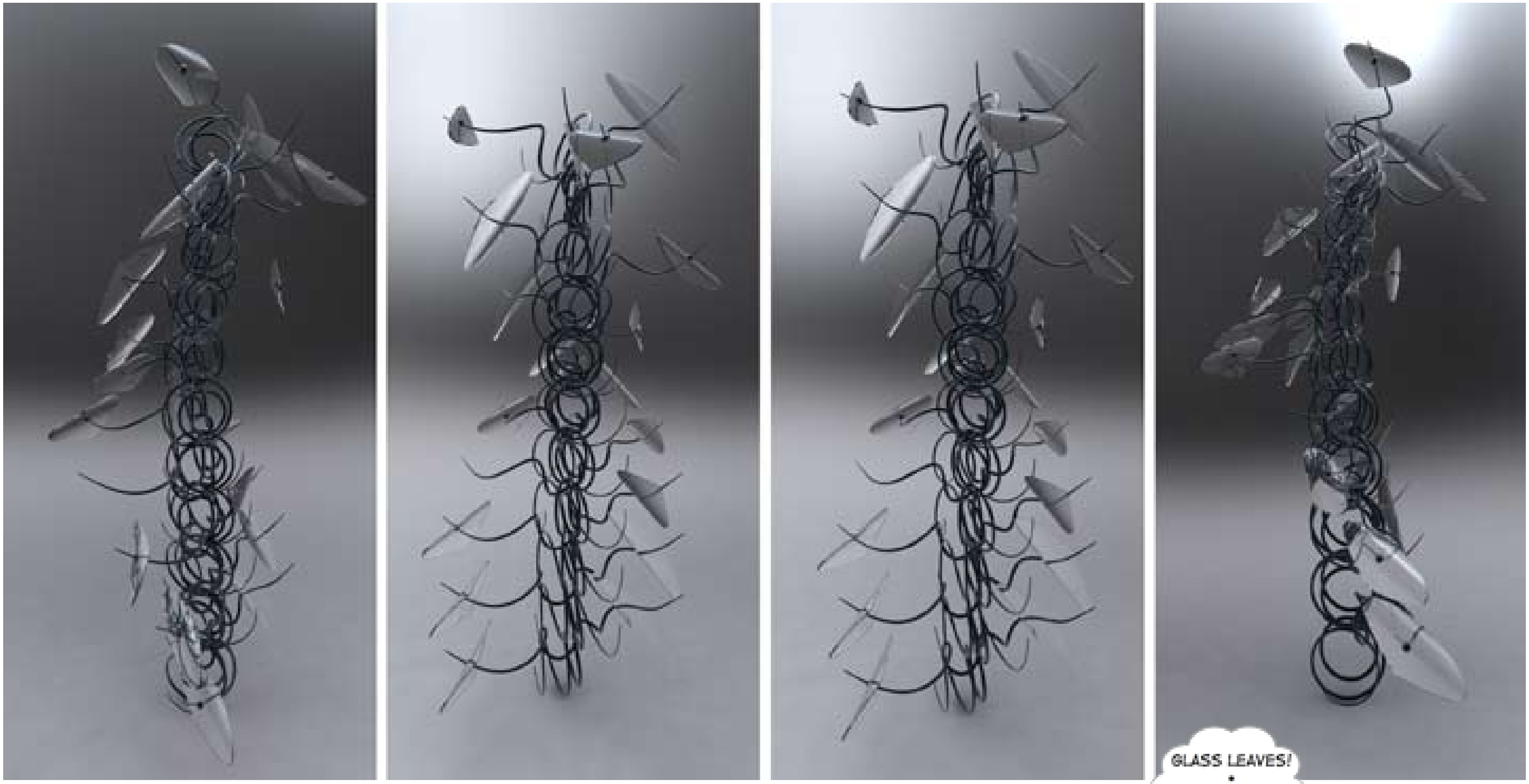


eTree & Glass Leaves

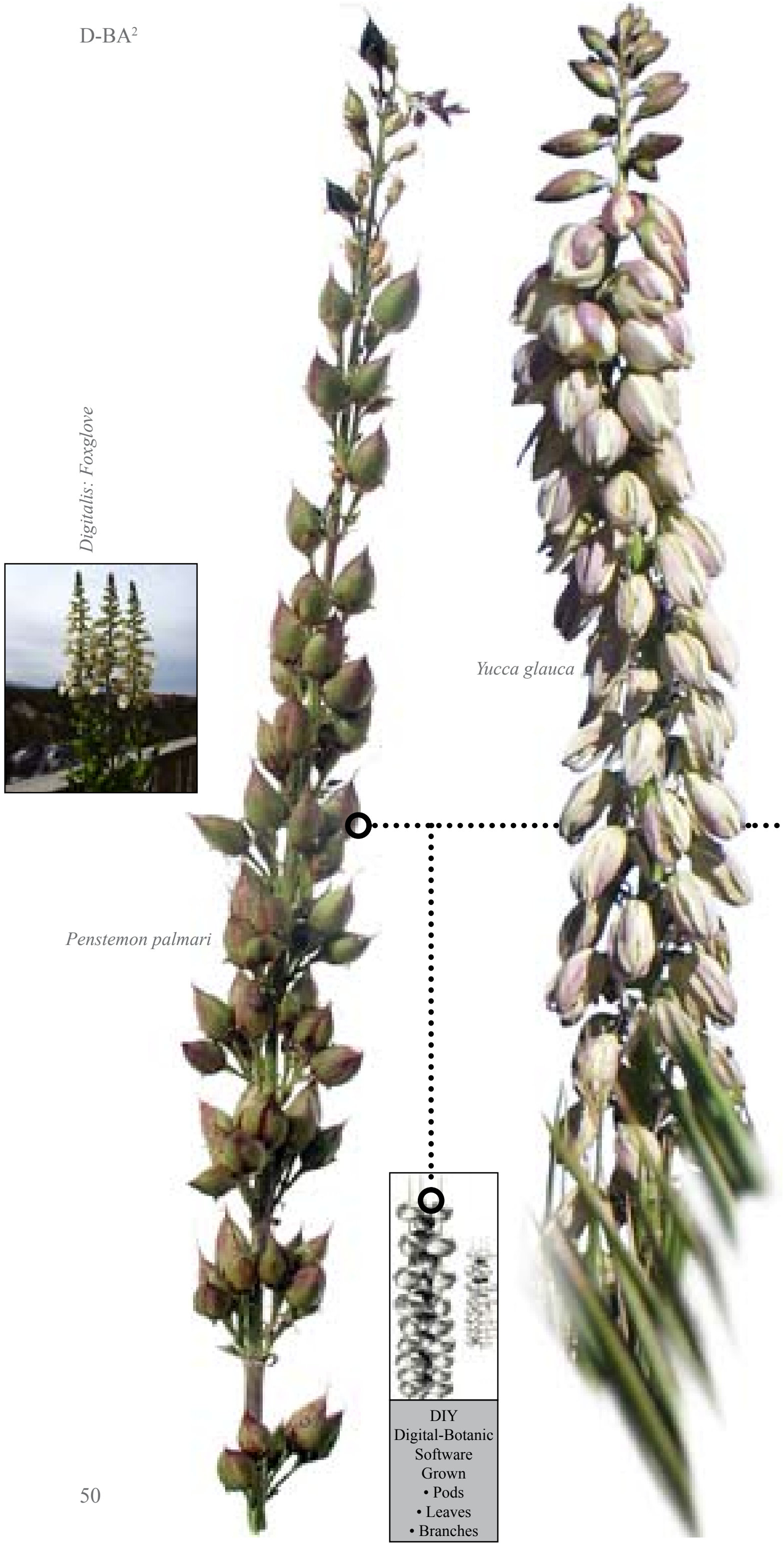


eTree & Glass Leaves

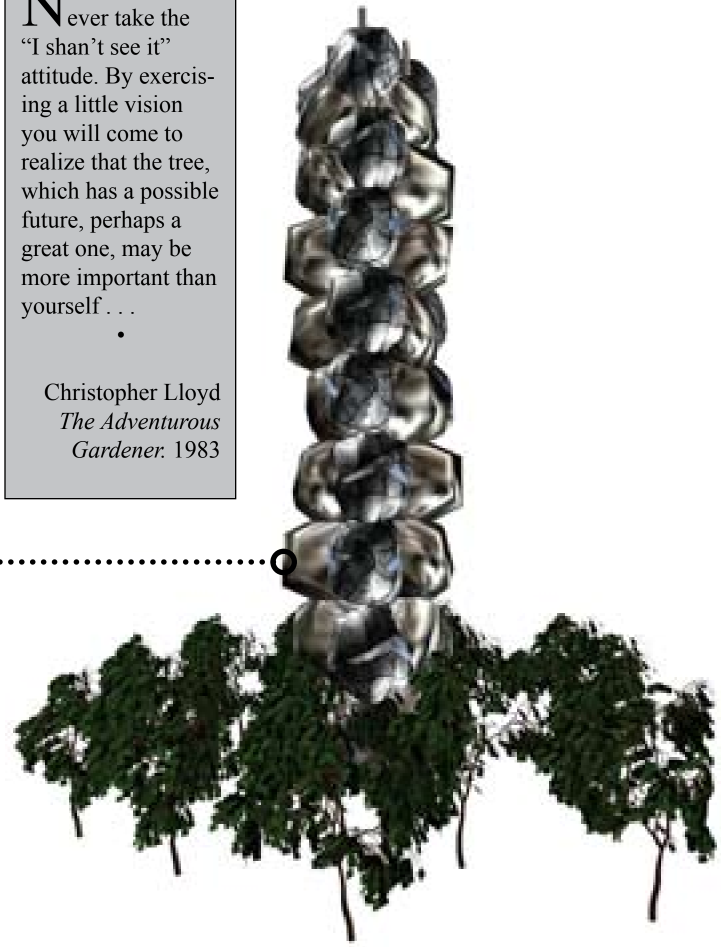
2008-ongoing
Leaves sprouted from the eTree (20-21) in a study for populating and surfacing branching structures with scale-like panels. Rendered with Hypershot.



Flower Stalks, Stacks, & Clusters

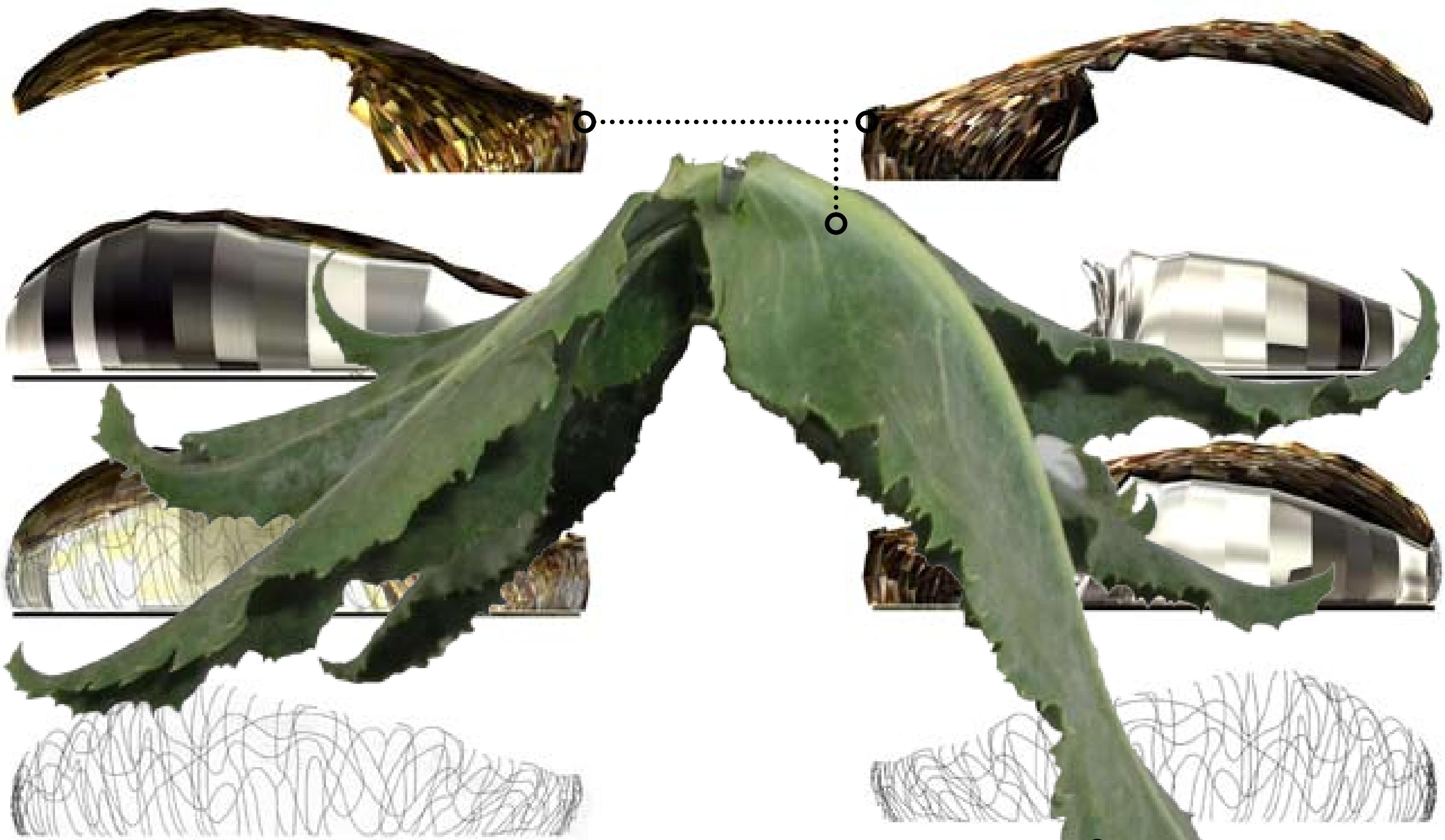


> Never take the "I shan't see it" attitude. By exercising a little vision you will come to realize that the tree, which has a possible future, perhaps a great one, may be more important than yourself . . .
>
> •
>
> Christopher Lloyd
> *The Adventurous Gardener.* 1983



FlowerTowers. 2004/2005-ongoing
Above: eTree stacked and clustered. An early model from tall flower stalks with over-scaled seedpods schematically defining habitation units.
Left page 50: *Penstemon palmari* and *Yucca glauca*. Tall flowering stalks studied for clustering, asymmetry, and light orientation. The stalk curvatures later influenced the self-shading tower for Los Angeles (22-27).

Flower Stalks & Leaves

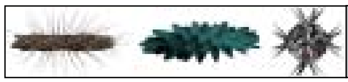


Leaf Models. 2004-ongoing
Foreground: Six living *Penstemon palmari* leaves configured into a study model.
Background: The digital model follows the form of one of the *penstemon* leaves for a studio's roof. It was developed from the idea that surface facets create self-shading topographies, thus reducing heat gain, while potentially increasing surface area for emerging technologies such as sprayed-on photovoltaics.

Left: *Penstemon palmari*
Below left: Plaza Canopy based on Penstemon leaf.

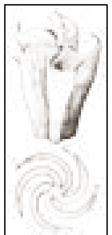
Leaf Whorling & Twirling

Procedures such as folding and twirling have been used throughout these pages. These movement- and growth-distribution formulations are sometimes seen in nature. For example, in the opposite upper-right photo of a datura flower unfolding while exhibiting directional spiraling at the same time. With other examples, directional patterns are difficult to detect, as in the spiraling spines of the datura seedpod, opposite. Near right: a single Xfrog generated leaf, visually modeled from a tobacco leaf, given a twirl with 9 leaf iterations.



DIY • Future Digital Seeds

Flowers & Pods / Folding & Twirling



DIY
Digital-Botanic
• Spirals
• Twirls
• Folds

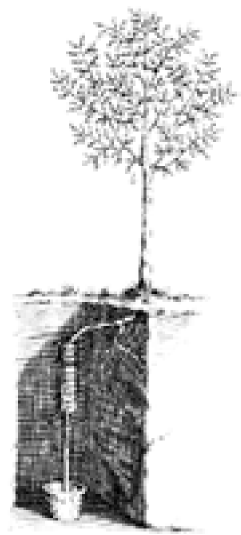
eTrees, Digital Nature, & BioArchitecture

Introduction

The idea is not to make buildings look like botanic organisms. The idea is to interlace nature and architecture, enabling the design of hybridized, biological structures. In this process investigating nature is design research. And, the overall aim is to create new architectural species incorporating natural attributes ordered in performance, materials, mechanics, communications, and form. Designing prototype structures to remotely sense and execute tasks such as passive air filtration, heat transfer, and water reclamation justifies the expectation that experimental bio-architecture will necessarily collaborate with science and technology.

Buildings derived from growth algorithms, parametric design, and CNC fabrication, animating and nurturing bio-architecture, are inevitable. New architectural skins, panels, floors, and skeletal systems, taking on biological responsibilities, will evolve new bio-aesthetics. My perspective, filtered through today's generative and computational software, is also historically influenced. I appropriate DIY scientific method from 18th- and 19th-century science while also looking to, say, the origins of modern buildings—specifically, to Louis Sullivan's botanic shape grammars and morphological design sequences (Sullivan, 1924. Dollens, 2005).

Over the last ten years I have digitally simulated experimental structures, grown from software, and projected them as bio-climatically operative. Toward this objective of responsive biological architecture, I use Xfrog, ParaCloud, Generative Components, and Rhino to develop branching tree structures (4-7). The software also comes into subsequent use for surfaces, panels, and



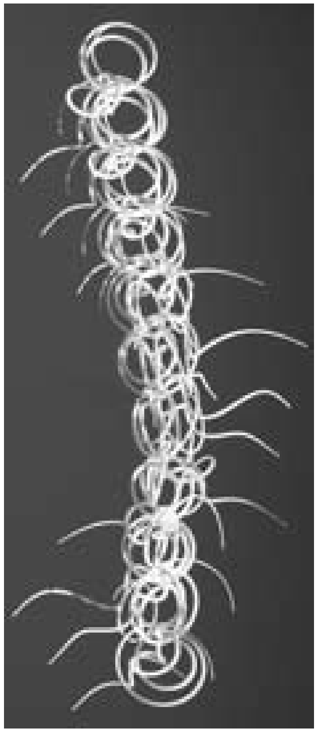
Stephen Hales. *Vegetable Staticks. 1723.* Learning how roots function and branch underground. (See digital animation sequence, top 44-45).

pods with attributes appropriated from individual and/or massed leaves, roots, flowers, barbs, and tendrils. (Or sometimes from shells, skeletons, scales, and minerals.)

Digitally generated architecture, hybridized from computational plant simulation, is part of a process observation for ordering design forms infused with botanical properties. This search, linking design and nature, involves tracking ways to visualize and model algorithmically from plants and trees. Doing so addresses generative programming, biological structure, and environmental remediation in the context of biodesign, sustainability, and machine fabrication.

Biology and botany (or nature in general) are, of course, not new sources for architectural development. Design inspired by nature, articulated by idea-eye-hand material production has been used for tens of thousands of years. Architecture's ancient craft origins viewed through ur-building technologies, such as weaving, knotting, and pottery, may be understood as appropriations from nature (Herrmann, 1984). But contemporary design looks less toward nature for inspiration than it does toward industry. Accordingly, design could learn from and collaborate with ecology, biotechnology, biochemistry, genetics, and material science. Designers might tap scientific research taking inspiration and visualization, from bioresearch that are second nature to scientists and engineers. Consider the design implications of ideas and information generated by scientists constructing synthetic bacteria that off-gas methane as an alternative to oil-based fuels (Ball, 1999; Benyus, 1997; Mattheck, 1998; Vincient, 1990; Wade, 2007).

Instead of burning fossil-fuel, heating oil and coal-produced electricity, buildings might eventually have tanks of bacteria farmed methane. Standard architecture may have vats of bacteria, processing sewage and gray water. Both of these bacterial scenarios bring life forms into mechanical devices. They hybridize biomechanical systems similar to ones organization needed for bio-architecture (Dawkins, 1982. Estévez , 2003. Wilson, 1999).



Above: Flexible STL eTree, digitally grown in Xfrog, whose trunk has been repressed in favor of piercing, interlocking, looped branches and tendrils. 20-21 & 46-49.

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Right page 59: STL eTree illustrating branches looped and fused into the trunk, creating a 3D truss, column, or beam.

eTree Generation

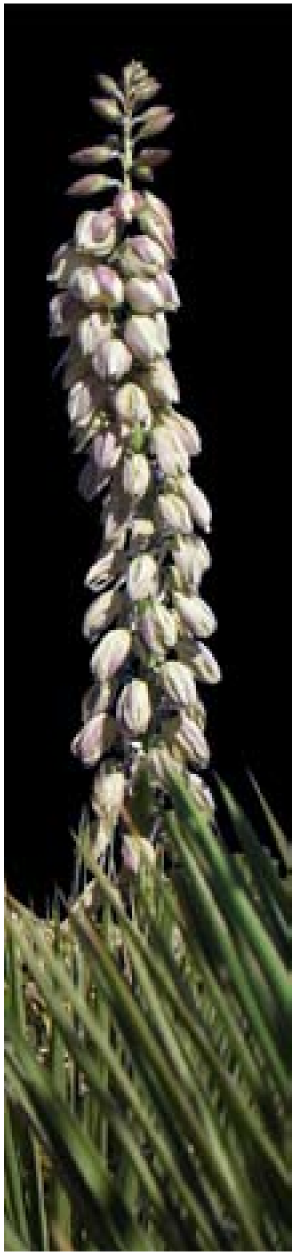
One program for simulating plant morphology is Xfrog. The software is generally employed to computationally "grow" lifelike digital trees, shrubs, and flowers for special effects in film. Xfrog has the ability to produce forms based on botanic attributes, imparting to its 3D files selected attributes of living organisms—for example, branching, leafing, and spiraling. But its design-growth parameters can also be tasked to generate original structures based on the organic-derived algorithms it uses to mimic, say, an oak or an elm. Metaphorically, such manipulation may result in species of digitally grown design. For example, branching in trees may be transformed—in a sense, computationally hybridized—to produce experimental structures with a botanic performance and heritage.

On pages 8-9 you see an STL model of a building's frame, originated as a simulated grove of four eTrees, then prototyped from an Xfrog file. For this frame, selected tree branches were programmed to loop as braces reinforcing the central trunk (eliminating the collar beams, straight braces, tie beams, and queen posts from a traditional truss). Alternating with the looped branches, others were programmed out-stretched, as cylindrical tubes configured into a rectangular plan, like a multistory building frame minus joists and floor platforms.

The eTree trusses employ simulated tree trunks and branches following natural geometries formulated by both the software's modified L-systems and Xfrog's proprietary growth and environmental rules (Prusinkiewicz and Lindenmayer, 1990. Lintermann, 1998. Dollens, DBA, 2005). The tree-to-truss design process relies on natural proportions and processes, such as phyllotaxy, phototropism, and/or gravitropism. While this process does not copy nature, it numerically models facets of nature's growth patterns, calculated from the biological analysis of plants and trees (Jean, 1995. Niklas, 1994).

The digitally grown and STL-modeled trusses have implications for machine fabrication. Their curved, looping, tubular forms (left) have springlike qualities causing them to continually curl and fuse back into their trunks (or to each other in later versions—opposite); this spiraling, looping operation equally braces the structure in X and Y directions. The overall structure is a self-reinforcing, three-dimensional brace—effectively a flexible, asymmetrical truss.

Stabilization of seismic movement is one obvious requirement that the eTree trusses look to fill. Equally valuable, if further away, are shape-shifting facades reconfiguring themselves as weather conditions change. These types of environmental response are directly inspired from observing plants—bringing to mind Claus Mattheck's idea for "trees as instructors for designers" (Mattheck, 1998). The idea behind such design research is to fuse botanical aesthetics, biological function, digital programming, and structural performance—looking first to natural forms and organisms, then finding useful properties, and finally interlaying that information in a project's design.



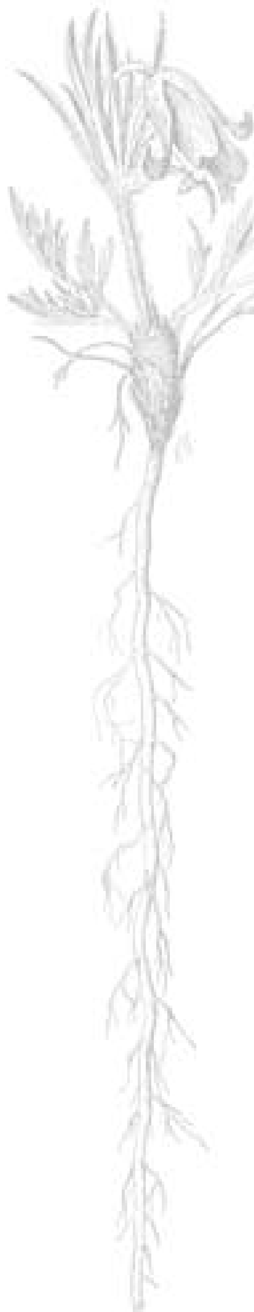
Yucca glauca. Narrow leaf yucca.

Digital-Botanic Heritage

Initially I attempt to identify design principles, generative strategies, or aesthetic logic secreted in plants; second, reflect that information in digital simulations; and third, develop the simulations as responsive projects with physical models. In a recombinatory sense, to hybridize biological ideas with architectural forms—evolve new systems from them—and then articulate the new design into parts and pieces capable of supporting and sheathing experimental buildings. For example, developing projects to clad the eTree structures with leaflike skins, bio-membranes, or monocoques.

Design experiments of this kind lead toward botanically-informed architectures carrying the generative heritage of digital files originally modeled as simulated plants. The projects do not exactly mimic a plant's aesthetic, morphology, or anatomy but are, nevertheless, algorithmic cousins infused with plantlike proportions and morphological mathematics.

Mobilizing environmental conditions asks a building's structure and surface to sense changes and address them. Integrated components such as remote sensors, robotic actuators, and digital intelligence are currently options—and good ones—but ultimately, biological living materials, prosthetic organs, and hybrid, semi-living/semi-mechanical systems will be necessary. Then botany, technology, experimental gardening, chance-via-software, aesthetic decisions, citizen science, and DIY ingenuity can result in visual hypotheses aiding emerging architectural species.

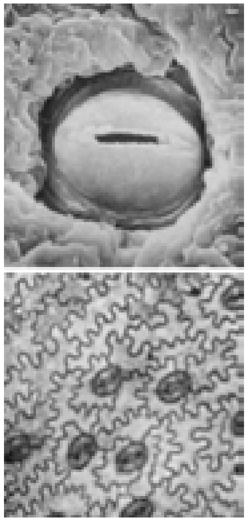


Pulsatilla. Anemone.
Botanic Systems: Seen & unseen.

Hybridizing Architecture

Beyond trusses and structural design, digitally-grown component façades, panels, surfaces, pods, and modular units are subjects of this research. By morphologically transforming simulated leaves, flowers, stems, roots, and seedpods, the resulting design components retain simulated plant attributes for clustering, massing, fusing, and connecting. I think of these transformations as a procedural set of digital operations encoding biological-like properties into final projects and models. Additionally, the procedures help reveal how spaces, digitally generated from plant simulations, can environmentally enhance aesthetic ends while assuming environmental goals.

For the software-grown, parametric BioTower (28-35), I concentrated on an interlocking branch armature protruding out of the facade (resembling a woven cylindrical basket 30, top #1). From the branches sprout a series of spiraling and clustered digital leaves and biomechanical systems acting as filtration membranes for the building's interior. The sensor-activated façade was inspired by, and modeled on, the stalks of blooming flowers from narrow leaf yuccas (*Yucca glauca*). The yucca's floral spikes express a growth pattern following Fibonacci spiraling up the stalk (opposite). They illustrate sequential and punctuated placement of forms responding to environmental orientation for heat/shade/light/air distribution around a cylindrical core. This pattern information, genetically determined in the yucca and numerically translated through Xfrog, strengthens the BioTower's botanical heritage. The plant geometries and hierarchies inherited through Xfrog help map potential shapes for enhancing or avoiding heat and light while maximizing photovoltaic and passive wind control. And,



Scanning Electron Microscope (SEM) view of leaf stoma (top) and stomata (bottom).

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Right page 63: five SEM views of *Opuntia phaeacantha* for the digital-botanic project to reformulate traditional adobe products as thin, lightweight, and strong hybrid materials.

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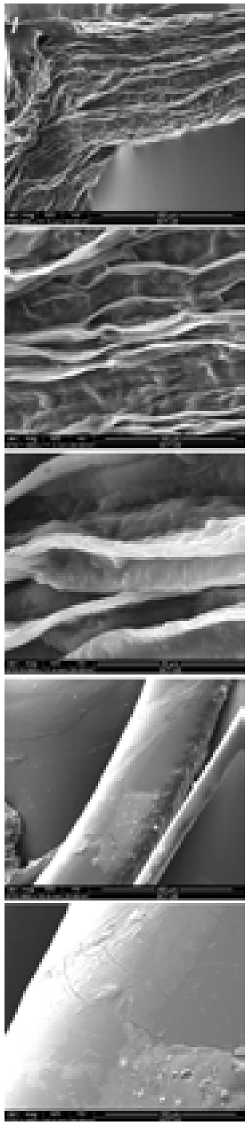
Microscopy photographs: Alberto T. Estévez. Genetic Architectures Research. ESARQ. Universitat Internacional de Catalunya, Barcelona.

experientially, from the inside of the building looking out, the view is like that filtered through a tree's canopy.

From a design perspective, the thrust of the ArizonaTower represents an attempt to hypothetically root a building—to bring into an architectural dialogue, not only the aesthetics of what is seen, but also the potential of what is hidden (14-15). Yet, to be clear, I am not, at least at this point, suggesting that there are, or should be, architectural roots. My intention is to think of underground anchoring, low-pressure pumping, and water circulation. And reasons for investigating root networks are multiple: they anchor and foot, and they are biological ecologies counterbalancing above-ground components. Equally important, underground biological systems bring to mind mechanisms for water storage and distribution, bacterial sensors, and information circulation. New underground forms and configurations may be inspired not only by roots, but also by rhizomes, tubers, and bulbs (as well as their bacterial symbiants), culled for ideas to model facilities, such as cisterns, for harvested and recycled water, as well as for on-site sewage and bio-reactor filtration.

An overview of the prototype STL models made between 1999 and 2009 (6-7) illustrates a strand of digital tree evolution and potential structural and aesthetic direction. From the first simple tree with two gnarly branches, the eTree's complex branching increases until models illustrate design pushed for growths scaled to habitable, if hypothetical, spaces. For example, in the final image of the sequence, the ArizonaTower sprouts forms at forking botanical nodes, where pods and polygons, grown enormously out of scale, become roomlike, and are eventually reprogrammed from pod to cube to architectural capsule (see also 14-15).



Leaves and Monocoques

Leaves as shifting, aggregate clusters, responding to directional winds, or as profile- and surface-reducing organisms in heavy storms (or wilting in extreme heat), have implications for architecture and industrial design. I have been examining the physiological pores (stomata) that leaves use to breathe—millions on the underside of a single leaf (opposite). Using images from scanning electron microscopy, you see individual, biomechanically organized cells tasked with opening and closing (as in a camera's aperture) low-pressure hydraulic (turgor) systems.

Scientists use information from microscopes in specifically professional ways—designers could respond to it in equally legitimate, if differently visualized, ways (but do not usually have channels to such information). With information from microscopy, designers might grapple with visualized translations of biomechanics for architectural structures, materials, and fabrication methods; thus re-envisioning molecular and cellular nature for hybridizing buildings with embodied biological functions. We don't need to wait twenty years for Dupont to develop a stomata panel distributed through Home Depot—one should be DIY-started and tested now.

It is to the cellular level I sometimes look for ideas to translate leaf (and other plant) functions into design potential. Ideas for developing architectural skins, not as lungs but as breathing membranes, has occupied a place in my thinking since 1996 and continues today on two fronts. One—though not a focus for this text—involves formulating, envisioning, and making prototype organic adobe products that are thin, lightweight, and strong; specific electron microscope research (62-63) for this project focuses on the prickly pear cactus, *Opuntia*. Another parallel line of design I began in 1999 with the observation that almond shells have different inner and outer surfaces (polished inside, rough out) connected by a filamentous, porous structure. After grasping how almond shells breathe and ventilate through their shell pores, I fit them into an investigation for seedpod bio-models influencing monocoque and panel design (64-65). I came to think of them as my test specimens for design research: akin to botany's *Arabidopsis* or biology's genetic test fly, *Drosophila*. I am now considering the aesthetic and technical performance of porous surfaces across a range of shapes and folds, as found naturally in the forms and curvatures of leaves, bark, and seed pods—leading to monocoque prototypes whose bio-perforations inhale, filter, and exhale.

Above: 3D test components populated over a warped surface by ParaCloud for testing the idea of individual monocoques as part of an aggreate curtain wall.

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Right page 65: Seed to Panels—Almond shell interior, exterior, and structural in between = nature's monocoque.

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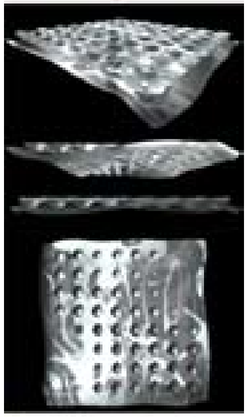
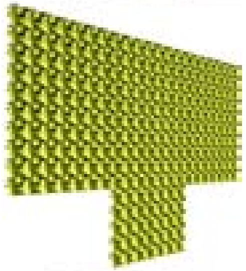
Below the almond: three panel designs for interchanging interior and exterior air, developed between 1999 and 2006 and related to the self-shading Tower for Los Angeles—22-27. Discussed in *The Pangolin's Guide to Biomimetics & Digital Architecture*.

Conclusion

One vision for integrating buildings and biological design includes inventing new architectural systems—thinking of them as natural; thinking that architecture is part of nature. A parallel strategy fosters collaborations between design, biology, and industry thereby encouraging designers to enter industrial and manufacturing production in order to create new biomaterials. Biology and technology will define our buildings' increasing ability to interact with nature. Such buildings are likely to be nurtured, and their functions guided, from software, computation, environmental sensors and actuators, and later from living systems. In this scenario, software and scripting become interpretive tools for generating, analyzing, and integrating design into nature.





Presently, branches, leaves, and flowers are pushing me in new directions. In 2007 I began using ParaCloud, not only to populate components onto irregular surfaces, but also to understand parametrics as a way of generating iterative, individually-scaled panels, hybridized with natural properties. On pages 20-33, I'm illustrating tests for parametrically linked components of façade panels as possible elements for deformable skins. These units, based on leaves, are self-supporting and, in their shape variations, require ParaCloud's or GC's generative abilities. For example, the LA Tower (20-25) exterior was generated from an Xfrog grown tree-truss whose branch tips defined a point cloud that in turn articulated a glass surface and that surface defined the underlying matrix hosting the façade's 2,000 plus panels.

Buildings, cities, and their infrastructures are going to be environmentally beneficial, contributing to cleaner air, their skins functioning like leaves, alerting us to pollution and allergens. Architectures will be adjusting, folding, accommodating, and reorienting themselves to reduce solar gain in hot periods and heat loss in cold, as well as aerodynamically reconfiguring in response to shifting wind loads. Such biomechanical functions may also assist interior air exchange with passive ventilation, noise abatement, and toxic filtration. And, I see no reason why, eventually, buildings should not contribute to carbon sequestration, photosynthesis, and watershed reclamation while, at the same time, providing new habitats for urban bird and native plant life.

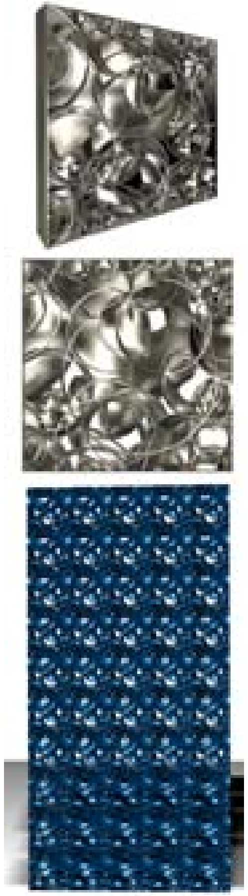
If we consider design as part of nature, we need to begin reconceptualizing nature without artificial categories—consequently realigning design/nature in education and design practice. Using the tools of technology, science,

Prototype panel. 2004
Adobe, hemp, and *Opuntia* formulated as part of a thin-wall panel system or monocoque.

and nature to give buildings and cities biological properties, architecture may be reanimated as an environmental asset, rather than a liability. We may look to digital generation and fabrication as one pathway from toxic, formulaic architecture, seeing it instead as a driver of architectural speciation. Viewing design in an evolutionary frame holds promise for creative, technical advancement as today's highly lethal species of buildings, products, and urbanisms die out, replaced with fitter species.

Before bio-architecture or cities can be tested or publicly and professionally considered, before residents and viewers can react to biologically living structures, there have to be examples or prototypes to consider, debate, and refine.

What has preceded is a set of ideas realized as drawings and models for contemplating nature, architecture, digital nature, and the integration of botanic functions into cities, buildings, and lives. In an elemental way, the work samples an ongoing experiment in generative biodesign from plants to software. Such works also illustrates potential directions for environmentally related design linked to botany and biology while encouraging research for living and hybrid architectures. In a metaphorical sense, I hope my studies are digital-seeds for a next generation of ideas and designs.



Bubble Panel & Block.
Related to, and derived from, investigations of almond shells, panels, monocoques, and skins. This permeable block was designed for circulation of air and light as an interior partition. Its design was based on masses of water bubbles

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"The points that I would emphasize are: First, that this sharp division between mentality and Nature has no ground in our fundamental observation. We find ourselves living within Nature. Second, I conclude that we should conceive mental operations as among the factors which make up the constitution of Nature. Third, that we should reject the notion of idle wheels in the process of Nature. Every factor which emerges makes a difference, and that difference can only be expressed in terms of the individual character of that factor. Fourth, that we have now the task of defining natural facts, so as to understand how mental occurrences are operative in conditioning the subsequent course of Nature.

A rough division can be made of six types of occurrences in Nature. The first type is human existence, body and mind. The second type includes all sorts of animal life, insects, the vertebrates, and other genera. In fact all the various types of animal life other than human. The third type includes all vegetable life. The fourth type consists of the single living cells. The fifth type consists of all large-scale inorganic aggregates, on a scale comparable to the size of animal bodies or larger. The sixth type is composed of the happenings on an infinitesimal scale, disclosed by the minute analysis of modern physics."

Alfred North Whitehead
Nature and Life, II. 1933

PodHotel, Barcelona

PodHotel. Barcelona. 2004-2005
Project for grouped eTrees sprouting habitation pods around three central trunks.
See 38-39.

Addendum:
Citizen Designers Do-It-Yourself

Do-It-Yourself (DIY) architectural research—or laser cutting, or CNC fabrication, or plant/architecture hybridization—may sound condescending, but that's not my intent. In the last decade an explosion of open systems, common copyrights, hacked electronics, citizen science, biofuel conversions, urban foraging, city farming, bicycle kitchens, cellphone emergency-response planning, hacked biology, and of course the MAKE movement have marked professional knowledge barriers as distinctions to be gone around. All these activities, or micro-movements, suggest that design and urban research could be conceived differently, with alternative goals from those of entrenched political and bureaucratic agencies.

So why not bio-architectural research from citizen scientists? Why not re-envisioning cities and the materials of cities? Why not DIY digital botanic architecture? I'm serious.

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A couple of years ago Jenna Didier, Oliver Hess, and I discussed a program called MatterApp. We subsequently tested it at M&A (Materials & Applications), a Los Angeles-based organization for experimental permaculture, architecture, and advanced design co-directed by Didier and Hess. The idea was to bring people together, brainstorm, and build prototype mechanisms using sophisticated or even bizarre ideas with the intent that experimental fabrication would employ new materials, new and ancient technologies, hacking, and/or home brewed mechanical extrapolations. This effort seeded a later, intensive burst of DIY industry when Didier, Hess, and M&A volunteers used it to design, engineer, fabricate, and install M&A's Summer '09 pavilion and aquaculture garden—designed, researched, prototyped, built, and installed over a period of approximately twelve weekly work sessions with the goal of producing, as Didier notes, "both edible fish and plants for humans and habitat for native birds and insects."
(See M&A's website: emanate.org)

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While this was not a group of citizen scientists, it was a group of citizen designers, artists, and architects taking a summer R&D program into their hands. Germane here, in terms of architectural research, is the designing, testing, and making outside of standard studio, financial, and contractor hierarchies and channels. Design research, theory, and prototyping could/should take place in a similar sphere.

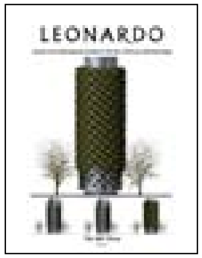
One subcutaneous message in these pages is of design research taking place outside most (but not all, I have to admit) established channels. Found and scavenged information—like

DIY • Make
STL
Fabrication

http://www.makerbot.com/

appropriated land for urban gardens—becomes data compost as it is layered onto projects, feeding their appetites for expensive consulting technologies, systems, and calculations. Stewart Brand's "information wants to be free" is probably not true; nothing in nature is free. But Brand's slogan is appealing and its generic sister tract "Appropriate it / Sample it!" seems more to the point.

So some of my DIY research sources are noted by graphic markers that present icons with a few thematic words relating to the page's respective content. Often these tiny icons represent ideas or idea-sources that were instrumental in the project's development, historically antecedent to it, or important in its generative idea/design process—following the links and leads will, I think, give interested readers latitude to extrapolate a parallel DIY process.



Leonardo Vol. 42, No. 5, 2009
Dennis Dollens. *Architecture as Nature: A BioDigital Hypothesis*
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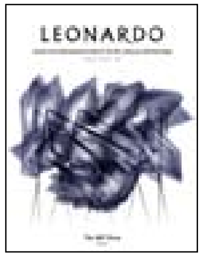
Forthcoming September 2009



Leonardo Vol. 38, No. 1, 2005
Dennis Dollens. *A System of Digital-Botanic Architecture*
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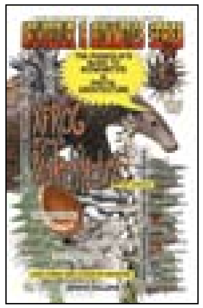
http://www.mitpressjournals.org/doi/abs/10.1162/leon.2005.38.1.15



Dennis Dollens. *A Pangolin's Guide to Biomimetics & Digital Architecture*
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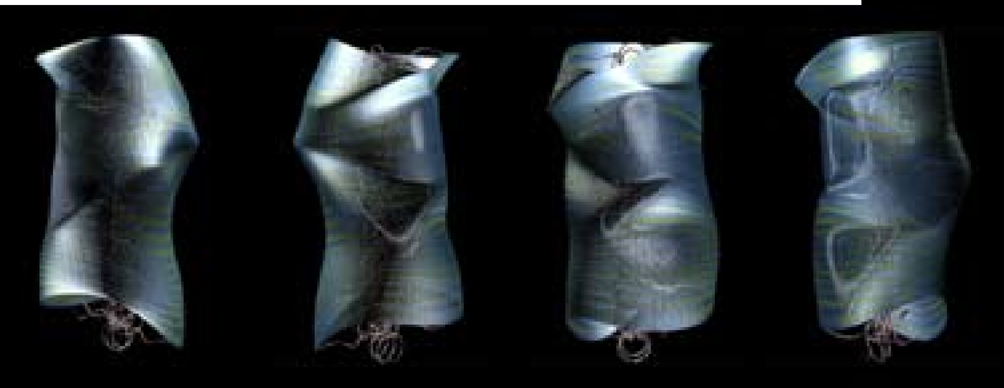

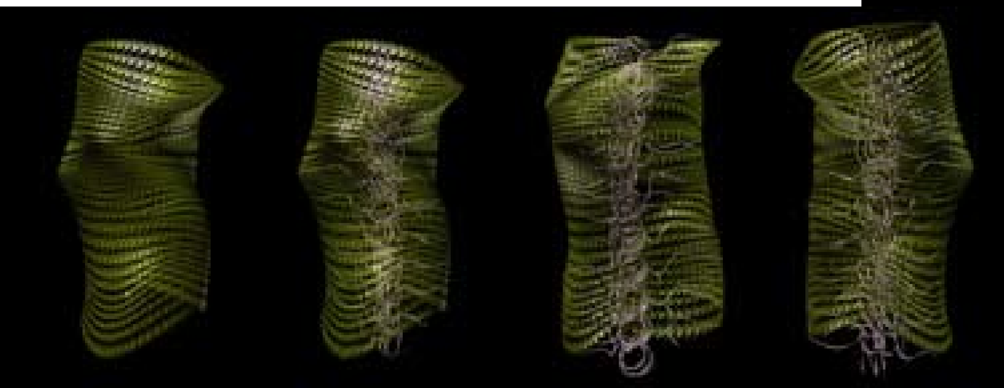

Looking through a filter of aesthetics, geometry, and botany in order to visually extrapolate from their procedural rules, geometries, and genetic forms, D•BA^2 proposes architecture hybridized through algorithmic plant simulation, generative design, and botanic information. The text discusses and illustrates an induced evolution in one (of many potential) emerging methods for design realized through software-simulated, plant-to-architecture morphology. The resulting digital-botanic architecture is manifested in prototype ideas, structures, surfaces, materials, and systems. Works are documented with drawings, renderings, and STL models.

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