CHAPTER 5

Polyhedral Materials:
A Problem-Solving Technology

IT IS UP TO MANUFACTURERS TO DEVELOP THESE NEW MATERIALS. IT IS UP TO DESIGNERS TO TRANSFORM THEM INTO THINGS THAT HAVE MEANING, LIKE INK FLOWING ON THE PAPER OF A LOVE LETTER.

— PATRICK KRUITHOF
Future Materials for Architecture and Design

Materials and design, whether in architecture or consumer products, are inextricably interwoven and co-influential. As Patrick Kruithof so aptly states in *Future Materials for Architecture & Design*, "It is up to manufacturers to develop these new materials. It is up to designers to transform them into things that have meaning, like ink flowing on the paper of a love letter."[1] It is indeed the materials we use and value that so strongly influence the tangible, emotional, aesthetic and utilitarian experiences we have with formed objects. I firmly believe that expanding the realm of useful material micro-architectures such as Flextegrity's technology, which offer both conventional and unprecedented future application potentials, is key to ever-wiser and more sustainable products. For implementing new or unconventional materials is never a meaningful goal in isolation, but only a crucial strategy to help us live better, smarter and more respectfully on the earth.

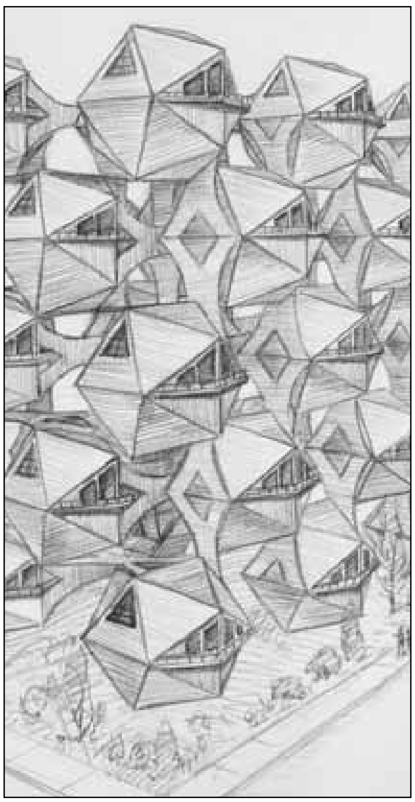


FIGURE 5.1
Icosahedral condominiums

Any new material offers both opportunities and risks to industrial designers and architects. There may be significant opportunities to enjoy radically new or improved technical or aesthetic behavior. The risks lie in incomplete understanding and characterization of the functional properties as well as the lack of previous design or manufacturing history. In architecture, for example, structures can be exceedingly complex in form, and the loads to be applied to the structure are equally complex. Hence, it can be difficult to analyze the loading on a given proposed structure and the resulting stress distribution within it. As a result, material elements and structures tend to be as simple and discrete as possible. Conventional design paradigms are constantly re-hashed even though they may not be optimal, but simply because it is more difficult to create and test new alternatives that will also meet established and traditional building codes.

However, I believe that creative exploitation of the properties offered by improved materials is increasingly critical to design and engineering innovation. Given this technological and economic impetus, materials and the processes to shape them are now developing faster than at any time in history. And the challenges and opportunities they present are greater than ever.

[1] Patrick Kruithof, *Future Materials for Architecture & Design*, Materia, Rotterdam, 2002

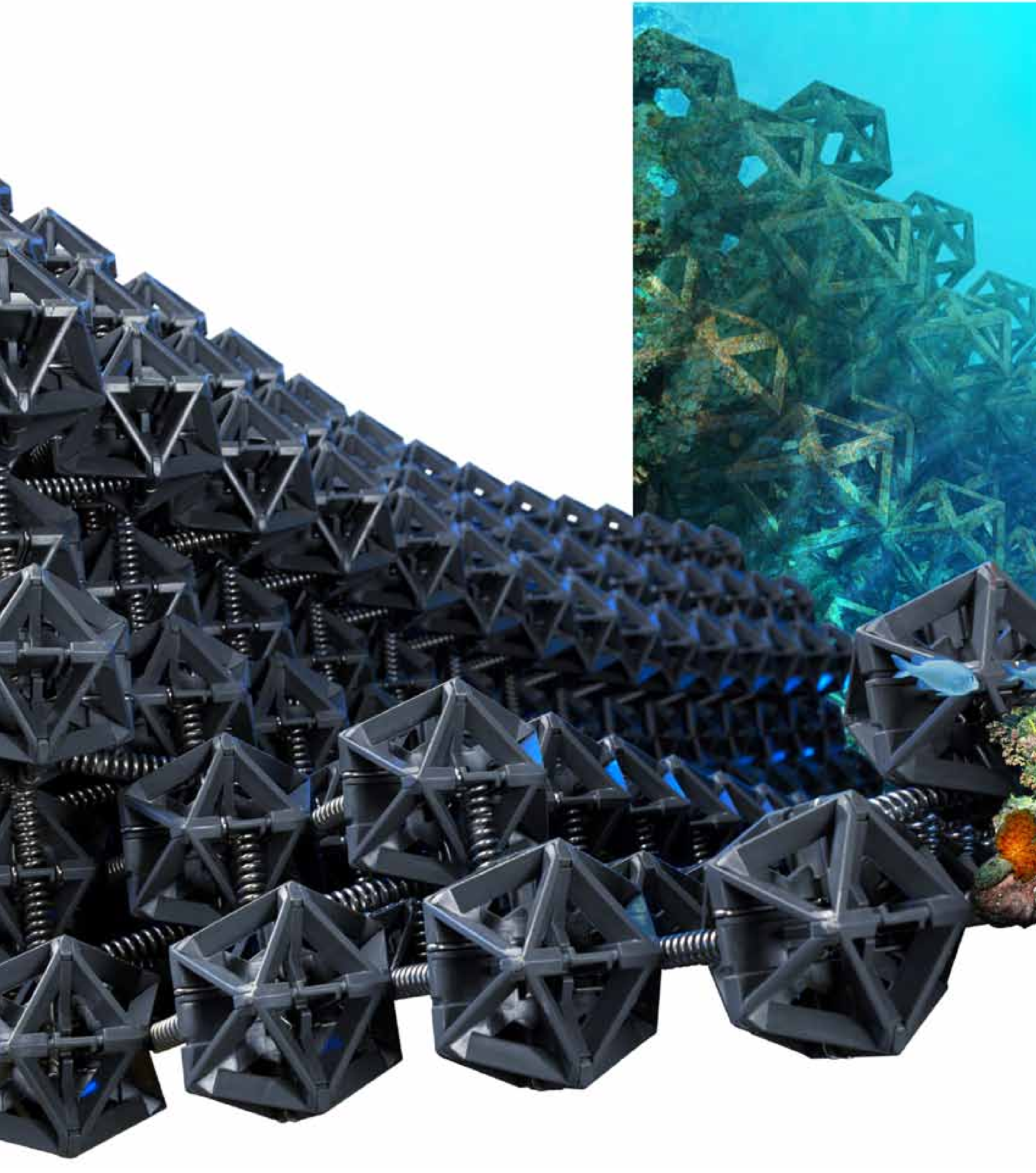


FIGURE 5.2

ARTIFICIAL REEFS

Strong, open-architectured, bio-friendly scaffolding to shelter growth of native flora and fauna…ideally formed from recycled iron that can be naturally oxidized and 'absorbed' back into the natural ocean floor ecosystem/environment for a healthier ocean. Different scaling of the icosahedrons provides protection from predators.

For example, recent catastrophes on all continents point to the need for structural materials that will perform well under increasingly extreme stress conditions. Advanced materials must be anticipatory of emerging needs in their design, and offer comprehensive solutions to real-world problems. I have strong reasons to believe that these advanced icosahedral architectures can address a number of increasingly complex material requirements. Accordingly, Flextegrity is engaged in the prosecution of multiple patents in the field of structural materials that address the opportunities presented by disaster-resistant housing, environmentally mandated stormwater management solutions, and other emerging 21st century challenges.

It is impossible to browse the daily newspaper from any large city without encountering news of still another devastating natural or man-made event that has negatively impacted the quality of human life somewhere on the planet. Pondering novel approaches and solutions to these challenges has been a major impetus to the development of Flextegrity technology. The examples in this chapter illustrate my vision and optimism.

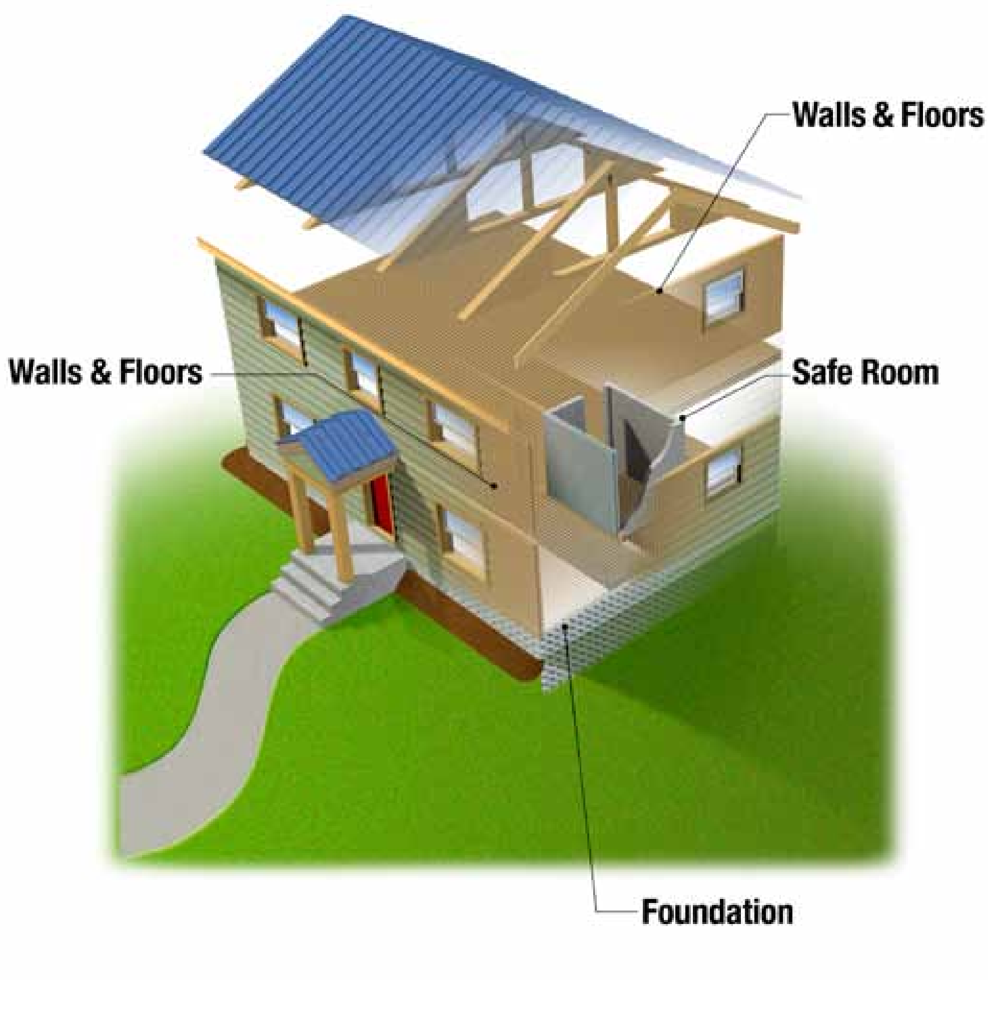


FIGURE 5.3
A conventional structure made from disaster-resistant materials

PROBLEM: LACK OF DISASTER-RESISTANT STRUCTURES

The changing global climate brings more frequent, severe, and disastrous weather events that overwhelm conventionally built structures. Present day housing construction is driven by a short-term cost mentality and traditional uses of materials. A building is only as strong as its weakest connection such as the point where rafters join walls and exterior walls intersect, making the structures prone to damage from earthquake and wind damage. We continue to rely on the same materials and designs in hurricane-prone areas even though existing methods often fail to meet the overwhelming stress/force demands on structures. Yet building codes and property insurers' regulations are becoming more rigorous as I write. It is imperative to re-think our designs and use of materials to anticipate catastrophic events and be resilient in extreme conditions.

Flextegrity Solution: Comprehensive custom-engineered applications leveraging the unique and robust properties of Flextegrity materials. The diverse design potential of Flextegrity materials could allow for retrofitting and new construction of disaster-resistant structures without sacrificing traditional architecture's look and feel. In new construction, the structure is designed as a 'whole' where the rafters and walls are of the same integral construction to create unprecedented resilience against novel external forces. Tough, continuous web-like assemblies for retrofitting existing foundations and walls could be factory-built to custom sizes and exact specifications.

SEISMIC ENERGY MITIGATION MECHANISMS

The macro-architecture of Flextegrity's material holds promise in decoupling a building's structure from the shaking ground and reducing earthquake-related damage through several mechanisms:

- Controlled and reversible ductile properties could allow the material to absorb some of the kinetic energy of the seismic event.
- The ability to enable small, prescribed amounts of six-degrees-of-freedom motion has potential to reduce the magnitude of structure uplift and the velocity of the subsequent impact.
- In response to ground motion, the material might be 'tuned' to allow carefully controlled rocking, which in turn reduces the tendency of a structure's mass to overturn.
- Properly placed 'pads' could provide some isolation between adjacent structures that may vary in height and resonant period, thus reducing the tendency of the structures to non-harmonically strike each other.
- When used as a ground-stabilizing layer, Flextegrity's material could help mitigate damage due to liquefaction and failure of water-saturated sand and/or mud. A single, fully-integrated layer could simultaneously stabilize non-conforming soil, increase load-bearing capabilities, and reduce entrance of water run-off from uphill sources. To further prevent unwanted soil saturation, the material's regular open architecture would enable insertion of horizontal perforated pipe into the lattice enabling lateral dispersion or channeling into secondary mitigation facilities.

In environments where moist, poorly consolidated alluvial soil directly overlays firmer materials, there is risk that 'waves' from seismic events can be further amplified. A layer of an anisotropically designed material has the potential to separate these disparate soil layers, improve drainage of the alluvial layer, absorb kinetic energy, and mitigate resonant frequencies.

FIGURE 5.4
Seismically stable office tower

Flextegrity brings new solutions for stormwater infiltration, slope protection, load support, earth retention, channel preservation, vegetative protection, and concrete strength enhancement. The ability to selectively control ductility and elasticity within a single block of the material also introduces opportunities to creatively solve problems related to dimensional changes due to seasonal weather patterns.

The material's strong but permeable internal matrix provides a natural filter for storm runoff by providing infiltration and the opportunity to trap sediments/pollutants on-site, in contrast to hard armor methods which allow little or no water infiltration and/or pollutant removal.

ADVANTAGES

Flextegrity's technology brings these important advantages to stormwater and other civil engineering projects:

- High strength-to-density ratio for ease of handling, transportation, and superior function
- Omni-axial permeability for vertical and lateral drainage
- Customizable flexibility/stiffness gradients in three dimensions
- Pre-fabrication potential maximizes onsite installation efficiency
- Easily constructed in limited right-of-ways with less weight, lower environmental impact and reduced need for heavy equipment
- Aggregate infill is not required to achieve high resistance to compressive forces
- Multi-axial tensile 'web' creates superior resistance to shear forces
- Optimal frictional interaction with surrounding surfaces and infill materials
- Easily inventoried and handled
- Installation in any temperature or weather conditions
- Installations may be permanent or reusable/transportable
- No leachates
- Predictable, engineered material behavior

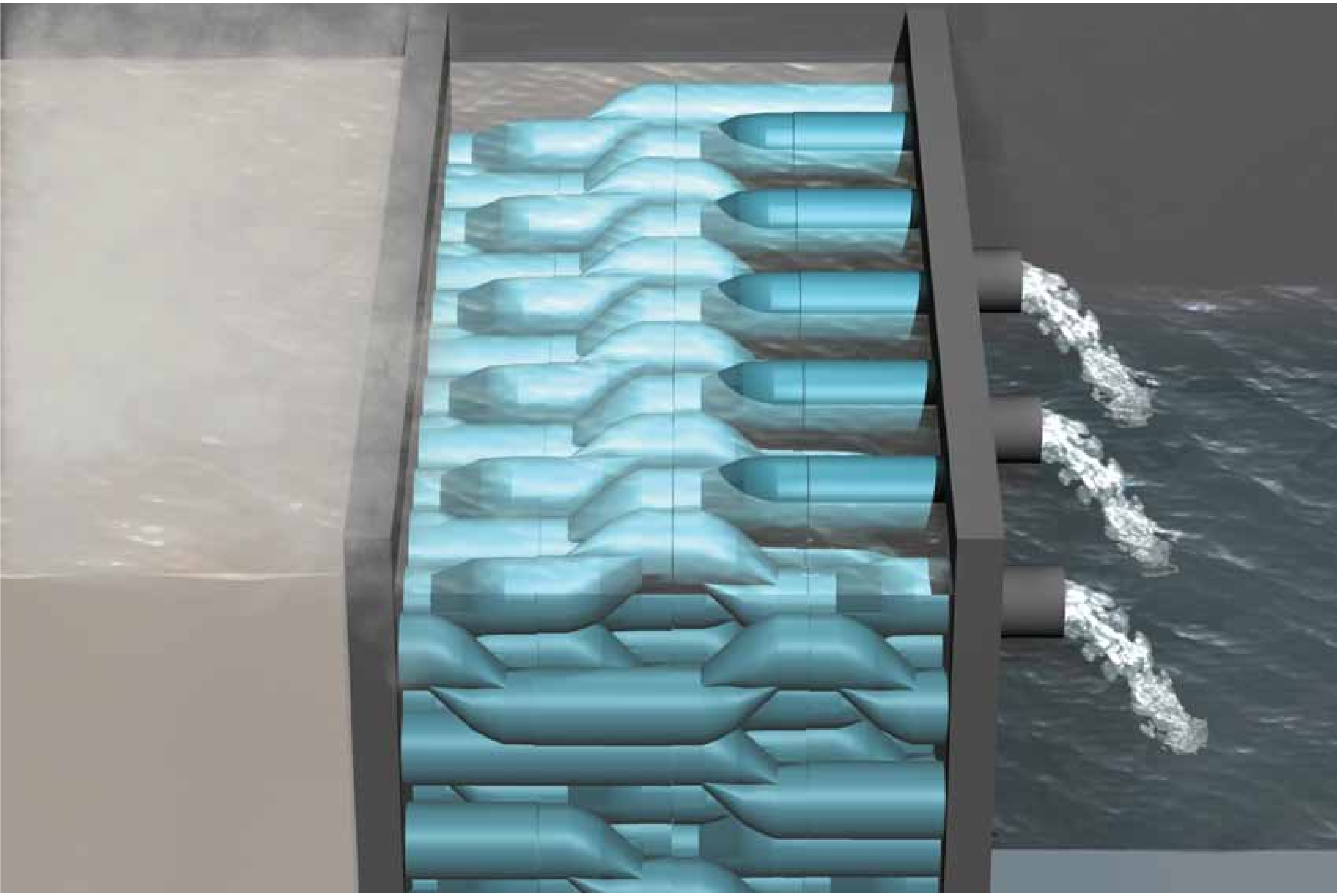
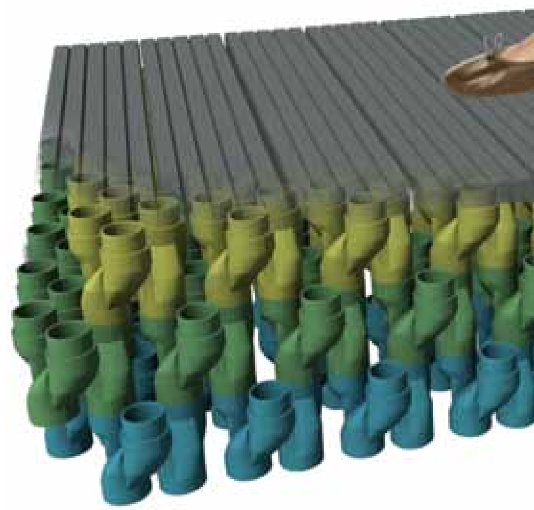


FIGURE 5.5
Heat exchange/filtration system for wastewater

PROBLEM: IMPERMEABLE, HARD-TO-REPAIR STREETS, SIDEWALKS AND PATHS

As described previously, conventional highways, streets and sidewalks are non-porous, aggravating runoff and its negative environmental effects. Paved surfaces present additional problems, as the material lacks any resilience and breaks under the pressure of a tree root. Successful repair is impossible—we are forced to jackhammer the problem, haul off the debris, and start over. Rather than being responsive to 21st century transportation demands and opportunities, most road-building and hardscaping paradigms have not evolved for decades.



Flextegrity solution: Intelligent, functional, longer-lasting streetscapes and paths. It becomes possible to create underlayment for roads, sidewalks and other hardscape that is strong, resistant to damage by temperature extremes, and porous for drainage of stormwater and natural percolation of petroleum-based pollutants. These next-generation transportation surfaces can be constructed using strong materials that offer the benefits of permeability and ease of maintenance. 'Uni-body' manufacture of panels and rolled goods can be custom-sized and produced to specifications off-site, then rapidly installed.

FIGURE 5.6

FIGURE 5.7

Using this technology, further ability is gained to incorporate functional and 'intelligent' elements such as conductivity, lighting, sensors and other microelectronics directly into the intrinsic material structure, enabling a single integrated layer of pre-assembled material to efficiently perform a variety of unique, responsive and useful functions.

In the home and garden market, strong, porous 3-D scrims can replace heavy, expensive, time-consuming methods of creating durable self-draining underlayment for hardscape (pavers/bricks) or natural materials (gravel/wood chips). It can function as a matrix to stabilize loose materials especially on sloped surfaces. It is ideal for light, strong, weather-proof, easily installed fencing material, and can be covered with composite 'tiles' or a tough continuous 'skin' to achieve additional aesthetic and performance effects.

ENVIRONMENTAL BENEFITS

Flextegrity materials combine the strength of traditional hardscaping methods with unprecedented permeability for low environmental impact and high environmental benefit:

- High permeability: decreases surface runoff of stormwater discharged from paved areas; reduces buildup of hydraulic pressure behind retaining walls; keeps soils permeable and minimizes compaction; reduces need for storm water ponds; increases groundwater recharge
- Improves stormwater quality by increasing water infiltration and reducing non-point source pollution
- Minimizes site disruption and development footprint by reducing or eliminating need for larger, onsite stormwater detention facilities
- Avoids the environmental destruction associated with mining of aggregates or the carbon and financial costs of hauling large volumes of heavy aggregates over long distances
- Open architecture provides a cooler surface that reduces heat island effect related to traditional hardscaping and pavements
- Improved aesthetics: supports a sustainable vegetated surface or other attractive infill material
- Recycled content when manufactured from recycled HDPE
- Potential for reusability of assembled panels, mats, bridges

PROBLEM: INFLEXIBLE, HEAVY, NON-INTEGRATED BUILDING MATERIALS

Age-old materials such as brick, steel, and wood don't truly integrate with each other. They are abutted, bolted and otherwise coerced to coexist. Their inherent design forces us to build most structures using 90-degree angles. But we only need to spend more time outside to observe that biological systems (the most supremely efficient in the structure and use of raw materials) do not use Cartesian coordinates to grow and sustain life.

Traditional building methods also complicate and slow the process. In the development of ships, airplanes, and cars, modular manufacturing practices have resulted in higher quality and enhanced features, while at the same time reducing costs and fabrication times. Yet this innovation is rarely practiced in architecture and civil engineering.

Flextegrity Solution: Flextegrity's technology truly represents a new paradigm in building materials and 21st century production strategies. It creates the opportunity for the first flexible, permeable, structural material in the marketplace. The geometry mimics natural structural efficiencies and can be integrated to form limitless iterations for exterior and interior constructions, architectural motifs, landscaping, and fencing. As a relatively lightweight, easy-to-assemble material, it will be equally appealing to the contractor and the home handyman.

Systems-built housing becomes a possibility as this technology enables 'custom-knitting' of lighter, stronger, safer, more portable structures in a controlled factory setting. Designs are also highly customizable for function and aesthetics.

FIGURES 5.8-5.11
Floret modular townhouse

FIGURES 5.12-5.15
Disaster-resistant Floret beach condominiums

OTHER PRIME APPLICATIONS IN SEARCH OF FLEXTEGRITY'S 'NEW MATERIALS' SOLUTIONS:

BIO-MATERIALS AND OTHER MEDICAL APPLICATIONS:

Components for artificial body materials that need to emulate the strength of bone, flexibility of muscles and connective tissue, and physio-electronic conductivity of nerves. Florets mimic alveoli in the lungs.

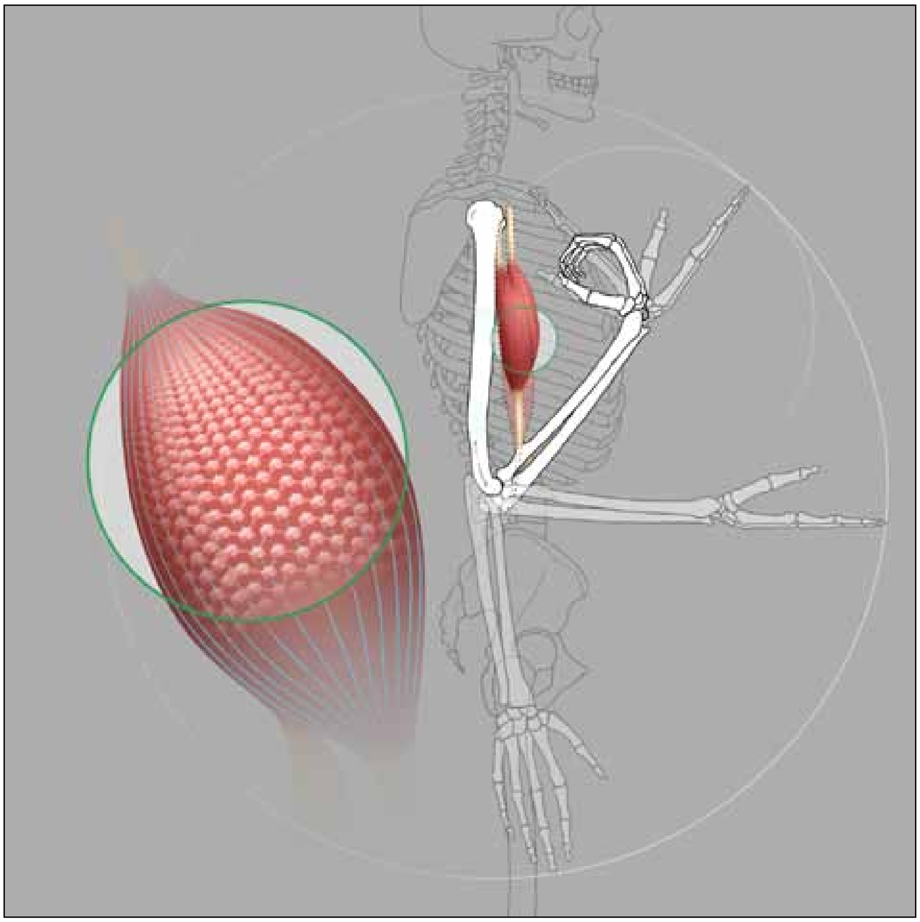


FIGURE 5.16
The ordered, continuous array gives the ability to incorporate functional elements such as conductivity, circuitry and sensors into to single integrated body of strong, flexible, responsive material.

NANO-SCALE MATERIALS

Potential for extremely thin/strong 3-D membranes, self-assembling at molecular scale by leveraging electro-chemical and other bonds.

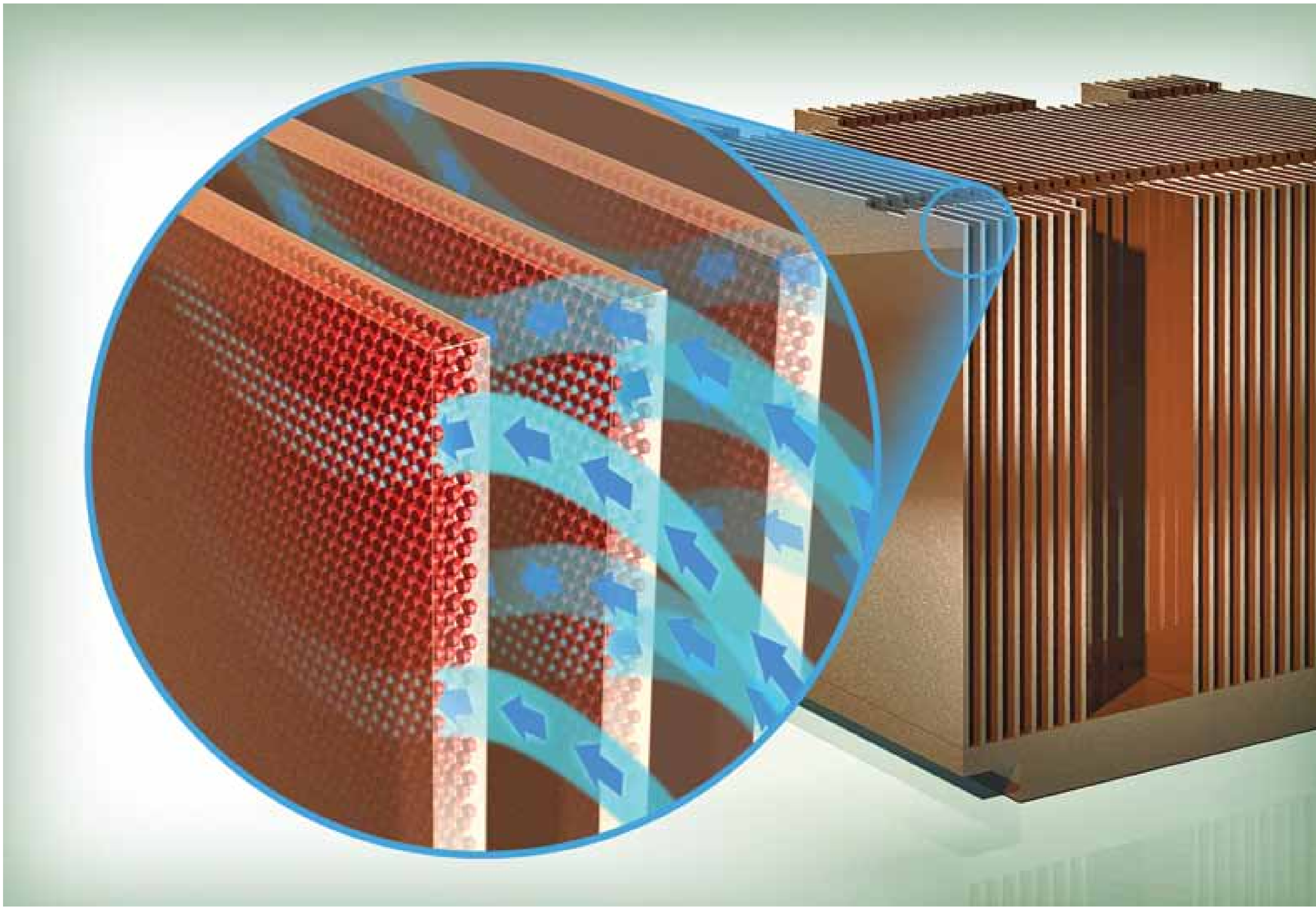


FIGURE 5.17
Heat sinks can be improved due to highly enhanced surface area and intra-material aerodynamics provided by highly customizable 3-D micro-architectures.

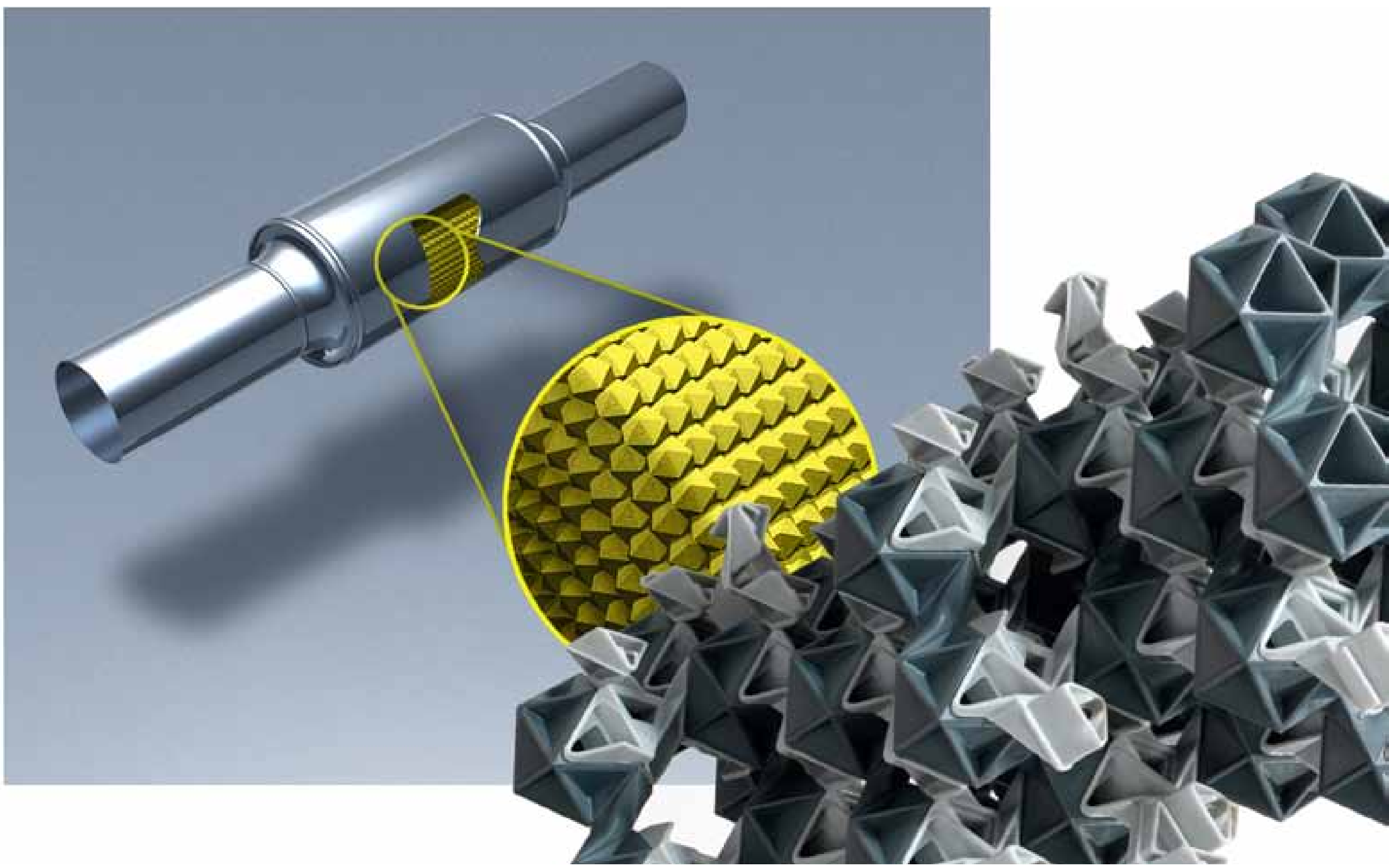


FIGURE 5.18
Catalytic converters gain enhanced surface area for reactive catalysts, coupled with enhanced permeability for improved airflow.

AVIATION | MARINE | MILITARY APPLICATIONS

High potential strength-to-weight ratio, flexibility, structural integrity that accompanies the geometry is ideally adaptable to use of state-of-the-art light and strong composite materials.

FIGURE 5.19
Lightweight vehicle armor and flexible personal ballistic protection

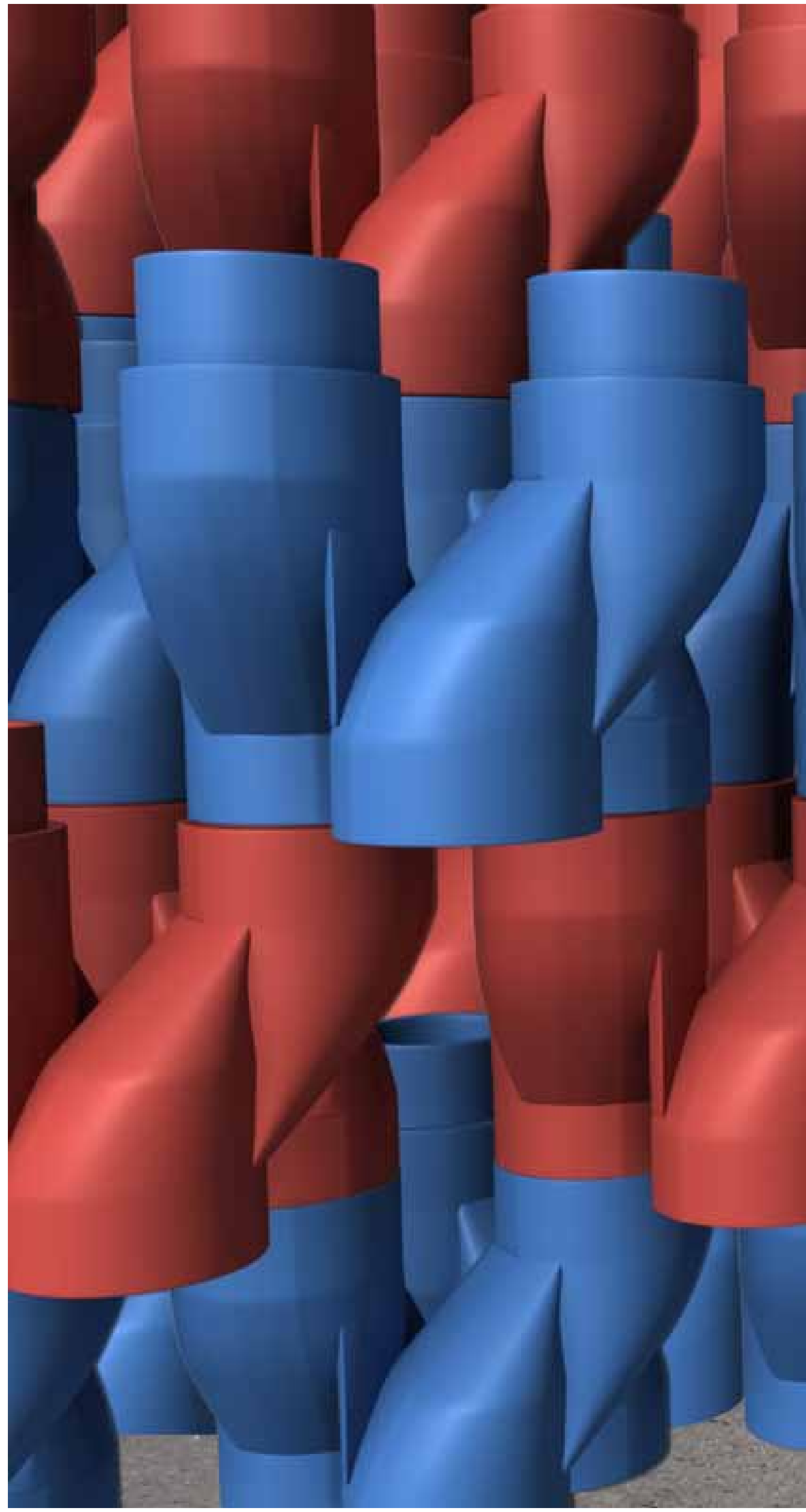
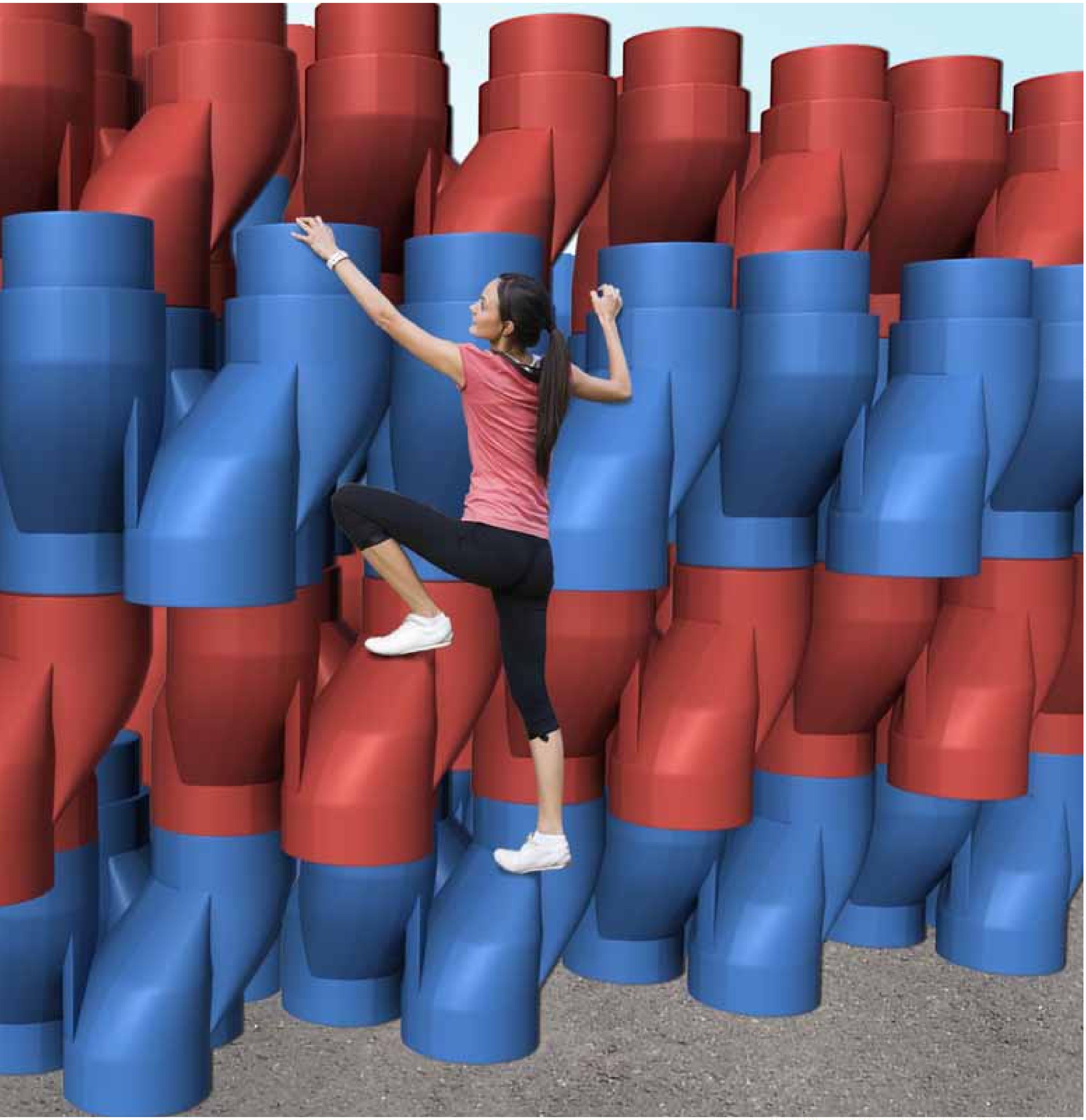


FIGURE 5.20

Florets can be made from virtually any material. Their unique interconnecting modularity makes them ideal for civil engineering applications. The array can be scaled for play structures, sea walls or roadbed substrates.



ART | DECOR

Ability for amateur and professional artisans to create unique, personalized geometrical constructions that might include conductive connectors, transparent/translucent icosahedron components, LED/ fiber-optic elements for use as a lighting device, and programmable dynamic ‘performance.’

FIGURE 5.21

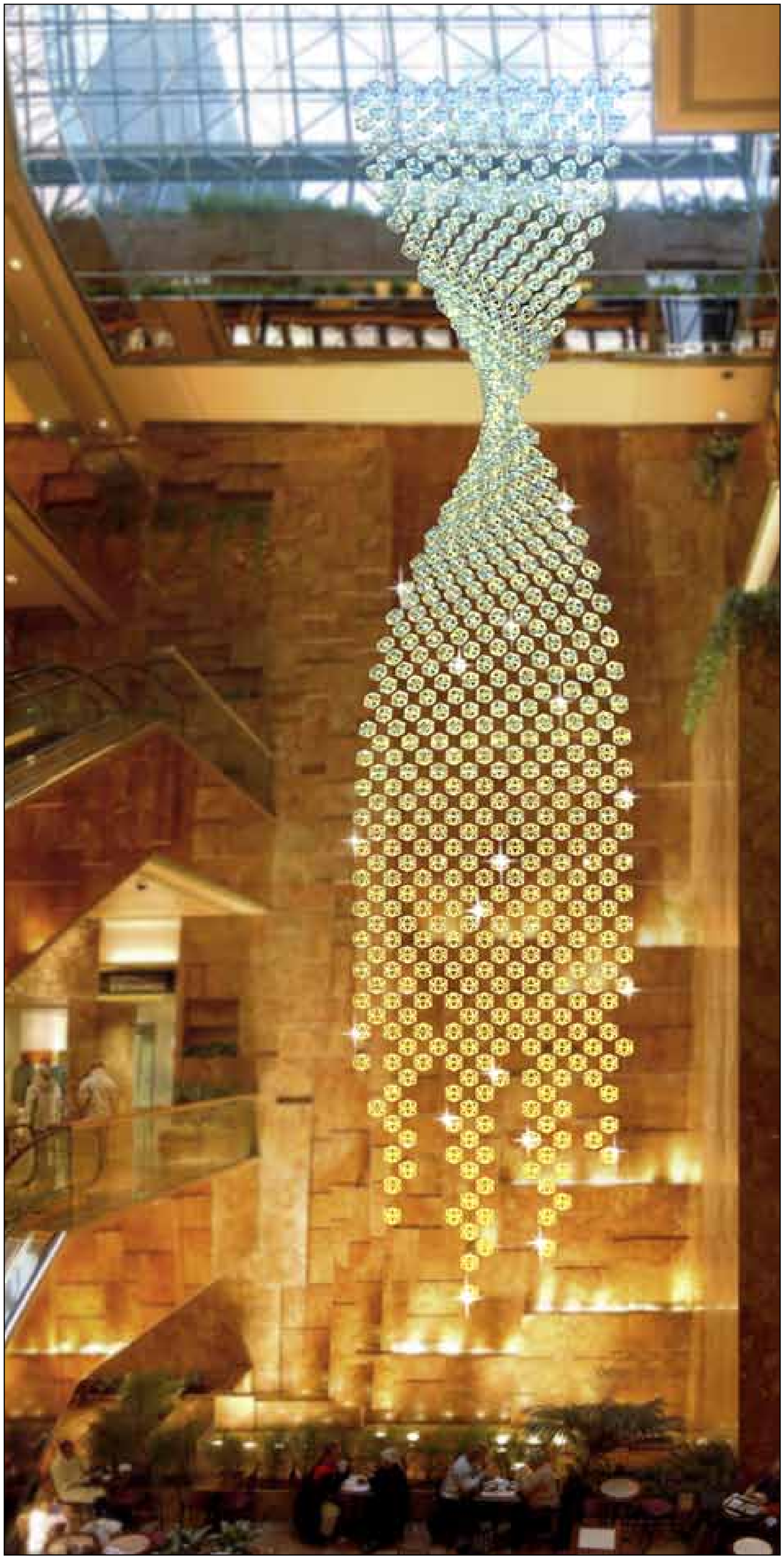
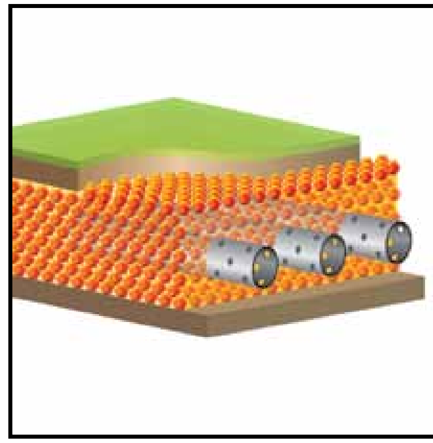


FIGURE 5.22
Lighting feature in hotel atrium

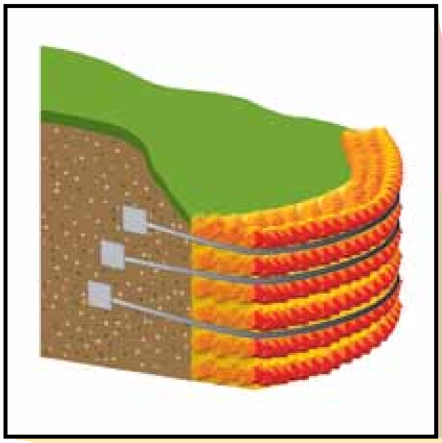
FIGURE 5.23

Flextegrity arrays can provide underlayment and/or replacement for roads, sidewalks and other hardscape that is strong, resilient to damage by temperature extremes, and porous for drainage of storm run-off and natural percolation of petroleum-based pollutants. The ability is gained to incorporate functional elements such as conductivity, lighting, and sensors directly into the intrinsic material structure so that a single integrated layer of pre-assembled material can efficiently perform multiple useful functions.

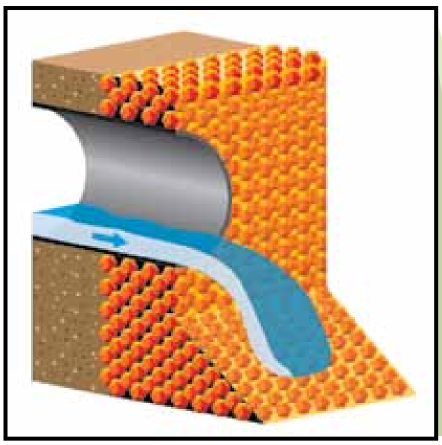

Tasty Treats
101
Styles
Ice Cream



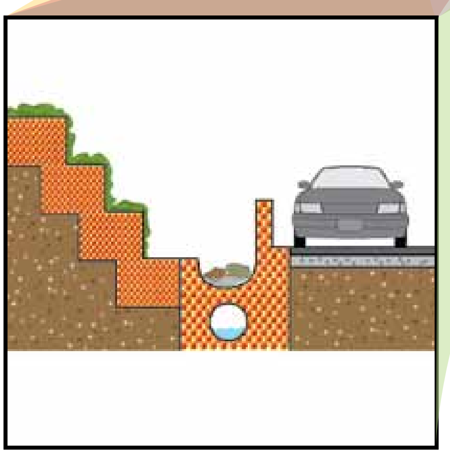
STRUCTURAL LATTICES, GROUND STABILIZATION & LOAD SUPPORT



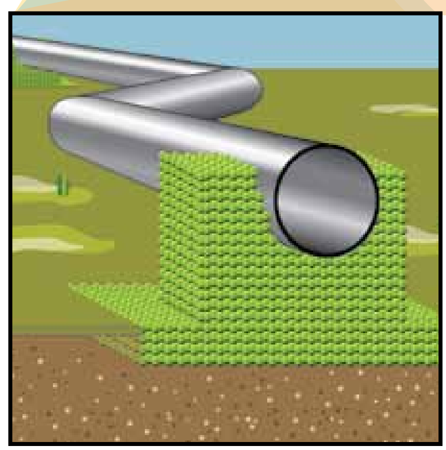
EARTH RETENTION & SLOPE PROTECTION



SLOPE PROTECTION & EROSION CONTROL

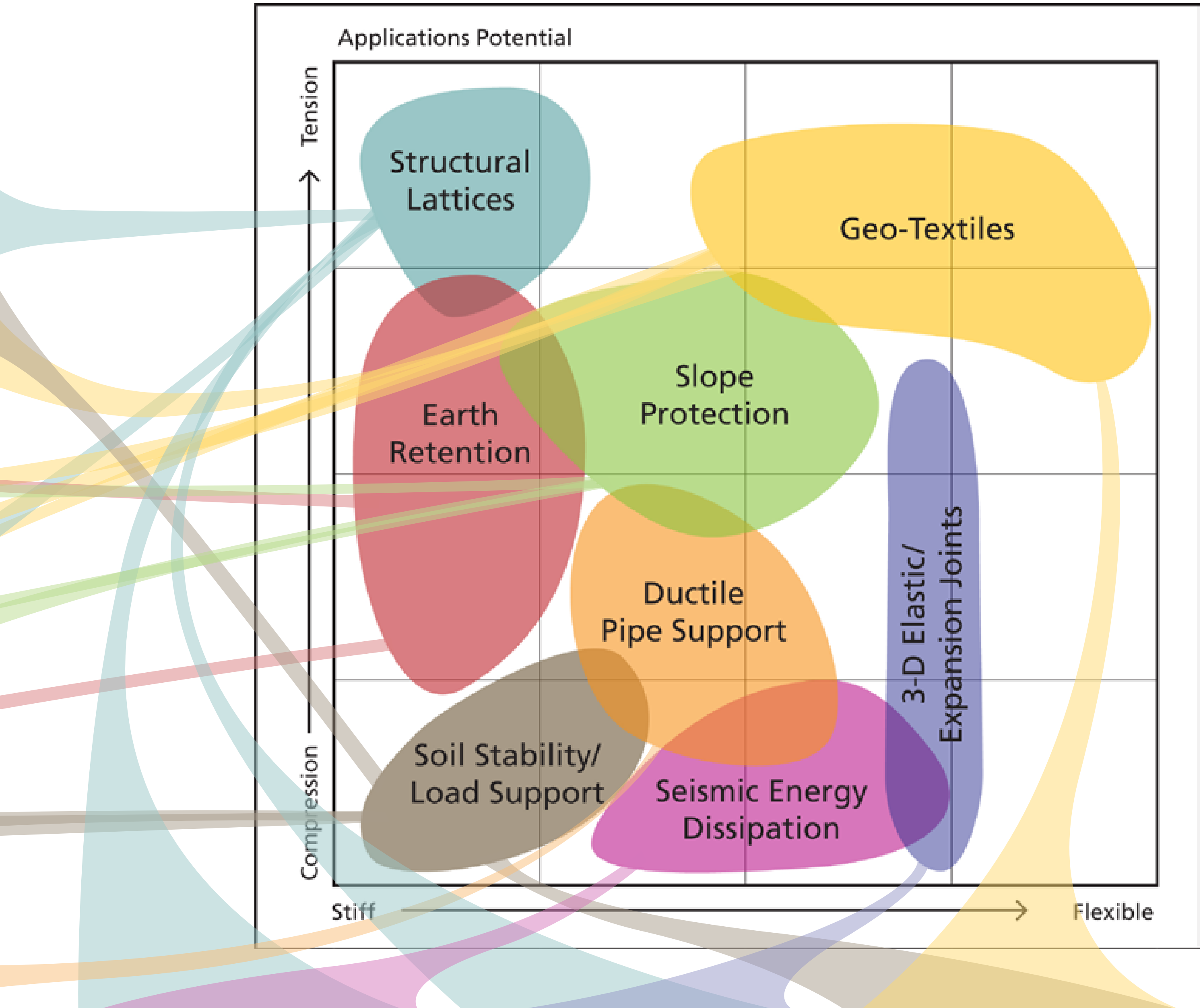


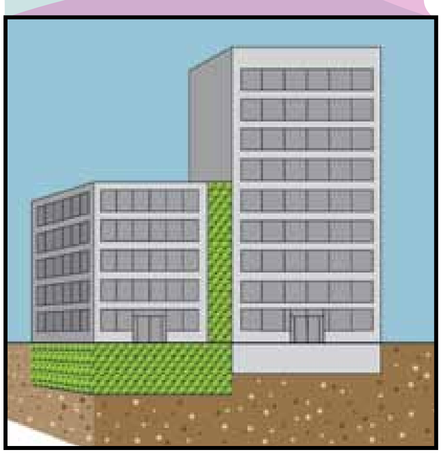
SLOPE PROTECTION & EROSION CONTROL



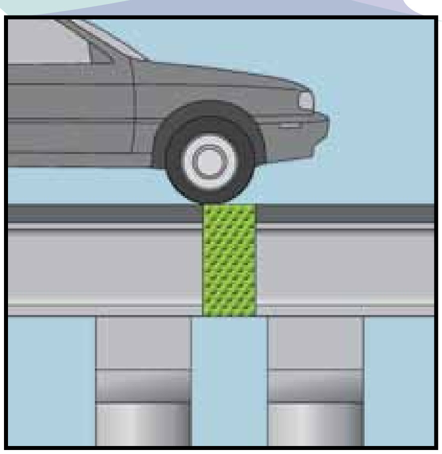
DUCTILE PIPE SUPPORT

FIGURE 5.24

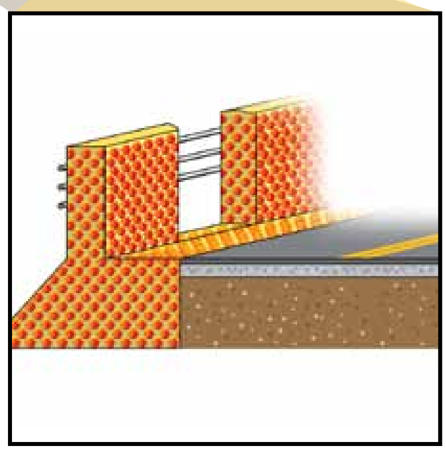




SEISMIC ENERGY DISSIPATION



3-D ELASTIC EXPANSION JOINTS



GEO TEXTILES

3-D ELASTIC | EXPANSION JOINTS

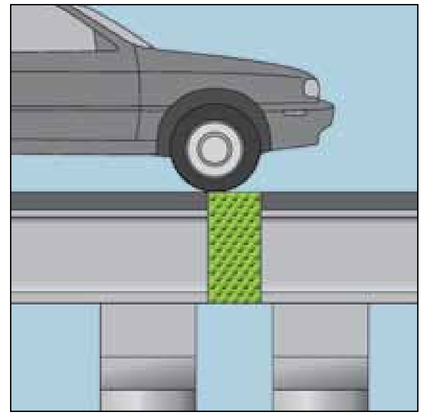


FIGURE 5.25

Because of their ability to selectively control ductility and elasticity within a single block of the material, Flextegrity's advanced polyhedral materials lend themselves for use in strong, flexible, self-draining joints/connectors for 'thick' dimensional surfaces/elements that need to bend or be held in continuous tension. When engineered into bridges and other structures, these materials have the capacity to bear substantial stress loads, yet absorb fluctuating pressures and seasonal temperature-related dimensional changes without damage. Dimensional changes in multiple axes can be accommodated by the closely controlled elastic properties of the structural lattice architecture.

PROBLEM: ENVIRONMENTALLY DAMAGING CIVIL ENGINEERING PRACTICES

Environmental damage from erosion and water run-off is increasing as we pave our cities and suburbs. Simultaneously, water quality is decreasing as current water control methods channel run-off directly into streams and rivers. The more we pave, the less opportunity for water to percolate through the soil before reaching the aquifers and rivers that provide clean water for our cities. Sidewalks, as a familiar example, are relatively easy to apply but the material is impermeable, contributing to polluted run-off into our waterways. Municipalities and contractors face an increasingly high bar of EPA-mandated stormwater control regulations, and are searching for versatile and effective solutions.

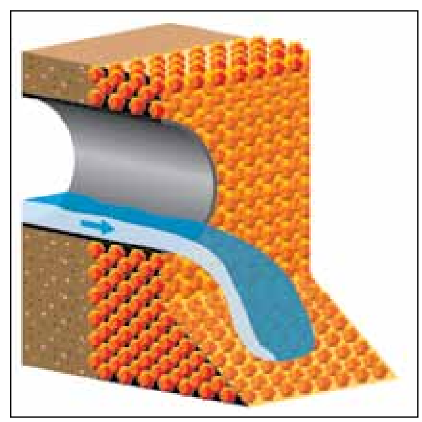


FIGURE 5.26

Flextegrity Solution: Meet demand for EPA-required soil stabilization and stormwater control products that balance strength and durability needs with environmental requirements. Flextegrity can produce structural 3-D 'geotextiles' that are load-bearing yet permeable, allowing for the controlled drainage of stormwater and natural percolation/de-activation of petroleum-based pollutants. The assembled array can prescriptively flex under stress, and the component parts are easily dissembled and reassembled for maintenance. Designers will gain the ability to create natural forms that begin to look and behave more like the natural landscapes they replace.

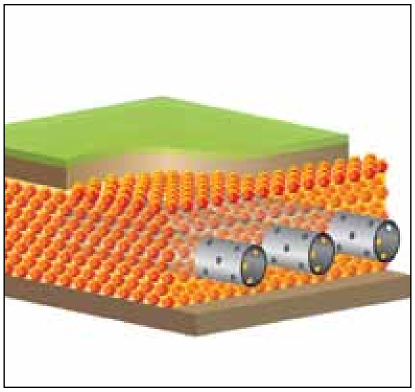


FIGURE 5.27

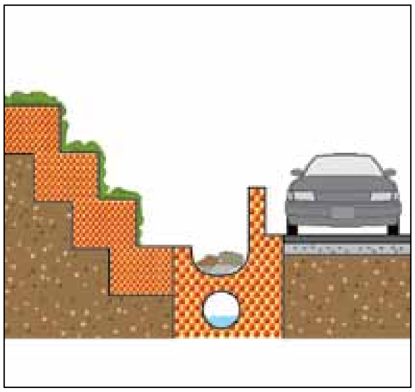


FIGURE 5.28

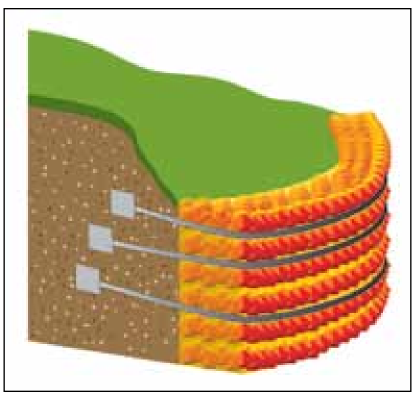


FIGURE 5.29

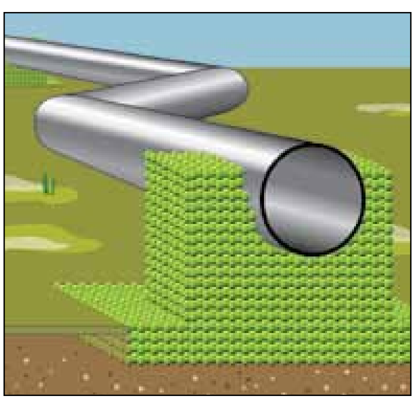


FIGURE 5.30

GROUND STABILIZATION | LOAD SUPPORT SYSTEMS

Flextegrity's internal architecture and multi-axial tensile 'web' prevents shear failure and limits lateral movement of aggregate infill without compromising permeability. It provides superior load distribution over weak soils, distributing loads laterally and reducing contact pressure on poor quality, unstable subgrades.

SLOPE PROTECTION | EROSION CONTROL

Flextegrity materials are ideal for protecting channels exposed to severe erosive conditions while maintaining natural permeability. When strategically integrated with conventional protection materials such as concrete, aggregate, rip-rap and vegetation, the intrinsic tensile network improves their performance under hydraulic stress. In areas of low to moderate intermittent flows such as ditches and swales, the system's open architecture allows roots to grow in all directions throughout the matrix for greater vegetative lock-up and stability against short-term flow events. Auxiliary cabling/tendons may be incorporated to provide additional stability against gravitational and hydrodynamic forces. The 3-D geometry enables embedding of functional elements such as plant seeds, fertilizer, water-storing gels, and weed suppressors.

EARTH RETENTION SYSTEMS

The material's structural properties are excellent for steep front-face vertical applications such as highway embankments, especially in challenging sites where subgrades are comprised of unstable soils and right-of-ways are limited. Enhanced design flexibility and aesthetics are possible because of the porosity and potential for a completely vegetated face.

BIO-SENSITIVE PIPE SUPPORT

Flextegrity's material architecture presents the opportunity to design dynamic, resilient load support systems. Weight can be distributed over a larger area without impeding drainage in challenging environments such as permafrost, wetlands and sand. The permeable icosahedral material would allow gradual infiltration with native vegetation.

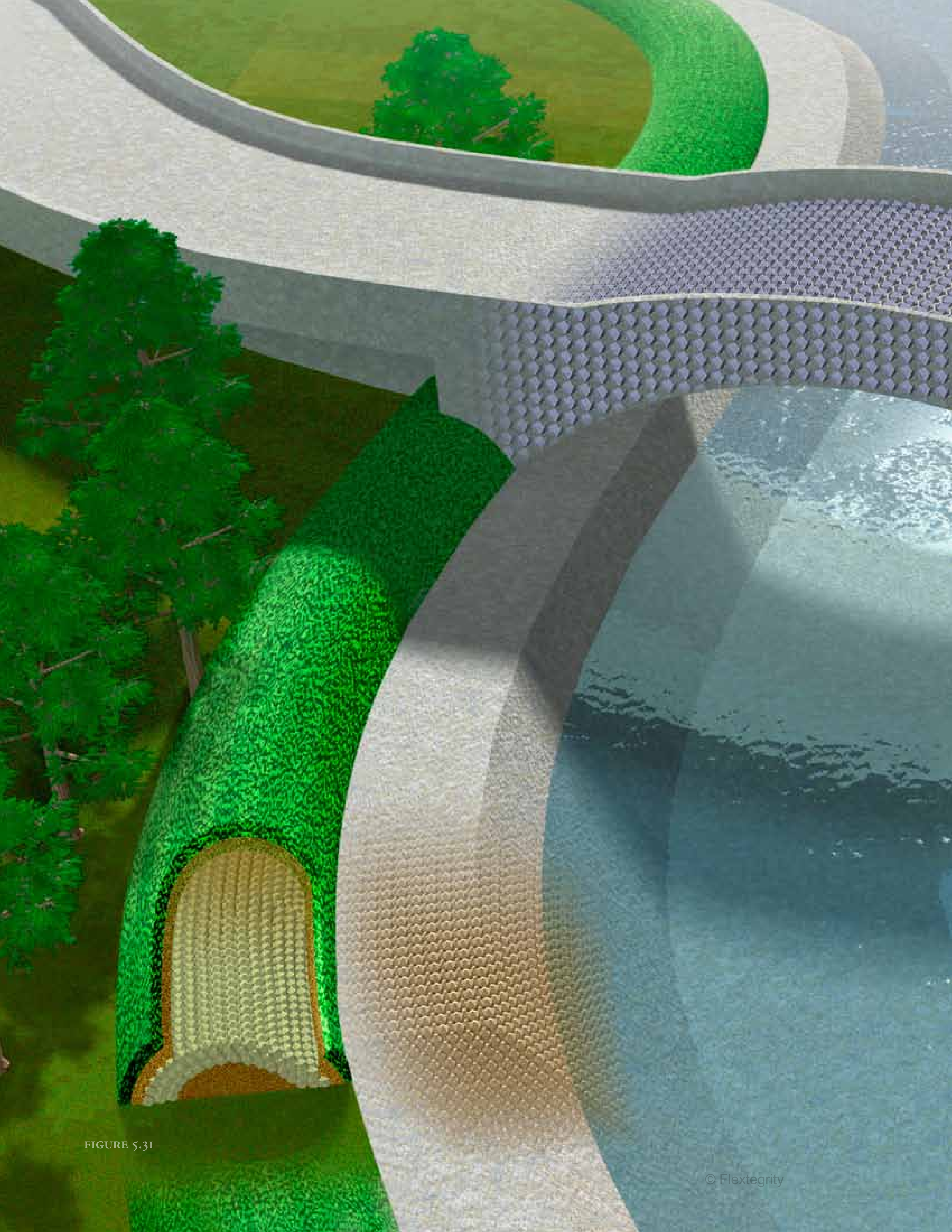
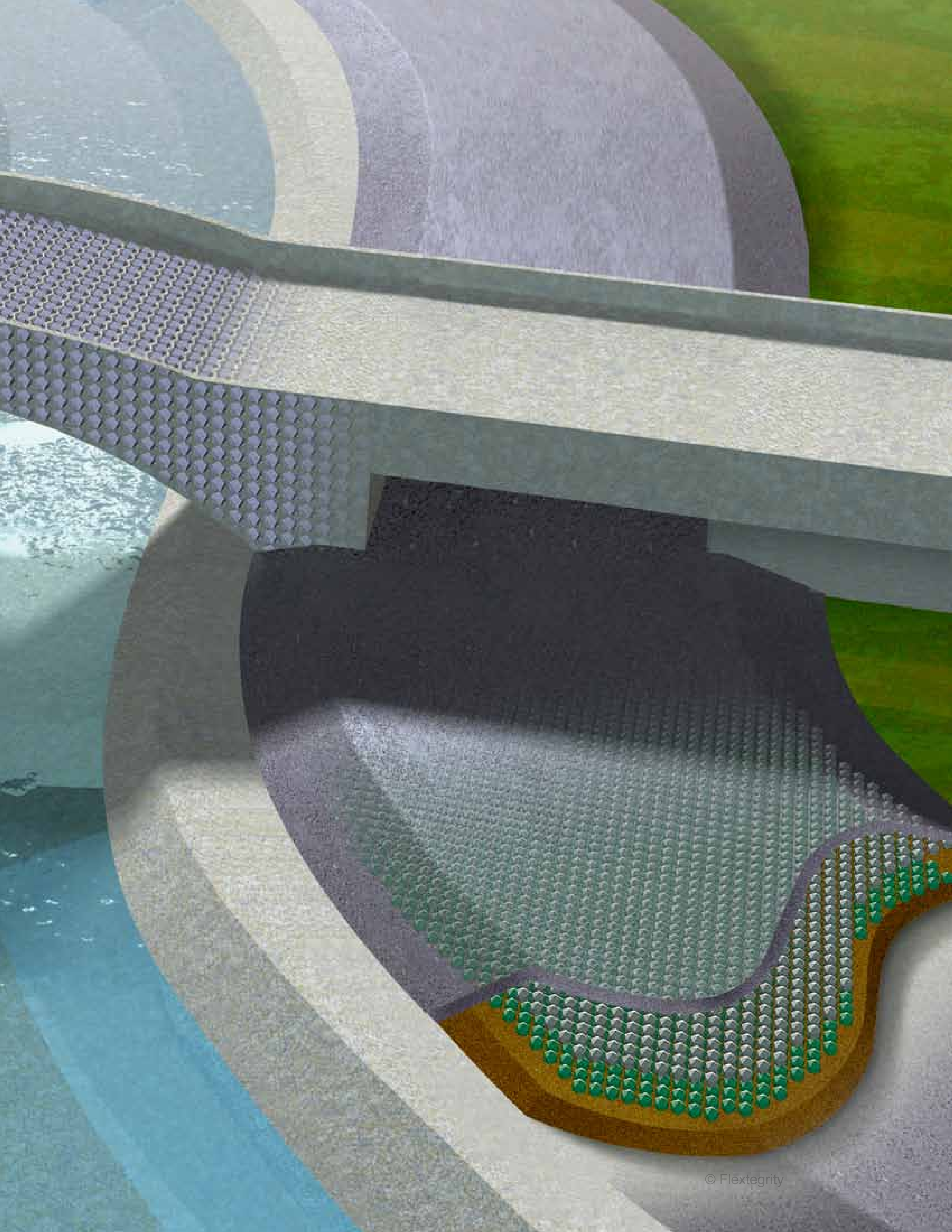


FIGURE 5.31


© Flextegrity

Credits

EDITOR
LaJean Lawson

CONTRIBUTING EDITOR
Kirby Urner

BOOK DESIGN
Jason West, Designwest

ILLUSTRATIONS
Bill Giobbi: 2.17, 2.18, 2.19, 2.20, 2.23, 2.24, 2.25, 2.27, 5.4, 5.5, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15, 5.20

Aaron Jarrett: 4.1 (modular housing), 5.1

George Laird: 2.12

Dan Mandish: 5.2, 5.3, 5.16, 5.17, 5.18, 5.19, 5.22, 5.23, 5.31

Jeff Miller: 2.13, 2.33, 2.34, 2.35, 2.36, 2.37, 3.6, 3.7, 3.8

Kirby Urner: F.7, 3.2

Jason West: 2.3, 2.4, 2.8, 2.15, 2.16, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.22, 4.23, 5.24, 5.25, 5.26, 5.27, 5.28, 5.29, 5.30

PHOTOGRAPHY
Sam Lanahan: Introduction photo of R. Buckminster Fuller, F.1, F.2, F.3, F.4, F.5, F.6, F.8, F.9, F.10, 3.1, 3.4, 3.9, 3.11, 3.15, 3.19, 3.20, 3.21, 3.22, 3.23, 3.24, 3.25, 3.26, 3.31, 3.33, 3.37, 3.38, 3.39, 3.40, 3.41, 4.18, 4.19, 4.20, 4.21

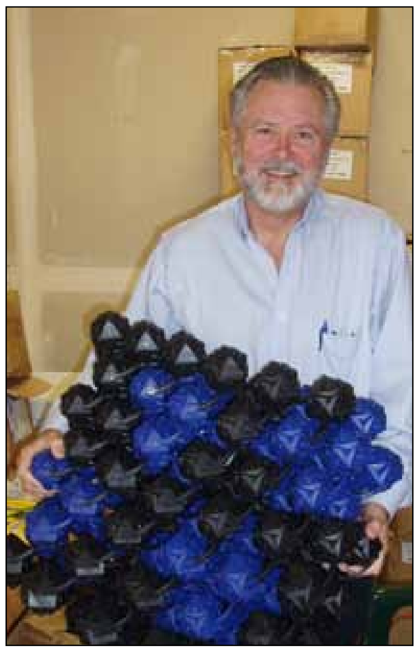
Polara Studio: 3.5, 3.10, 3.12, 3.16, 3.17, 3.18, 3.34, 3.35, 3.36, 3.42, 3.43, 3.44, 3.45, 3.46, 3.48, 3.49, 3.50, 3.51, 3.52, 3.53, 3.54, 3.55, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 5.6, 5.21

Kirby Urner: Back inside cover

MODEL BUILDERS
Altman-Browning Engineering: 3.5

Sam Lanahan: 3.9, 3.10, 3.11, 3.12, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.24, 3.26, 3.31, 3.33, 3.34, 3.41, 3.43, 3.45, 3.50, 3.51, 3.52, 3.53, 3.54, 3.55, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 5.6, 5.21

Glen Stockton: 3.35, 3.36, 3.42, 3.44, 3.46, 3.48, 3.49


The author holding a radial array.