

Digital-Biomimetic Architecture

Dennis Dollens

Abstract

This essay (abstracted from a lecture on 29 March 2006 at the University of Barcelona), explains how biomimetics for design and digital production can integrate procedures to conceive, visualize, generate, and model architecture by studying forms and processes in nature and how that process has evolved in Dollens' work. Looking to seeds, plants, diatoms, algae, shells, etc. for biomimetic information suitable for design extrapolation to new architectural forms, the presentation considered how sustainable environments could be integral with technical innovation, new attitudes toward genetics, biomaterials, and science/design collaboration. Specifically, the presentation illustrated how works "digitally grown" in the plant-generating software Xfrog, can be used to prototype ideas suggesting new systems of architectural conceptualization and organization that merge technology and nature. And, finally, the presentation considered how digital animation, especially as illustrated in *The Cathedral*, can be analyzed as a filter for biomimetic visualization in a context of nature, design, and technology.

Introduction

The Cathedral (Baginski, 2002), (Dollens, 2006), may seem an unusual introduction to biomimetics, yet we can extrapolate from its spectacular images and troubling ideas that, architecture is a natural process of growth with properties of biological development. Furthermore, in *The Cathedral*, architecture is an extension of the natural (non-earth) environment as well as human thought, and thus, this Academy Award nominee, is an extension of our biological world. For *The Cathedral*, architecture is alive. Architecture grows like a tree but no tree that has ever existed on earth, it is alive but alive in an alien sense; *The Cathedral* consumes and imprisons souls as part of its organic growth. And, while the subject of the animated film is more attuned to social dystopia than architectural theory or genetic architecture, I see this digital production as a useful and inspirational work, setting the stage for this essay. I'll come back to *The Cathedral* in my closing; but first I want to touch upon some ideas and the concept of biomimetics that are currently extending architecture and architectural thinking into new realms of nature, science, and digital production and that are also undercurrents in *The Cathedral*.

This discussion of design work and theory is itself evolving and part of a process, a search for ways to envision environmental architecture and design derived from nature or given properties found in nature. I'm testing this approach, called biomimetics, which is frequently used in engineering and scientific research, to explore

forms, shapes, connections, as well as, importantly, biological properties from the natural world. Biomimetics is the technical term used in biochemistry, biology, pharmaceuticals, and by material scientists in their quest for properties in living organisms and natural systems that can be extrapolated from observation and scientific analysis, in order to recreate those properties for industrial, medical, and biological products (Benyus, 1997). This is not a new concept; it has been used for many years, although for biotechnology, biochemistry, genetics, and material science, it is a newly invigorated approach. What we are experiencing at this time in design history is one approach for the re-examination of nature using tools of technology and science. Still, it is important to recognize how long biomimetics has been with the design profession.

For example, long before the word biomimetic existed, the gardener, Joseph Paxton (who later went on to design London's Crystal Palace) found structural inspiration and building ideas from waterplants. Paxton, working in Industrial Revolution England, grew a *Victoria regia* waterlily and paid particular attention to the plant's leaf structure which is 1.8 meters in diameter. (Colquhoun, 2003). The plant structure, as you can research for yourself, is a radiating, cantilever system with cross bracing supporting the great leaf's surface. From his observations of the lily pad's natural structure, Paxton extrapolated and designed an architectural system of furrows and ridges (like a self-reinforced truss) for the frame of Chatsworth's enormous greenhouse called the Great Stove (because of its heating systems). And he did this around 1835. The Great Stove was an extraordinarily advanced building (aesthetically and structurally), using new technologies. For it, Paxton also designed the steam-milling machine for fabricating the structure's non-standard, wooden ribs and he contracted for the largest sheets of glass then in production.

Visual Biomimetics

Biomimetics for design is emerging in colleges and universities all over the world. The idea of finding a wide-spectrum method for considering nature is slowly appealing to a world facing limited resources, nuclear proliferation, and a climate out of sync. In such a situation, letting nature take a role as teacher has a logic that crosses academic barriers and suggests that visualization of natural processes is a valuable component and potentially an equal partner with traditional biological disciplines researching nature. One can take an object from nature; a shell, a bone, a plant, a flower, a leaf, and start looking at it and investigating it as a source for design properties and then take those observations and draw them, or scan them, or section them under a microscope, and comprehend them as discrete elements that may have application to design work and thought. Yet that gathered data will be enormously enhanced if understood through the lens of collaborating science. So, I am suggesting a research method for design and architecture based on observation and extrapolation of forms from nature—a visual biomimetics for design that also includes the possibilities of designers and scientists teamed as equals for a paradigm shift that redefines what

potentials a collaboration between science and design holds.

Such an approach brings into view a method for design thinking that includes the possibility of creating buildings as we know them, but more interesting, it provides a path to conceive buildings that are aesthetically, materially, and mechanically more advanced in terms of the environment and sustainable technologies. Additionally, such a method or system is also intended to stimulate the designer into thinking about new materials and environmental resources from the perspective of science and how such data may factor into the visualization and creative process. We can develop this method, looking to and from nature, in partnership with current and evolving design practice or in experimental design-science teams to rethink industrial products and for producing biomimetic architecture—that is, better functioning and less toxic products, infrastructure, buildings, and ultimately cities. Additionally, this approach is sympathetic and combatable with processes for integrating genetic research and bio-fabrication from important research programs such as those stemming from Barcelona's own Genetic Architecture's at ESARQ, UIC—founded and directed by Alberto T. Estévez.

I use software as a tool for digital-biomimetic extrapolation. The program is called Xfrog and it's generally used for landscape architecture. Xfrog will generate beautiful, life-like trees, shrubs, and flowers. The software has the ability to produce forms based on botanic algorithms that impart to the digital, 3d design, the essence of a growing plant. Xfrog's growth parameters can also be experimented with—manipulated—to grow new types of forms derived from biological algorithms applied to architectural geometries. The orientation and progressively scaling of a plant's leaves, for example, can be translated and that information used for architectural clustering and massing aesthetics. Algorithmic generation will also suggest how forms may follow some of nature's methods found in leaf and flower arrangement—useful for calculating exposure to light and views, or for creating sun, shade, and air-flow systems for natural temperature and ventilation as part of a buildings design's intelligence. Thus, biological growth that determines branching, leaf formation, flower orientation, etc., is, in a sense electronically hybridized, producing structures and/or mechanical systems that are digitally-grown for architecture with botanic properties.

Recently I've used Xfrog in an ongoing process to generate skeletal frames and cluster-studies for multi-storied buildings. Implementing enormously overgrown leaves and flowers in Xfrog in order to understand orientation and massing based on flowers that grow on tall, vertical stalks, such as penstemons and yuccas. I've then translated this digital-botanic material in various geometries—cylinders, spheres, distorted spheres, prismatic crystals, rectangles, and cubes—while keeping the basic flower arrangements. My intention is to give residential towers properties other than rectangular facades. By using the hybridized information from Xfrog, biomimetic properties from plants can be sustained in the digital model so, for example, from the biological models where flowers spiral up and around a central, structural stalk, I can digitally-grow an armature with distributed pod-like forms for an apartment building or hotel. Use of observed flower placement paired with Xfrog's biological simulations of

phyllotaxy, begins to illustrate some of the methods that design massing, structural-frame, and from can respond to. This process is not a copy of nature, it is extrapolating and studying qualities of a plant to understand some of the geometric relationships used by growing organisms, then interpolating those qualities into new uses. The idea behind these experiments is to take a design project and to subject it to a biomimetic process that looks first to natural forms and organisms, finding an environmentally sound potential, and then investigating these potentialities for design development.

As an emerging design specialization, biomimetics has many areas yet to explore. And, clearly there are various ways to study and understand biomimetic approaches—visual, structural, mechanical, chemical, molecular—all offer differing aspects and all part of the natural world. It seems to me that the least desirable outcome is for design to be fashioned to look like nature with conventional materials, methods, and attitudes. Such an approach, merely making a conventional building look like a natural form, clearly violates the spirit behind biomimetics of looking to nature to learn. One potential way around superficial-biomimetics is in the organization of design teams involving scientists and designers for a new kind of partnership involving research, development, and design—potentially including designers on teams with material scientists for the actualization of new materials with biological properties.

It seems to me that to make more than stylistic progress with a proposed methodology for design such as biomimetics, it is important to also have a perspective of design's evolution, since design is part of the natural history. Design history includes thoughts contained in writing as well as thoughts embodied in objects (architectural, engineering, industrial, artistic); texts and thoughts-in-objects help spark the continuum of ideas evolving over time. We take ideas from the past and we modify them, then grow them again. The inclusion of a natural history of ideas in biomimetics gives us some previous design experimentation to underpin a new foundation on which we may seek to avoid a priori aspects of style with a replacement process learned from nature while also answering to nature in the form of benign manufacturing and 100% recycling. This process allows design deeper hybridization with new technologies, physics, the environment, and biological sciences while still holding the designer's role as central.

Here is a brief example of history and biomimetics overlapping focused on The Museum of Natural History in London. The structural elements that are important to this thesis are the museum's arching metal trusses that cross its main atrium space. For its time, the museum was structurally advanced—large-span trusses engineered using triangulation and built in steel—bridged its central hall. Yet, ironically, underneath these metallic arches, we see far more advanced structural principles illustrated in biological structures. This building houses some of the museum's collection of dinosaur skeletons. If you stand in the atrium, you can look up to the trusses or across to the dinosaurs and compare the dinosaur's enormously complex neck, spine, and tail with the truss above. You see a truss built by man and a truss built by nature. Why talk about this skeletal truss? We don't want to build a dinosaur. Yet, study such bone

systems—biomineral structures—and their revelations will not only be beautiful, they will be lessons in engineering and detailing. I'm not suggesting retrofitting the museum with bio-trusses nor am I criticizing the original designers who created a fine hybrid structure of architectural styles and Industrial Revolution engineering.

I'm suggesting we bring biomimetics into focus in such obvious cases in order to comprehend and to teach how visual and biological information contained in the Natural History's artium for example, could be articulated, reinterpreted in light of biomimetic potential, designed, and prototyped. Thinking of extrapolating design ideas from both kinds of structures—biological and man-made—is what I try to do with students. What would a biomimetic adaptation of a dinosaur truss be today? How could a biomimetic variation be situated in a building with large spaces requiring very long beams or very strong columns? How could some of the poetics of the organic system be incorporated in a digitally created work? What were the mistakes and successes of the steel trusses above the dinosaurs? Since obviously, those trusses and each generation of their successors have some survival ability. One can begin to imagine a design brief setting goals differently when the program is seen as part of a natural cycle.

The example of an atrium with nineteenth-century Industrial Revolution architecture sheltering dinosaur skeletons is dramatic. But the skeleton of a chicken or a fish will provide equally wonderful, amazing potential. With natural elements, common or exotic, the potential for extracting biomimetic ideas and information is, for all intensive purposes, unlimited. And, extracted information can be greatly supplemented when collaborations between biologists and other scientists are seen as rewarding for creative, environmental, and economic development that satisfy both designers and scientists. Design can flourish in our own era of emerging technological, biological, and environmental possibilities compatible with a sense of experimental, aesthetic potential. In the past, such extrapolated forms could not be realized, they would be impossible to structurally draw, engineer, or build. Yet, now they can be drawn, they can be engineered, and with enough money, they can be manufactured. So today, designers can incorporate ideas of technical innovation and material development into current practice and understand the digital and computational systems needed to produce them. To be ready for new technologies, designers need to be thinking of ways that our products can be better, that industrial design is compatible with architecture and that architecture is more responsive to science and the environment.

Design Metaphysics: Louis Sullivan

Looking to the work of Louis Sullivan, an American architect who died in 1924 can be instructive in a biomimetic light. He wrote a book in 1924 called "*A System of Architectural Ornament*" and it is, perhaps, the most important book ever written on architectural metaphysics, design, and theory in the United States—following in the tradition of Thoreau, Emerson, Whitman, and Dewey (Sullivan, 1967). It discusses and

illustrates how to develop a series of designs through a system of increasing complexity and increasing layers, from geometrics to organic branching, that expresses a poetics of nature for architecture. Sullivan related a building's design to plant morphology and if his suggestions of design sequence are studied it becomes clear that his analog *System* has biomimetic parallels and those parallels have digital implications (Dollens, *A System*, 2005). Louis Sullivan discussed the idea of growth-like architectural ornament long before we had the possibility of putting his ideas into a computer. He took geometric forms, boxes, circles, straight lines and used simple drawing manipulations to create a geometric foundation for further drawing. We can think of this as the basic geometries of development. He then used the idea of plant growth (that has relationships to some of Xfrog's growth potentials) to overgrow his geometries. His idea of growth, intergrowth, and overgrowth can serve now as a template for design-thinking using layers of computational growth in digital production, say with Xfrog or with L-Systems. Sullivan saw nature as a lens for architecture and civil structures, for poetry and philosophy. His work and words, in relation to emerging biomimetics and computation, seem to me to deserve serious attention and retroactive reinterpretation. I think Sullivan's work is an example of history and ideas as biological, alive in the sense of still communicating contemporary relevancy—forces of man's nature.

Sullivan provides more than inspiration for digital work. We can appreciate him as a poet and philosopher who looked through architecture for a metaphysics of biological life, civil systems, and aesthetic production. Sullivan established in his *System* a method to evolve form and structure, as well as for evolving thinking how botanic forms can relate and express architectural and social concepts. His works are vast overlays, one idea over the other—ideas manifested in lines, forms, and materials all responding to conditions his design process isolated for them to function in. Following his *System* with digital tools, one's ideas become armatures to grow intricate form, and over this form, to grow branches, vines, and leaves in a reconceptualization of the environment as part of new building (structure and skin), that in turn, begins to illustrate a transformation of design ideas into potential forms or material objects. Louis Sullivan conceptually advanced the development of the skyscraper. He constructed a theory for the tall building where organic frame, material skin, ornament, and social use define the expression of modern architecture; and biology was one of the important metaphors for that definition. He published these ideas not only in the *System* but also in an essay called "The Tall Building Artistically Considered."

In an era when Gehry's buildings billow and flow and Herzog & de Meuron's architecture brings back ornament, pattern, and botanic imagery (and their recent book is called *Natural History*), Sullivan's writing and theory tells us that his conception of growth and integrated organic systems is even more logical today with digital generation and manufacturing than it was when he created it. So, if Sullivan's buildings seem dated, that's more an expression of his time (and history's flow)—his embedded ideas are alive and biomimetically sound; they are still available to inspire vastly

original works paralleling some of nature's ways. I think Sullivan's ideas must be considered an expression of nature. So if his architecture looks dated, just consider that the theory behind them has not lost its clout. Sullivan gave us a morphological language in *A System of Architectural Ornament* that is still useful, poetic, and powerful. His morphological language and beautiful drawing have, metaphorically, planted the seeds of the work that follows. Sullivan thought out the evolution of lines and forms to develop his grammar for a new architectural ornamentation that we may employ as a fundamental biomimetic text and a foundational metaphysics.

Case Studies

Contemporary design can still harvest Sullivan's ideas by attempting to understand his underlying principles in a digital context, and then grow them differently—growing them to be cellular elements capable of incorporation into current structures, for example as ceilings, canopies, walls, columns, and beams (*Digital-Botanic*, 2005). Through such an approach, I have been growing components—creating a biomimetic kit of parts. Most of these specific forms are not fully determined because they have not yet been given a functional program. I'm trying to keep the concept of experimentation and design research as the prime focus. In designing and teaching, I ask students, as I ask myself, to look to natural expressions of plants, and to question how these plants work and how they function in life, and to further seek what in the plant's form and life cycle may be related to extractable, biomimetic form.

A biomimetic process is part of what I have done with the tumbleweed (*Salsola kali*) beginning in 1995. The tumbleweed is a complex, branching growth with wildly irregular, sharp, curved barbs that sometimes interlock with each other. As a system of links, the barbs hook one branch with several others (Velcro-like), making a thicket of branches, stuck together, giving the overall plant a resilient flexibility, and a kind of aggregate strength where weak elements in collaboration with other weak elements achieve great strength—an iterative structural technique found over and over in nature. In the overall form of a ball, the tumbleweed's hooked branches make an extremely strong, truss-like sphere that rolls along fields distributing its seed—the form and structure are part of its evolutionary function of propagation. I have used ideas from the tumbleweed to generate many digital plants, and from the plants, various types of architectural elements. From those digital growths I have further grown digital armatures developed from the idea of barbs as connections to create structural systems for hypothetical buildings. The various designs are arrived at through a series of iterative Xfrog steps and Rhino digital manipulations that use analog and computational evolution to grow and articulate structural forms. Furthermore, these are realizations of ideas extrapolated (a kind of intellectual biomimetics) from Sullivan's *System* in collaboration with the visual biomimetics discovered in tumbleweeds. Yet this work is not intended as specific building proposals—it is purely hypothetical—attempts to grow forms based in observation and 3D experiment, that hopefully lead in the direction of architecture and material design.

Genetic Architecture

Architecture is part of evolution, an expression of human's place in the natural system—even when, as it currently seems, that system is being eroded and severely damaged. When we look to ancient forms of architecture we see that even human architecture, at some level, has relationships to insect and/or animal architecture. This is profound and we should relearn how architecture is genetically related to us and develop it again as environmentally responsive. Human architecture, at least partially, looked like cellular forms at one point in history, for example the cellular configuration of rooms in circular Indian pueblos, such as those found in the American southwest. Part of my thinking suggests that **architecture is genetic**. Yet, how can architecture possibly be genetic? It is genetic in the sense of a biological extension of our systems and thoughts most clearly articulated in the theories of Richard Dawkins (Dawkins, 1983). So ask: if the nest of a bird is genetic, or the paper and saliva of a wasp's nest is genetic, why isn't an adobe house or the cell-like structure and social organization of a pueblo genetic? Initially, humans used mud, sticks, water, dung, plant-matter, and fabricated—evolved—mud into bricks—living soil—and constructed an architecture that was in some senses materially, biologically alive. I speculate this architectural, cultural expression must still be part of the human genome; collectively our DNA/RNA does not change quickly. We have only evolved extraordinarily fast in terms of technology, science, and engineering and in doing so have lost track of biological materials and building. So part of working with my hypothesis of Digital-Botanic Architecture, independently, but also in university workshops and lectures, is to develop and test some of these thoughts (*Genetic Architectures*, 2003). What can we do to develop advanced materials that have some of the qualities of a living organism? What can we do to design construction materials and buildings that breath, or eat pollutants, or harvest sunshine without creating new toxins?

The area around Santa Fe, New Mexico, where I live part of each year, is one of the great cultural ecotones of earth architecture, the pueblos and later colonial buildings are made with adobe—earth, sand, salt, straw, dung, and water—and considerable new construction is also made of mud. So, in New Mexico I'm experimenting with these same materials and organic additives manifested in tests for enhanced types of earth plasters or sprayed adobe. I am experimenting with plant fibers (such as those used in papermaking) in adobe mixes, testing traditional botanic additives such as juice from *Opuntia*, commonly known, as prickly pear cactus that might strengthen and seal the fiber-mud. I'm looking at how this work could be an example of a biomimetically reformulated material and how such fiber-adobe could be used in lightweight applications with great durability and wall thinness. I have been working on these materials for a strong, very thin, sprayed-on pulcrete or sprayed-on pulp-based, earth plaster (modified adobe). These material experiments take place on small, exterior structures that are exposed to harsh environmental conditions. In Santa Fe the test structures are regularly surviving snow loads that are 60cm thick, in addition to

surviving extraordinarily strong winds. These are examples of work that can be seen as design research, biomimetic steps to evolve materials, fabrication, and architecture. A current focus of this ongoing experiment uses adobe pulp to manufacture shingles and surface panels fabricated in ways similar to papermaking and suitable for use in building prefabrication.

Digital-Botanic Growth

If there is a valid challenge to re-engineer and re-conceptualize building materials from toxic to green that designers can initiate or be involved with, my example would be the biomimetic experiments with mud, fiber, etc. noted above. But, I also think we must not lose focus on digital practice and potential in the near-emergency to act environmentally. Technologies that let one feed a digital file into a machine's computer and the machine makes it into a three-dimensional object have the potential of mimicking, in form, some of the complexities of nature that traditional construction cannot touch. With machine model building (and eventually machine full scale component building) using software that can grow 3D forms, presents a new order in design evolution. In the 1960's Aristid Lindenmayer developed algorithms called L-systems. L-systems are computational algorithm used for biological simulation, and L-systems are part of Xfrog software. So, when I say digitally-growing architecture, I am using algorithms taken from nature—phyllotaxis, phototropism, gravitropism etc.—that Xfrog places, along with its own innovations, in a software package.

I began teaching in Barcelona around 2000 and have taught at ESARQ or at ELISAVA at various times. From the beginning I frequently co-taught with the architect, Ignasi Pérez Arnal. And, in 2004 he invited me to work on a project that had come into his Barcelona office, A+. His commission was for a footbridge in the French Pyrenees that he believed would be a project in which some of the ideas we had worked together on for classes could be tested and developed. After some beginning Xfrog designs, we started looking to add biomimetic information and came to study a very beautiful animal called the *Euplectella aspergillum*—a sponge that grows underwater around the Philippines. It is made up of microscopic silica (glass) spicules that have a range of shapes. The variation of spicules can be seen as a kind of form lexicon and we incorporated some of that lexicon's shapes into elements of our design, along with curves and lattice structures from the sponge.

Additionally we used information from a seedpod common to the Barcelona tree, *Tipuana tipu*. We liked the winged seedpod because it spirals as it falls. Depending on wind speed the seedpod spirals at different frequencies like a helicopter; describing potentially graphic information in the form of spirals. We came to understand that the flight path of this seedpod is genetic-encoded behavior determined by the seed's DNA/RNA, that also determines its physical, aerodynamic shape. And, while this potentially visual information, the flight path, is not part of the seed's obvious physical form, it is an example of extended phenotype in plants—a non-physical attribute of the plant's genes—part of a survival tactic for the tree to disperse

seed. Coming to terms with biological information as part of the design process, prompted us to ask what kind of design, shape, form, and function is inherent in natural organisms, and how can they be viewed biomimetically? The end-weighted, single-blade wing makes the spiral aerodynamically possible, but ultimately plant genetics make the wing that makes the spiral. Pérez Arnal and I then used this line of thinking to develop the central core of a spiraling structural system for a potential architecture—sort of a spiraling truss. We combined ideas from the spiraling seedpod and form the *Euplectella* for the bridge in the Pyrenees.

The bridge has three different spirals, each a different diameter, each coiled in a different frequency, and each intersecting the others. For greater structural stability, handrails and the walkway provide rigidity, yet both of these components are still related to the rectilinear lattice seen in the *Euplectella*. The bridge is a lightweight, non-intrusive structure that spirals across its site in a small mountain village. We were trying to convey the idea of a rope bridge—like those made in forests, jungles, and mountain passes—by having our structure curved and arched, rope-like, over its site and receding into the landscape. And, while the bridge surely has a design personality, we think it modestly joins the site as an element of the landscape.

Conclusion

What this paper considers are ideas leading to designing parts of industrial, sculptural, and architectural systems. Designer's may begin to think about designing their own parts and fabricating their own components and not merely rely on standard components specified in manufacturer's catalogs. Designing one's own systems and components, we understand construction and aesthetics at a deeper level and are more carefully involved with the full process of building and assembly—and hence can also provide information for disassembly—recycling. The designer goes back to design, not just making spatial compositions and material specifications. Technology, bioengineering, computation, and fabrication industries are radically changing the design professions—in the next few years construction of what is now impossible will be standard. From the example of the electronics and communication industries we can predict that architecture and design will become more intelligent, more responsive, more entertaining, more protective—perhaps almost alive. New systems, in my view, are going to define our buildings, they are going to be powered by our buildings—architecture whose skins function like leaves—. New building is going to be more local and powered by hybrid biology-technology because, clearly, the way we have gone is a disaster and is not sustainable. Building and design should contribute to the environment not create new parasitical and toxic future problems.

We saw in *The Cathedral* depictions an off-world, dystopic horror of a system out of order, where architectural growths literally entomb humans, doing so in compelling graphic forms and illustrating a morphological transition from biological-plant to biological architecture—this is a point that I'm particularly focused on:

biological potential in design is going to be native in a world of bioengineering and genetic manipulation. The fantasy of a growing architecture, of biological architecture is not so distant and it does not have to be toxic. And, while today, *The Cathedral* is animated science fiction, it points to both aesthetic potential from technology as a tool and social concerns embodied in technology-gone-wrong. Architecture as it enters the twenty-first century has biological potential that has been basically dormant; already there are scenarios where we can imagine architecture as alive.

I think *The Cathedral* not only illustrates one growth scenario but presents a meditation on what architecture is and that it could be alive. For designers, I stress the power of the film includes this: *The Cathedral* is a biomimetic illustration, a seed for potential aesthetic and theoretical growth, where architecture and design will be alive and that the world we create with technology and clean materials need not be that of a dystopia.

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