

# MATERIALS COLLECTION PRIMER

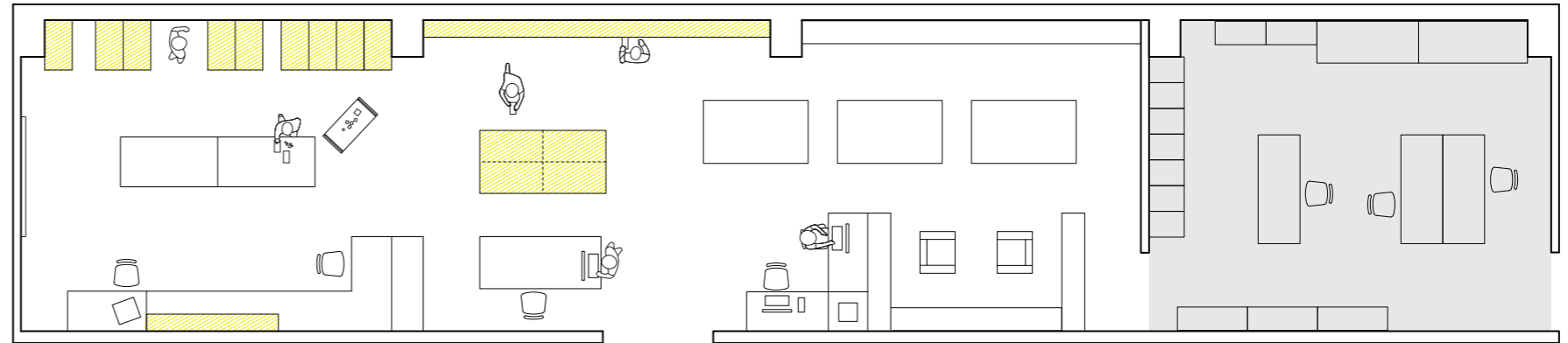
## INTRODUCTION

Generative relationships between the experiments and concerns of contemporary design practice and innovations in materials science and engineering are driving the development of radically new material forms, properties, and processes. New demands for thermal, mechanical, and aesthetic performance, closed-loop cycling, resource and energy efficiency, and equitable production relations influence material industries and become conceptual drivers of contemporary work. These factors radically alter design and construction processes, as well as exert impacts from nanoscopic to global scales.

This primer is an introduction for students investigating material topics in design and describes the organizational structure of the Materials Collection at the Harvard University Graduate School of Design (GSD). Basic material terms and definitions provide a point of departure for students seeking more advanced resources. The GSD Materials Collection taxonomy was developed by drawing terminology from sources of design, materials science, and the construction industry. This taxonomy provided the organizational structure to the primer contents – Composition, Form, Properties, and Processes.

## TABLE OF CONTENTS

<b>GSD MATERIALS COLLECTION</b>	<b>2</b>
<b>COMPOSITION</b>	<b>3</b>
Each of the 5 compositional families – Biocomposites, Polymers, Metals, Minerals, and Ceramics – are summarized. General examples of types, processing, terminology, and materials in use are also provided.	
<b>FORM</b>	<b>14</b>
Materials are classified into three broad categories – planar, linear and volumetric – which are then further defined by types and subtypes.	
<b>PROPERTIES</b>	<b>15</b>
Mostly derived from the material sciences, properties speak to the abilities of each material to be fitted to the mechanical, hygro-thermal, electrical, optical, acoustical, and durability task asked of it.	
<b>PROCESSES</b>	<b>17</b>
Processes classifies the manufacturing methods used to make the material. Processes can deform the original substance, be additive, or subtractive. They include: casting, molding, machining, deforming, surfacing, joining, and rapid prototyping.	
<b>CREDITS</b>	<b>19</b>



## MATERIALS RESEARCH

The Frances Loeb Design Library provides several resources to support research of materials – the Materials Collection’s online database, which provides access to the on-site collection, the Materials Collection Primer, written as an introduction for students investigating materials topics in design, a subscription to Materials ConneXion, a Materials Collection Research Guide with several non-library material resources, and books focused on materials for research and practice – GSD faculty material research, material catalogs, materials specific to architectural innovations, exploration of materials in architecture and landscape architecture, and fabrication and manufacturing of materials for architecture and landscape.

**Search** the Materials Collection by using the online catalog (<http://materials.gsd.harvard.edu/materials>)  
*Harvard University ID required*

**Learn** more about materials at Harvard and beyond with our Research Guide (<http://guides.library.harvard.edu/gsd/materials>)

**Visit**  
Frances Loeb Library, Special Collections, lower level, L12

## ABOUT

The Harvard Graduate School of Design’s Materials Collection emerged in 2004 as a manifestation of the School’s evolving engagement in materials. It is a collection of material samples ranging from innovative new materials to those found everyday in the built environment. The collection is one for designers, different than those for material scientists, yet it is not a typical material sample library found at a design firm that is organized by project use or application. The Materials Collection places emphasis on material composition and functional traits of the material samples, encouraging users to rethink conventional applications and promote material experimentation in design practice. These leading concepts are realized in the physical arrangement of the collection and data entry points of the online catalog.

The GSD Materials Collection is a collection of objects which visitors are encouraged to handle and study. The Materials Collection has been developed according to faculty and student research agendas, and has been focused in these areas:

### Material Ecology

Materials that demonstrate the externalities and impacts of material production and use both within and outside of designed installation.

### Fabrication Materials

Materials that can be used in the GSD Fabrication Lab, as well as alternatives to those currently in use.

### Bio-based Materials

Materials derived from plant and animal based renewable resources and surplus stocks.

### Recycled Materials

Materials made from recycled material stocks including polymers, metals, and ceramics.

### Urban Scale Materials

Materials implemented and affecting climatic, aesthetic, and hydrological conditions at an urban scale – particularly ones contributing to or mediating urban heat, such as roofing, surfacing, infrastructural.

### Materials in Use

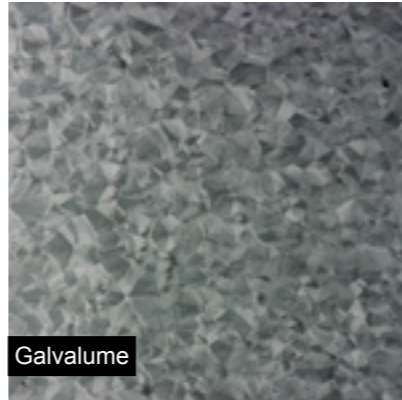
Materials used in contemporary design projects.



Green Wall



Aramid Fiber Honeycomb Cores



Galvalume



Dichroic Glass



Hydroton Clay Pebbles

**BIOCOMPOSITES** A

Biologically derived composites of polymers and fibers that contain mostly organic and sometimes inorganic compounds sourced from living organisms and/or formed by biochemical processes

**PLANT** A1

Derived from or produced by organisms associated with the biological kingdom Plantae

**ANIMAL** A2

Derived from or produced by organisms associated with the biological kingdom Animalia

**FUNGI** A3

Derived from or produced by organisms associated with the biological kingdom Fungi

**POLYMERS** B

Petroleum-derived, human-made, non-renewable materials comprised of long, repeating, molecular chains whose central atom is almost always carbon

**THERMOPLASTIC** B1

Synthetic or semi-synthetic, organic polymers, whose polymer chains are linear and not cross-linked

**THERMOSET** B2

Synthetic or semi-synthetic, organic polymers, whose polymer chains have been irreversibly, densely cross-linked

**ELASTOMER** B3

Synthetic or semi-synthetic, organic polymers, whose polymer chains are networked and loosely cross-linked

**METALS** C

Pure metallic elements, compounds, and alloys characterized by metallic bonds whose atoms readily lose electrons to form positive ions (cations)

**FERROUS** C1

Ferrous pure metals and alloys, metals based on iron

**NON-FERROUS** C2

Non-Ferrous pure metals and alloys, metals with little or no iron content

**MINERALS** D

Inorganic, crystalline solids, and chemical compounds possessing a characteristic crystalline structure and chemical composition, sometimes with restricted variations

**GEOGENIC** D1

Inorganic, crystalline solids and chemical compounds formed by geological processes

**ANTHROPOGENIC** D2

Inorganic, crystalline solids and chemical compounds manufactured by humans

**CERAMICS** E

Nonmetallic, inorganic solids formed by the ionic bonding of mineral material through human based processes of mixing and/or heating

**CLAY-BASED** E1

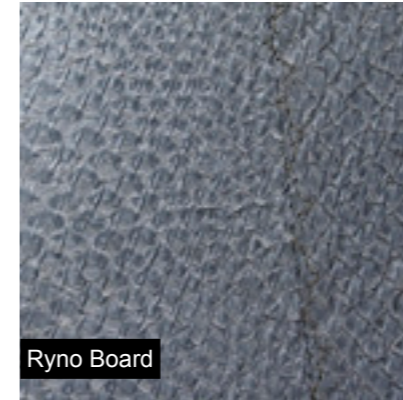
Inorganic, crystalline composites made of fired clay, typically aluminosilicate and kaolinite, resembling glass in brittleness

**CEMENTITIOUS** E2

Inorganic, crystalline composites made of a combination of lime, alumina, and water

**GLASS** E3

Inorganic, non-crystalline solids that are silica-based



**BIOCOMPOSITES** A

*Biologically derived composites of polymers and fibers that contain mostly organic and sometimes inorganic compounds sourced from living organisms and/or formed by biochemical processes*

**PLANT** A1

*Derived from or produced by organisms associated with the biological kingdom Plantae*

**PHYSICAL ATTRIBUTES**

The combination of cellulose, a crystalline polymer, and hemicelluloses, an amorphous polymer, make wood strong in tension. Lignin, another organic polymer, provides resistance to compression and makes wood an excellent fuel.

**TYPES**

**Wood** is the cellular tissue of the tree inside the cambium and is composed of 40-50% cellulose, 20-30% hemicellulose, and 20-30% lignin. Lignin makes timber strong in compression and tension. Wood and wood products are often graded based on the quality of the feedstock. The common tree name usually differs from the commercial name for the lumber, listed here. The commercial name for a lumber can include several botanical species. Softwoods refer to woods derived from coniferous/evergreen trees (gymnosperms). They are mostly softer and easier to work than hardwoods. They include: spruce, pine, fir, and cedar. Hardwoods refer to woods derived from deciduous/broad leaf trees (angiosperms). They

are mostly harder in density than softwoods. Domestic hardwoods include: maple, beech, oak, poplar/aspens, and birch. Hardwoods, grown in tropical regions are typically valued for their rot-resistance, and lustrous colors. They may have irregular grain or hard mineral deposits that effect machining, and a few are endangered. They include: teak, mahogany, ipe, wenge, ebony, and rosewood. **Leaves and stalk:** flax, ramie (China grass), hemp, jute, piña (pineapple leaves), bamboo fiber/bamboo viscose, abaca (Manila hemp), henequen, istle, paper (wood pulp and cotton rag), cardboard, raffia, sisal (agave leaf), kenaf, bagasse (byproduct of sugarcane and sorghum production), rattan, thatch (reed), wicker (rattan, reed, rush), wheat, straw, coconut timber, carnuba wax (palm leaves), papyrus, vegetable/natural tannin. **Bark:** cork, bark. **Sap, pitch, or latex:** natural rubber, plant-derived resins, rosin, amber, pine tar, turpentine. **Seeds, nuts, fruit or drupe:** kapok (seed pod), seeds, cotton (seed fiber), coir (coconut husk), bayberry wax, linseed oil (flax seeds), linoleum, guar gum. **Cellulose:** cellulose acetate, cellulose triacetate, viscose, rayon, modal, lyocell, tall oil/talol. **Other:** bioplastics (PLA, PHB, PA11) (starch-based and corn-based), vegetable dyes can come from the root, berries, bark, wood, or leaves of a plant

**PROCESSING**

Debarked, chipped, plainsawn, quartersawn, rough sawn, flat sawn, rift sawn, sanded, burned, kiln dried, air dried, dip coated, impregnation

(fungicidal, insecticidal, dampproofing, fire-proofing), retification, lamination, rotary cut (veneers), slicing (veneers), pulped, digested, Kraft process, coated, whitened, pressed, foamed, printed

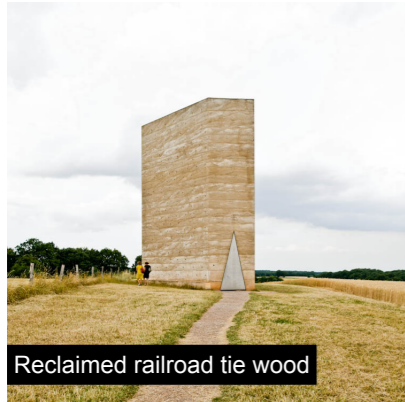
**APPLICATIONS**

Panel products, structural timber beam, coasters, instruments, packaging, utensils, tool handles, furniture, cladding, flooring, chop, dimensional lumber, structural timber, glue laminated timber (glulam), plywood, structural veneer lumber, blockboard, oriented strand board (OSB), Particleboard, fiberboard, insulating boards, plasterboard, cement fiberboard, structures, facades, furniture, insulating materials, sheathing paper, rope, geotextiles, flooring, filters, carpet, mattresses, wall coverings, fiber, textiles, cellophane, bioplastics, finishes, mulch, paper, furniture, roofing, surfaces, natural dyes

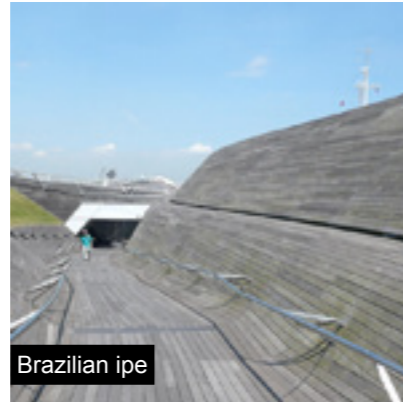
**TERMINOLOGY**

**Timber** is wood in standing trees with the potential for lumber. **Lumber** is sawn or processed wood that has been sawn to specified dimensions and dried. **Veneer** refers to a thin layer of wood produced by slicing solid stock along the grain of the wood. **Manufactured wood products:** Glued structural members have an assembly of layers of wood glued under pressure. However, unlike plywood, the layers are thick and the product is usually only used for weight-bearing members. Examples are: glue laminated timbers (Glulam), structural composite

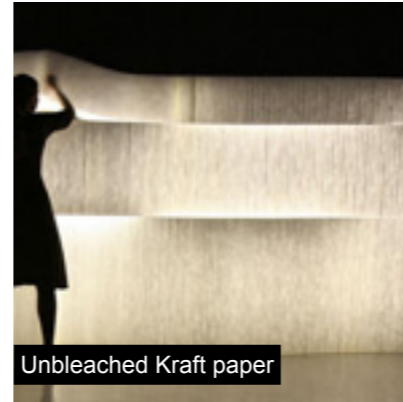
lumber (SCL), laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), and oriented strand lumber (OSL). Engineered wood includes glued structural members as well as finger-jointed lumber and I-Joists. Plywood is assembled of at least three veneer layers laid cross grain and glued together under pressure. Construction and industrial plywood is usually made from domestic softwood. Hardwood and decorative plywood is made from hardwoods. Composite panels extend or modify natural wood sizes or properties. Particleboard is assembled from particles of waste wood with an adhesive, cement, or gypsum binder. Waferboard and oriented strand board (OSB) are made from green roundwood. Fiber-based panels such as hardboard, medium density fiberboard (MDF) and insulation board are assembled from small wood fibers with binders in a dry process or without in a wet process. **Heartwood** is from the central core of a mature tree and is typically both stronger and darker in color than sapwood. **Sapwood** is from the outer growth rings on a tree and is usually lighter in color than heartwood. **Greenwood** is freshly cut, unseasoned (undried) wood. **Grain** is often used to describe a fine or coarse grain in reference to the annual rings but can also mean the direction of fibers on sawn lumber—spiral grain, straight grain or curly grain. **Figure** is any distinctive appearance on a wood surface resulting from structure, irregular coloration, or abnormality. Knots in wood are the expression of where a tree limb grew from the trunk. These are often



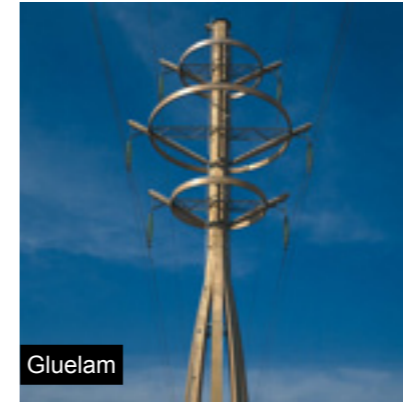
Reclaimed railroad tie wood



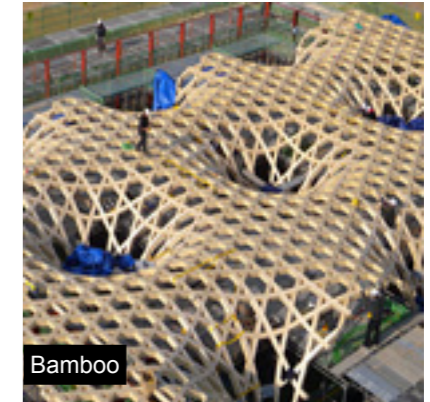
Brazilian ipe



Unbleached Kraft paper



Gluelam



Bamboo

harder than the surrounding wood and affect the mechanical properties of the wood. Wood free of knots is called “clear.” The homogeneity of clear, straight-grained wood makes it the easiest wood to work.

**ANIMAL** A2

*Derived from or produced by organisms associated with the biological kingdom Animalia*

TYPES

**Hair:** wool, cashmere (cashmere goats), pashmina (changthangi goat), mohair (angora goat), angora (rabbit hair), camel hair, alpaca (llama), horsehair, cow hair, human hair, yak fiber, guanaco fiber, chiengora (dog hair), possum fiber, qiviut (wool of the musk ox), vicuña wool. **Skin, tissue:** sinew (tendon), leather, hide, rawhide, catgut, parchment, vellum, sheepskin, pelt, fur, alligator, crocodile, snake, fish, cow intestine **Biom mineralization:** opal, egg shells, bone, horn/ivory, seashells, pearl, hooves. **Other:** fertilizer/guano, sea sponges, byssus fiber/sea, spider silk, beeswax, milk casein, natural dyes

PROCESSING

Salted, cured, brined, dried, tanned, soaked, dehairing-lime treatment, defleshed, delimed, plumped, split, shaved, setting out, nourishing, beat, staked, sleeked, ironed, plated, embossed, dyed, glued, sewn, shaped, calendered, spun, reeled, thrown, gimped, texturized, woven,

knit, felted, hexagonal stitch, bonding, flared, bleached, treated

APPLICATIONS

Plaster additives, upholstery, paper, soil amendments, insulation, textiles, surface coverings, rope/cord, wax, natural dyes

**FUNGI** A3

*Derived from or produced by organisms associated with the biological kingdom Fungi*

TYPES

**Saprophytic** (a fungus that lives on dead organic matter), **mycorrhizal** (fungi that form a symbiotic relationship with a tree or other plant), **endophytic/parasitic** (a fungi that lives on another living species, deriving its sustenance to the detriment of its host).

APPLICATIONS

Packaging, insulation, mycoremediation, pest control, natural dyes

TERMINOLOGY

**Mycelium/ mycelia** is a fungal network of threadlike cells. “Myceliated” describes the condition where the mycelium has colonized or infused through a substrate. **Mycology** is the study of fungi. **Hyphae** are individual fungal cells. A **substrate** such as straw, sawdust, compost, soil or other organic matter on which mushroom mycelium will grow.

MATERIALS IN USE

**Railroad tie wood, reclaimed**

Biblioteca Municipal de Azkoitia  
Azkoitia, Basque Country, 2006  
Estudio Beldarrain

**Brazilian Ipe hardwood**

Yokohama Ferry Terminal  
Yokohama, Japan, 2002  
Foreign Office Architects

**Unbleached kraft paper or tissue paper**

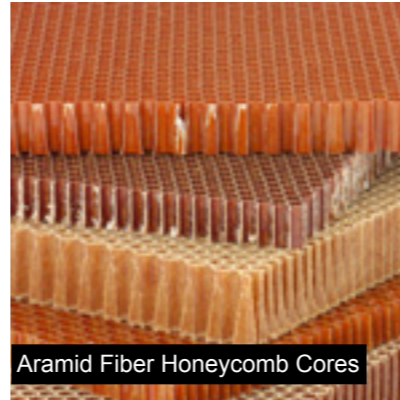
Softwall  
Molo Design

**Gluelam Scotch Pine**

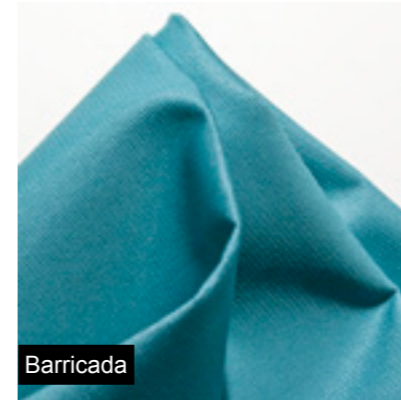
Corolle: high tension electricity pylon  
France, 1994  
Martin Szekely

**Bamboo**

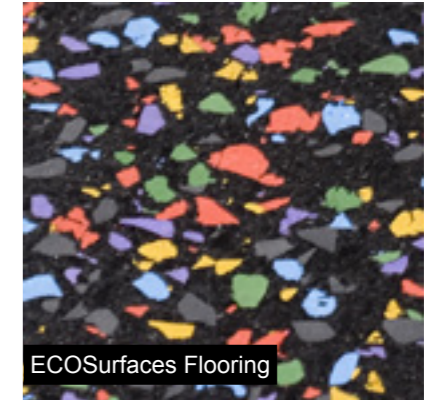
Haesley Nine Bridges Golf Clubhouse  
Yeoju, South Korea, 2010  
Shigeru Ban



Aramid Fiber Honeycomb Cores



Barricada



ECOSurfaces Flooring

## POLYMERS B

*Petroleum-derived, human-made, non-renewable materials comprised of long, repeating, molecular chains whose central atom is almost always carbon*

## PHYSICAL ATTRIBUTES

The chainlike molecules of synthesized polymers form both amorphous and crystalline arrays that allow easy formation into complex shapes, low in heat conductance, and low softening temperatures.

## PROCESSING

Injection molding, sandwich injection molding, extrusion, calendaring, compression molding, casting, foaming, direct digital manufacturing, pultrusion, blow molding, rotational molding, thermoforming, gas-injection molding

## APPLICATIONS

Adhesives, carpets, gaskets and weatherstripping, laminates, coatings, pneumatic structures, roofing materials, vapor barriers and waterproofing, waste piping and venting, water supply piping, fibers in fiber reinforced concrete, pipework and fittings, drainage systems, underground services, window and door frames, cladding, tensile membrane structures, bathtubs, sinks, glazing, decorative laminates, seals, sheet liners (water features and landfill sites), flooring

## TERMINOLOGY

**Fillers** are added to improve the workability, weight, and volume expansion characteristics of a material in order to reduce the material

costs of the plastic. Can include kaolin, chalk, glass beads and talc. **Reinforcement materials** are used to improve the mechanical properties of plastics with fibers and textiles. **Stabilizers** are additives used to retard the degeneration of polymers caused by heat or photo-oxidation. **Fire-retardants** inhibit or prevent combustion in plastics. They are added during polymerization. **Foaming agents** are additives that cause plastics to foam and produce a lighter weight and more insulative product. **Coupling agents** are used to facilitate the mixing of polymers or polymers and other materials that are incompatible. **Colorants** are insoluble pigments or soluble dyes used to color the plastic. **Polymerization** is the process of joining ethylene end to end to produce the long chain macromolecules. **Plasticizers** are incorporated into plastics to increase their flexibility. The addition of the plasticizer separates the molecular chains, decreasing their mutual attraction. **Commodity plastics** (versus engineering plastics) are commonly used in low physical properties and are commonly used in the production of everyday low-cost products. Includes vinyls, polyolefins, and styrenes. **Engineering plastics** (versus commodity plastics) have superior physical, chemical, and thermal characteristics and are used in demanding environments. They include acetals, acrylics, polyamides, and polycarbonates. **Resins** are prepared by polymerization and used with fillers, stabilizers and other components to form plastics.

## THERMOPLASTIC B1

*Synthetic or semi-synthetic, organic polymers, whose polymer chains are linear and not cross-linked* • pliable or moldable when heated, returns to solid state when cool, can be remolded

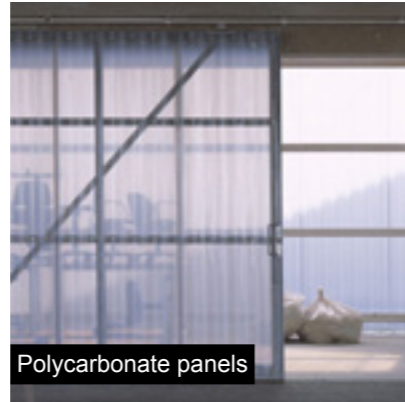
## TYPES

**Polyolefins** make up half of total global polymer production. It is low cost and non-toxic. Examples of materials in use include milk jugs, plastic corks, thin walled plastic packaging, toys, cups. • Polyethylene (PE), High Density Polyethylene (HDPE/PE-HD), Trade name: Tyvek, Low Density Polyethylene (LDPE/ PE-LD), Polypropylene (PP), Expanded Polypropylene (EPP), Ethylene Vinyl Acetate (EVA/EVAC), Lonomer resin **Styrenes** are easy to process and are low cost. They are categorized as general purpose (GPPS)—used for disposable food packaging, CD cases, and lighting diffusers—expanded (EPS)—used for electronics packaging foam, helmets, and thermal insulation—and high impact (HIPS)—used for product housing and toys. Trade name(s): EPS, Styrofoam. • Polystyrene (PS), Acrylonitrile Butadiene Styrene (ABS), Styrene acrylonitrile (SAN), Styrene butadiene styrene (SBS), Styrene ethylene butylene styrene (SEBS) **Vinyls** have a glossy appearance and are low cost. Half of the global production of vinyl is for the construction industry. They contain chlorine and dioxins that have been shown to be toxic. Examples of materials in

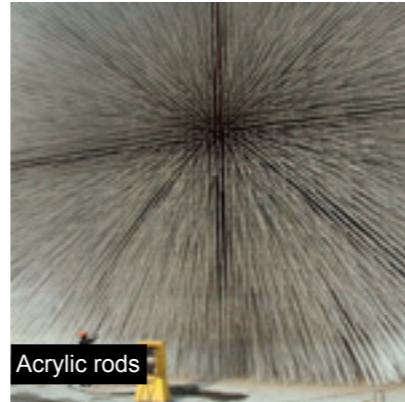
use include records, extruded window frames, doorframes, guttering, credit cards, medical tubing, as a coating for upholstery and wallpaper, and electrically insulating products. • Polyvinyl chloride (PVC), Polyvinyl alcohol (PVOH), Polyvinyl butyral (PVB) **Acrylics** are used for applications where clarity, impact resistance and gloss are needed. They have a moderate cost and displays edge glow. Examples of materials in use include Corian counters, sheets for laser cutting, and control panels. • Polymethyl methacrylate (PMMA, Acrylic Glass), Polyacrilate (Acrylic) **Polycarbonate** is the toughest clear plastic but is prone to chemical and UV degradation. It is of moderate cost. Examples of materials in use include water bottles, spectacle lenses, police riot shields, beakers and CDs and DVDs. • Polycarbonate (PC), Trade name: Lexan **Thermoplastic Polyesters** have a high dimensional stability and are resistant to chemicals. Examples of materials in use include drink bottles, films for glass or plastic, light bulb housing, and mobile phone parts. • Polyethylene terephthalate (Trevira, PET, PETG, PETE), Polybutylene Terephthalate (PBT), Polycyclohexylene dimethylene terephthalate (PCT), Liquid crystal polymer (LCP), Thermoplastic polyester elastomer (TPC-ET) **Polyamides** are commonly known as nylon and are used in a wide range of applications. Examples of materials in use include bearings, electrical equipment housing, sports equipment, textiles, and rapid prototyping. • Polyamide (PA), Nylons, Aromatic polyamides. Trade name:



Nylon fabric



Polycarbonate panels



Acrylic rods



PET



GRP, ETFE

Kevlar **Fluoropolymers** are well suited to extreme environments. • Polytetrafluoroethylene (PTFE), Trade name: Teflon, Ethylene tetrafluoroethylene (ETFE), Fluorinated ethylene propylene (FEP) **Thermoplastic Rubber Compounds** combine the performance of rubber with the processing advantages of thermoplastics. Examples of materials in use include keypads, sportswear, and hot water tubing. • Melt-processed rubber (MPR), Thermoplastic vulcanizate (ETPV) **Other Thermoplastics** Acrylonitrile Styrene Acrylate (ASA), Trade name(s): Luran S, Bitumin, Polyimide (PI), Polyacrylonitrile (PAN), Polyvinyl acetate (PVA/PVAC), Paraffin, Thermoplastic polyurethane (TPU, PU), Acetal/ Polyoxymethylene/polyacetal resin (POM) (acetal family)

**THERMOSET** B2

*Synthetic or semi-synthetic, organic polymers, whose polymer chains have been irreversibly, densely cross-linked* • irreversibly cures, cure induced by heat, chemical, or suitable irradiation

TYPES

**Formaldehyde condensation resins** have a hard and glossy finish and operate across a wide temperature range. Examples of materials in use include electrical housing, tableware, adhesives for laminating plywood, and billiard balls. • Phenol formaldehyde resin (PF), Trade name: Bakelite, Urea formaldehyde

(UF), Melamine-formaldehyde/ melamine-formaldehyde resin (MF) (melamine), Phenolics: phenol-formaldehyde resins. Phenolic resin, Melamine phenol formaldehyde resin (MPF) **Polyesters and composites** Polyester fiber (taffeta), Polyester resin **Vinyl esters and composites** are popular for laminating materials. • Vinyl ester **Epoxyes and composites** are applied as coatings and adhesives. Applications include laminating, casting and structural adhesives. • Polyepoxide resin (EP) (Epoxy resin) **Polyurethanes** are versatile and used as a solid cast material, foam, adhesive and liquid coating. Examples of materials in use include spray foam, upholstery and mattress foam, sports equipment, Lycra, Spandex, and as a bonding agent for wood. • Polyurethane/polyurethane resin (PUR) **Other Thermosets** Unsaturated polyester (UP), Aramid phenolic Glycol, Glass-reinforced plastics (GRP) (fiberglass), Polyimides, Renewable polyethylene Copolyesters

**ELASTOMER** B3

*Synthetic or semi-synthetic, organic polymers, whose polymer chains are networked and loosely cross-linked* • polymer with viscoelasticity, colloquially "elasticity"

TYPES

**Silicones (SI)** are low strength but versatile. They are used as adhesives, gels, rubbers, and rigid plastics. They have electrical resistance and

high heat stability. Examples of materials in use include weatherstripping, medical equipment, lubricant, and kitchenware. • Silicone, Silicone resins **Synthetic Rubbers** are used in place of natural rubbers and have shape memory. Examples of material in use include gaskets, seals, and wetsuits. • Isoprene rubber (IR), Synthetic version of natural rubber (Cured rubber, Vulcanized rubber), Chloroprene rubber (CR), Trade name: Neoprene, Ethylene propylene rubbers (EPM and EPDM), most widely used elastomer in construction, Trade names: Nordel, Buna, Dutral, Keltan, Vistalon, Butyl rubber (IIR), Butadiene rubber (BR), Acrylonitrile butadiene rubber (ABR), Styrene butadiene rubber (SBR/ GR-S) **Other Elastomers** Modified bitumen, Elastane (Spandex, Lycra), Polyurethane gel, Polyurethane flexible foam, Styrene-butadiene Styrene (SBS), Thermoplastic Elastomers (TPE)

**MATERIALS IN USE**

**Nylon fabric**

Meet Wendy  
P.S. 1, New York, NY, 2012  
HWKN

**Polycarbonate panels**

Model Workshop  
Wolfratshausen, Germany, 2002  
Allmann Sattler Wappner Architekten

**Acrylic rods**

Seed Cathedral  
Shanghi, China, 2010  
Heatherwick Studio

**PET**

United Bottle  
2006  
INSTANT Architects

**GRP, ETFE**

Chanel Mobile Art Pavillion  
Hong Kong, New York, Tokyo, 2008  
Zaha Hadid Architects, ARUP

METALS C

*Pure metallic elements, compounds, and alloys characterized by metallic bonds whose atoms readily lose electrons to form positive ions (cations)*

PHYSICAL ATTRIBUTES

Metals are opaque, lustrous, strong, and comparatively heavy. They can be shaped and alloyed and are good conductors of heat and electricity. These properties follow from the close-packed crystal structure of the metallic bond.

PROCESSING

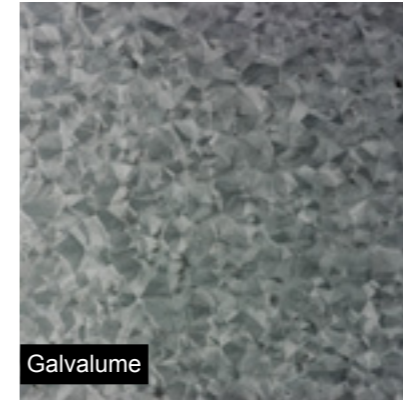
Annealing, anodizing, casting, drawing, electrochemical deposition, extrusion, forging, injection-molding, pressing, tempering, thermofusing/thermal welding, welding (oxy-acetylene welding, arc welding, gas metal welding, resistance welding), rolling (hot rolling, cold-rolling), stamping, thermal-arc spraying, electroplating, vapor deposition, sintering, welding, quench hardening, bending, cold forming, machining, riveting, soldering and brazing, laser sintering, panel beating, spinning, superforming, swaging, roll forming, electroforming, press braking, photochemical machining, laser cutting, electrical discharge machining, punching and blanking, water jet cutting, die cutting, powder coating, galvanizing, grinding, sanding, polishing, electropolishing, sandblasting, acid etching, CNC engraving or milling, foil blocking and embossing

APPLICATIONS

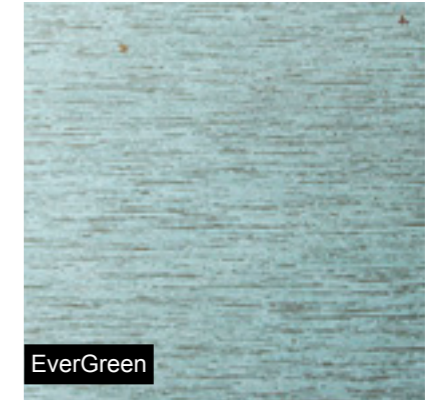
Structural system, cladding, roofing, coating, reinforcement in concrete, street furniture, drainage grates, railings, fasteners, pipes, guttering

TERMINOLOGY

**Alloys** are metals combined with other metal or non-metals. Bronze, steel, and brass are examples of alloys. **Corrosion**, or **rust**, is an irreversible reaction as a result of contact with oxygen. Cast iron and steel are especially vulnerable. Some metals create a passivation layer, a superficial corrosion that protects the core material. **Galvanization** (or galvanisation) is the process of applying a protective zinc coating to steel or iron in order to prevent rusting. **Magnetism** is a response to an applied magnetic field. Permanent magnets have magnetic fields caused by ferromagnetism, the strongest and most familiar type of magnetism. Non-magnetic substances include copper, aluminum, gases, and plastic. A material may exhibit more than one form of magnetism depending on its temperature. **Magnetostrictive metals** deform when exposed to a magnetic field. **Magnetorheological fluid** suspends micron-sized particles that harden in response to a magnetic field and soften when the field is removed. **Metallurgy** covers all the stages in the transformation of ore into metal. **Muntz metal/alpha-beta brass**: a form of brass with a high zinc content. **Shape memory metal**



Galvalume



EverGreen

is a metal that returns to its original shape after deformation by heating or cooling. Nickel titanium and nickel iron are common. **Superalloys** are alloys developed for use in gas-turbine engines that can operate at elevated temperatures.

FERROUS C1

*Ferrous pure metals and alloy. Metals based on iron.*

TYPES

**Iron** is plentiful and relatively cheap. It is extracted as an oxide, smelted by heating, and poured into ingots of "pig iron", 95% pure iron. **Cast iron** is re-heated pig iron, which can be toughened to make ductile iron and malleable cast iron. **Wrought iron** is iron hammered under heat to improve tensile strength. **Steel**, an alloy of iron and other metals, is less brittle, easier to work, and stronger than cast iron. Mild steel and medium carbon steel are commonly used for structural applications, low carbon steel for wire and thin plating, and high carbon steel for machines and tools. **Stainless steel** is an alloy that becomes corrosion resistant with the addition of a thin layer of oxidized chromium. Types are austenitic, ferritic, and martensitic; available polished or unpolished. **Weathering Steel** is a steel alloy containing copper. The iron oxide rust does not flake off when in contact with air. The patina varies with exposure, aspect and climate. COR-TEN is an example.

NON-FERROUS C2

*Non-Ferrous pure metals and alloy. Metals with little or no iron content.*

TYPES

**Zinc** forms a dull grey carbonate coating that makes it resistant to corrosion and weather. Zinc is also used as a coating for galvanized steel. **Aluminum** is the most widely used non-ferrous metal. It is light, strong, rust-resistant and easily worked. It is energy intensive to produce, but can be easily recycled. It is extracted from bauxite ore. **Lead** is corrosion resistant, malleable, resistant to acids, but toxic. **Copper** is an excellent conductor and relatively non-toxic. It weathers to a green patina, verdigris. **Tin** is a soft metal that forms a self-protecting oxide layer making it resistant to corrosion. **Brass** is an alloy of copper and zinc. It is easily machinable and corrosion resistant. **Bronze** is an alloy of copper and tin. Types include gun metal, bell metal, and phosphor bronze. **Titanium** is lightweight, very strong, corrosion resistant, and expensive. It is used in many alloys. **Chromium** (chrome) is very hard, does not corrode in air and can be polished to a mirror finish. It is often electroplated onto other metals. **Nickel, silver, gold, mercury, and magnesium** are other non-ferrous metals.





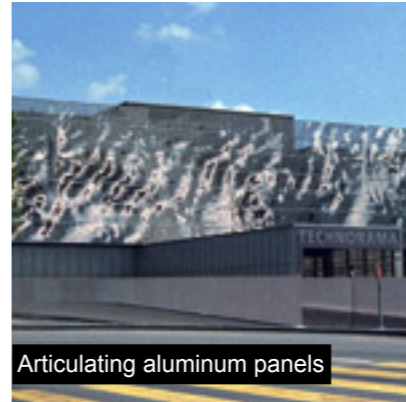
Steel structure and cables



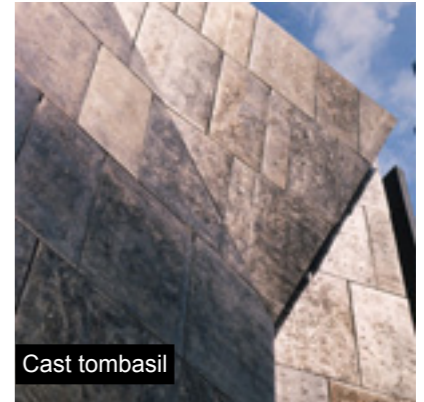
Steel shipping containers



Stainless steel woven curtain



Articulating aluminum panels



Cast tombasil

**MATERIALS IN USE**

**Steel structure and cables**

MFO Park  
Zurich, Switzerland, 2002  
Burckhardt + Partner AG, Raderschall  
Landschaftsarchitekten AG

**Repurposed steel shipping containers**

Nomadic Museum  
Santa Monica, CA, 2006  
Shigeru Ban Architects

**Stainless steel woven curtain**

Princeton Parking Garage  
Princeton, NJ, 2000  
TEN Arquitectos

**Articulating aluminum panels**

Technorama Facade  
The Swiss Science Center, Winterthur,  
Switzerland, 2002  
Ned Kahn

**Cast tombasil (white bronze) and copper panels**

American Folk Art Museum  
New York, NY, 2001  
Tod Williams Billie Tsien Architects

## MINERALS D

*Inorganic, crystalline solids, and chemical compounds possessing a characteristic crystalline structure and chemical composition, sometimes with restricted variations*

## PHYSICAL ATTRIBUTES

Mineral materials have a high density, hardness, compressive strength, thermal conductivity and resistance to weathering due to their crystalline structure. The structure varies according to geologic origin.

## GEOGENIC D1

*Inorganic, crystalline solids and chemical compounds formed by geological processes*

## TYPES

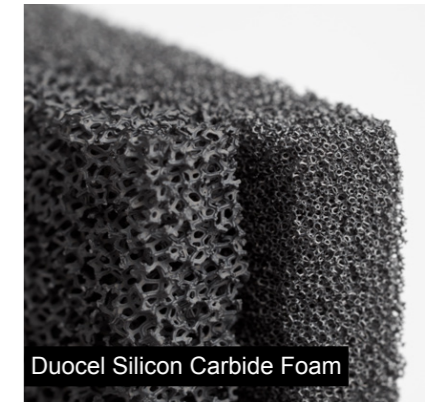
A **mineral** is a naturally occurring substance solid at room temperature, representable by a chemical formula, and having an ordered atomic structure. Minerals are classed by their dominant chemistry into silicates (the most plentiful) and non-silicates: native elements, sulfides, halides, oxides and hydroxides, borates, sulfates, phosphates and carbonates and nitrates. Mineral examples include quartz, feldspar, mica, asbestos, tourmaline, aragonite, calcite, gypsum, phosphate minerals, borax, talc, kaolinite, salt, vermiculite, and malachite. **Ores** are minerals that have a high concentration of a certain element, typically a metal. **Gems** are minerals with ornamental value distinguished from non-gems by their beauty, durability, and

usually, rarity. **Rock** is a naturally occurring solid aggregate of one or more minerals or mineraloids. It is often termed natural rock or stone in the construction industry. Rocks like limestone are composed primarily of one mineral—calcite or aragonite. Other rocks can be defined by relative abundances of key minerals; a granite is defined by proportions of quartz, alkali feldspar, and plagioclase feldspar. **Igneous rock** is formed from liquid magma. Main constituents are feldspar, quartz, mica, augite, iron pyrites, and olivine. The three types are plutonic, hypabyssal, and extrusive/volcanic. Examples include obsidian, tuff, granite, trachyte, diorite, gabbro, basalt and pumice. **Sedimentary rock** is formed by the weathering, erosion, and deposition of particles of older rocks with pressure. It may contain plant or animal fossils. Main constituents are feldspar, quartz, and mica. Properties vary considerably depending on the pressure and temperature in their formation, and type of binder—usually silica or calcite. The two types of rock are clastic and chemical/precipitated. Examples include oolite/egg stone, brownstone, conglomerates, sandstones, siltstones, “flagstone,” bluestone, limestone, dolomite, travertine, alabaster, Portland stone, and onyx. **Metamorphic rock** is formed from existing rocks though high pressure, high temperature, or chemical influences. Chemical composition and appearance vary considerably. The two types are orthorock and pararock. Examples include verd antique, asbestos,

gneiss, serpentine/serpentinite, slate/clayey shale, marble, soapstone/steatite, and quartzite. **Disintegrated rocks and stones** include the unconsolidated material above bedrock: boulders, cobble, sand, silt, clay, gravel, crushed gravel, pea gravel, bank-run gravel, crushed stone/rock, pebble, mineral aggregates, agricultural lime, and inorganic pigments consisting of colored earths and stone dust such as chalk, ochre, and umber. **Earth** in the top-most layer of the planet’s surface is composed of various ratios of disintegrated rock, clay, and decaying organic matter. These include: soil, loam, marl, clays (unfired), kaolin, topsoil, subsoil, sediment, bentonite, loess, chunam, and Fuller’s earth.

## PROCESSING

**Minerals and Rock:** sawing, cleaving, printing, abrading, drilling, water jet cutting. Surface finishing (manual and industrial): pointed, ground, chiseled, bush hammered, diamond sawn, chat-sawn, shot-sawn, honed, fine-pitched, flamed, sandblasted, polished, raw stone, cloven/split/cleft, embossed, planed, softened, quarry-faced/rock-faced, boasted, batted/tooled, quarry rough, rough cut, vermiculated, rough-punched, fair-picked, axed, sparrow pecked, fine-rubbed, gritted, eggshell/honed, acid washed, hydro, tumbled, plucked, broached, carborundum **Earth:** molding, ramming, cobbing, sun-baking, mixing, casting, filling, throwing

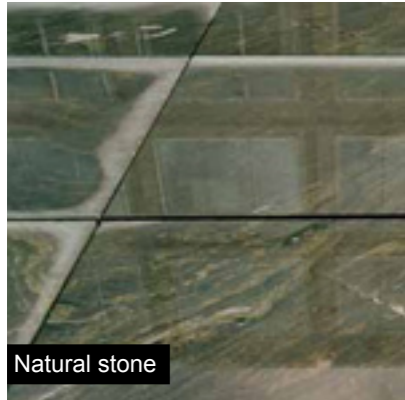


## APPLICATIONS

**Minerals and Rock:** cladding, floors, lintels, columns, roofs, paving, treads, curbs, worktops, sculpture, hearths, gabions, terrazzo, masonry grout, plaster, drainage, color additives, fertilizer, pavement base courses, concrete mixes, bituminous mixes, pervious pavements, landscape mulch, construction backfill **Earth:** cob, adobe/mud brick, pise/rammed earth, cast earth, compressed earth block (CEB), Dutch brick, earthbag construction, Superadobe, wattle and daub, earth ball finishing, peat walls, turf walls

## TERMINOLOGY

**Natural stone** is from a specific geographical region used for decorative purposes in construction and sculpture. There are 5,000 types of worldwide. Examples are Laurentide Green Granite (Quebec) or Carrara Marble (Italy). This nomenclature is specific to the trade and differs from petrological classifications. Trade nomenclature can mislead as to a stone’s true properties. **Dressed stone** is stone worked to desired shape and smoothed on the face. A **vein cut/cross cut** is made to expose the stratified layers of a sedimentary deposit. A **fleuri cut** is a cross cut across sedimentary layers exposing a cloudlike or mottled appearance. **Cut stone/dimension stone** is wholly dressed and finished at a mill and ready to be set in the building in conformity to drawings and specifications. It is rarely used for structural members, but common as masonry veneer or



Natural stone



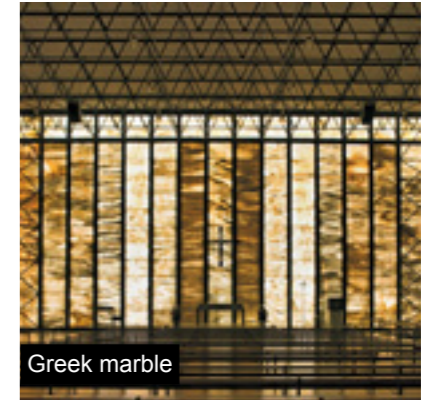
Earthen facades and floors



Earth



Rock-filled gabions



Greek marble

stone cladding. **Cast stone/reconstituted stone** is a hardened mix of concrete and fine stone aggregate surfaced to simulate natural stone. **Rubble masonry** is composed of collected fieldstones or stones as they have come from the quarry. **Ashlar masonry** is constructed of squared stones set in random or uniform courses. **Aggregates** are the product of natural processes (fluvial, glacial) or machine processes (crushed). They are typically a mix of different stone types. Graded aggregate contains a range of specific sizes, ungraded aggregate contains a broader range of sizes. **Lime** is calcium oxide or calcium hydroxide derived from limestone or chalk composed primarily of calcium carbonate. Burning (calcination) converts them into quicklime (calcium oxide, CaO) and, through the addition of water slaked lime or hydrated lime (calcium hydroxide, Ca(OH)<sub>2</sub>). When the term is encountered in an agricultural context, it refers to agricultural lime. Hydraulic lime will set underwater and non-hydraulic lime/ high calcium lime/ air lime cures by reaction with CO<sub>2</sub> (carbonation). **Soil types** include grades and combinations of sand, clay, silt, loam, and hardpan. Classifications are different for geotechnical engineering and agriculture. In the U.S., engineers use the Unified Soil Classification System (USCS), and soil scientists use the U.S. Department of Agriculture's soil taxonomy. **Clay** consists of fine particles of feldspar and various impurities. **Loam** is a friable mixture of relatively even proportions of sand, silt and clay usually with some organic

matter. **Silt** is composed of fine sand with fine decomposed organic material. The grains are microscopic and have little or no plasticity. **Sand** is composed of small particulates of rock ranging from 1/4" in diameter or less. It is predominantly quartz with no binder. The grains are spherical or angular in shape. **Topsoil** is the fertile surface layer of soil as distinct from the subsoil. It contains much organic matter which makes for poor load sustaining properties. **Subsoil** is the layer beneath the topsoil. This is usually used for earthwork construction.

**ANTHROPOGENIC D2**

*Inorganic, crystalline solids and chemical compounds manufactured by humans*

**TYPES**

Nitrogen in manufactured fertilizers, potassium water glass/potassium silicate, synthetic inorganic pigments made from oxides of titanium, iron, chromium and zinc, silicone resins (part inorganic and part organic), manufactured potash, slag, expanded shale, clay and slate, and phosphogypsum (a by-product of potassium processing for fertilizer).

**MATERIALS IN USE**

**Concave natural stone**

Weather Garden (Stone Yard)  
Park Hyatt Hotel, Zurich, Switzerland, 2004  
Vogt Landschaftsarchitekten

**Earthen facades and floors**

Aomori Museum of Art  
Aomori, Japan, 2006  
Jun Aoki & Associates

**Earth**

Storm King Wavefield  
Mountainville, NY, 2009  
Maya Lin

**Rock filled gabions**

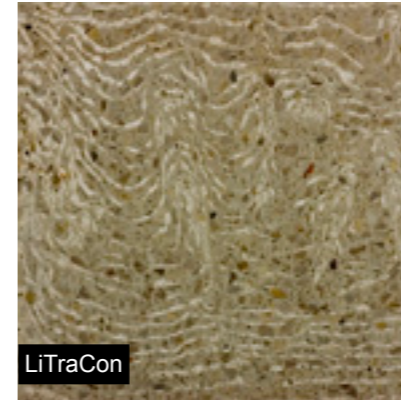
Dominus Winery  
Yountville, CA, 1998  
Herzog and de Meuron

**Greek marble panels**

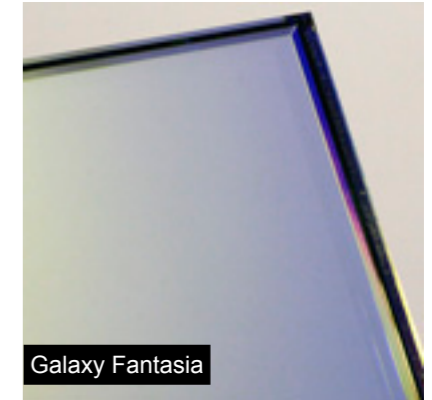
St. Pius Church  
Meggen, Switzerland, 1966  
Franz Fueg



Hydroton Clay Pebbles



LiTraCon



Galaxy Fantasia

**CERAMICS** E

*Nonmetallic, inorganic solids formed by the ionic bonding of mineral material through human based processes of mixing and/ or heating*

PHYSICAL ATTRIBUTES

Ceramics usually consist of metallic and non-metallic atoms. The ionic and covalent bonds render ceramics hard, brittle and resistant to heat.

**CLAY-BASED** E1

*Inorganic, crystalline composites made of fired clay, typically aluminosilicate and kaolinite, resembling glass in brittleness*

TYPES

**Primary Clay** fires to white, has the highest percentage of clay minerals, is the least contaminated, and is fired 1250°C-1400°C. Suitable for heat-resistant applications. Kaolin/China Clay is a fine white clay used to manufacture porcelain, China, and white Portland cement. **Secondary Clay** fires to red, yellow, or white, contains less clay minerals and more feldspar, and is fired at 1150°C-1250°C. Used to make stoneware and earthenware. **Tertiary Clay** fires to red or yellow, contains the least amount of clay minerals and more iron, lime and feldspar, and is fired between 850°C and 1050°C.

PROCESSING

Coloring, printing, sanding, reduction, dry-pressed, extruding, wire-cut, firing, drying, hand molding

APPLICATIONS

Facades, walls, paths, roads, roofing tiles, drainage pipes, structural clay tiles

TERMINOLOGY

**Fat clay** has a high loam content that increases the its elasticity but makes it susceptible to shrinkage and cracking. It is used to create machine pressed bricks and ceramic roofing tiles. **Lean clay** has a low loam content, low plasticity, and is used to produce hand-molded bricks and sanded facing bricks. **Grog** is a non-shrinking material that is added to clay to give dimensional stability. It can be sand, quartz dust, clay brick dust, slag, ash, or sawdust. **Brick** types include: hand molded, press-molded, extruded, and porous. Typical sizes are: Standard, Engineer, Elosure, Roman, Norman, Norwegian, Economy, Triple and Structural Clay Research (SCR) brick. **Glazes** are mixtures of fine clay, pigments and water that melt at lower temperatures than the base material. They give a clay product a vitreous surface after firing. **Refractory** means a material resists melting until high temperatures. Pure clay (hydrous aluminum silicate) is very refractory, most clays have impurities that allow the clay to melt at lower temperatures. Refractory ceramics include firebrick, used to line fireplaces. **Terra cotta** refers to earthenware or stoneware made of clay and pre-fired clay or grog. It does not shrink or distort during firing. Ceramic veneer is a type of terra-cotta.

**CEMENTITIOUS** E2

*Inorganic, crystalline composites made of a combination of lime, alumina, and water*

TYPES

**Cement** is a hydraulic binder. When mixed with water it begins an exothermic reaction that sets in both air and underwater to form a water-resistant hydrated cement. Portland cement is a standardized formulation of cement named after Portland stone, mined in Dorset, England. In the U.S. it has five compositional types set by ASTM C150: normal, moderate sulfate resistance, high early strength, low heat of hydration, and high sulfate resistance. European standard EN 197 divides Portland cements into five types based on the additional constituents: ordinary, Portland composite, blast furnace cement, pozzolanic cement, and composite cement. Other types of cement are: limestone cement, pulverized fuel ash (PFA), bunt shale cement, white cement, flyash cement, and expansive cement among others. The powder used to make cement (erroneously called cement itself) is a combination of calcium carbonate plus the aluminum, silica, and iron necessary to make the chemical reaction. **Concrete** is a mixture of cement, water, and aggregates. Admixtures such as plasticizers, air entrainers, water proofers, retarders, accelerators, and stabilizers can also be added. It can either be pre-cast or cast in situ. Types include: normal weight, lightweight-structural, lightweight insulating, heavyweight, cellular, gap graded, shotcrete/gunite, pre-placed,

pumped, ferrocement, fiber, nailing, no-slump, porous, tremie, polymer impregnated, polymer Portland cement, polymer, sulphur, reinforced, and prestressed.

PROCESSING

Dying, Hatschek process, reinforcement, mixing, precasting, serilith procedure, shuttering, spraying, wellcrete method, wet-mix procedure, curing, surfacing (embossing, point tooling, bush hammering, comb chiseling, sawing, grinding, splitting, polishing, blasting, flame cleaning, brushing, washing, acid etching, photoengraving), coating

APPLICATIONS

Civil engineering construction, foundations, building, pavers.

TERMINOLOGY

**Formwork** is a temporary mold to hold the cementitious liquid in place while it cures. It can be composed of boards, plywood, plastic panels, silicone rubber, steel, or polystyrene foam. **Solidification** is the process of change from liquid to solid cement. The three phases are initial set, solidifying, and final set. **Curing** is not a process of drying out. If water is removed, curing stops. The concrete continues to mature or afterharden even after a year, developing a higher strength. **Mortar** is a mixture of binder, sand, and water used to bond masonry units. **Grout** is a type of mortar used for filling recesses. **Concrete masonry units**



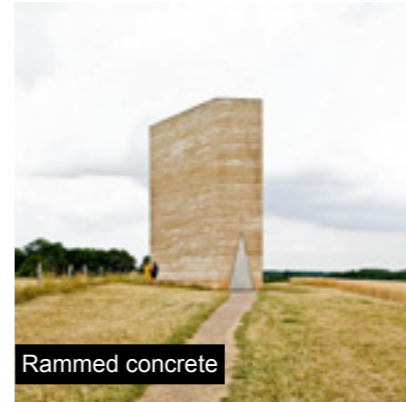
Tile, stone, ceramic rubble



Dichroic, anti-reflective, clear glass



Glazed terracotta rods



Rammed concrete



Pre-cast concrete pavers

**(CMU)/cinder blocks** are mostly made with lightweight concrete with lightweight aggregates.

**GLASS** E3

*Inorganic, non-crystalline solids that are silica-based*

TYPES

**Soda-lime glass** allows a high level of light transmittance and is nominally colorless and therefore used for windows. This glass is inert and used for food containers. Soda-lime glass has a relatively high thermal expansion, making it poor at withstanding sudden thermal changes. It is the preferred glass in contemporary construction. **Lead glass** (Lead crystal or lead alkali glass) has up to 30% lead oxide which gives the glass a sparkling brilliance and clarity not achievable with soda-lime glass. It is used for luxury tableware and radiation shielding. Glass containing less than 24% lead oxide is referred to simply as crystal. **Borosilicate glass** is composed of silica (70-80%) and boric oxide (7-13%). It can withstand extreme temperature changes, is lighter than soda-lime glass by 15% and is easy to work. Trade name: Pyrex. **Vitreous silica or silica glass**, aluminosilicate glass, and glass ceramics are other types of less common glass.

PROCESSING

Lampworking, lost wax cast glass, sandblasting, kiln casting, acid etching, ribbon machine process, fusing, slumping, water-jet cutting, pressed glass, handblowing, hand blowing into molds, blow molding, press and blow process, silvering, brilliant-cutting, cold-working, enameling

APPLICATIONS

Windows, glass wool (insulation), glazing, lighting fixtures, road marking, mirrors, glass brick, glass block, tablewares, packaging, security glass, bakeware, optical fibers, tubing

TERMINOLOGY

**Float glass** is sheet glass produced by heating molten glass and floating it over molten tin. A ribbon is formed, rolled and cut into sheets. It is naturally tinted green. **Rolled glass/patterned glass/cast glass** is translucent and made by melting glass and passing it through rollers to give it texture. **Toughened glass** is pre-stressed by heating and quenching suddenly with cool air (tempered glass) or by ion exchange (chemical toughening). **Laminated glass** is stronger and will remain intact when broken. Security glass/bullet-resistant glass and blast-proof glass are types that use a PVB (polyvinyl butyral) plastic film as the core. **Hollowware** accounts for most glass produced. It includes bottles, jars, tableware, tubular products, and hollow blocks used in the building industry. Most is made from soda-

lime glass. **Glass fiber** is glass that has been processed into thin strands. Includes insulating glass, textile fibers, and optical fibers.

MATERIALS IN USE

Tile and stone, wapan tiling, ceramic rubble

Ningbo Historical Museum  
Ningbo, China, 2009  
Amateur Architecture Studio

Dichroic, anti-reflective, reflective, and clear glass

Harpa Facade  
Reykjavík, Iceland, 2011  
Studio Olafur Eliasson

Glazed terracotta rods

The New York Times Building Sunscreen  
New York, NY, 2007  
Renzo Piano Building Workshop & FXFOWLE Architects

Rammed concrete

Bruder Klaus Kapelle  
Mechernich, Germany, 2007  
Peter Zumthor

Pre-cast concrete pavers

Southeast Coastal Park  
Barcelona, Spain, 2004  
FOA (Foreign Office Architects)



Sensitile Terrazzo Tiles



Bekitex



TruStone (E-Crete)

## PLANAR

**FILM**  
Sheeting with a thickness less than 0.1"

**SHEET**  
Sheets between 0.01" - 0.25" thick. **Rigid** or **Flexible**

**PANEL**  
0.25" or more in thickness. Wider than 2'. **Rigid** or **Flexible**

**TILE**  
Modular, small, thin pieces. Narrower than 2' on all sides. Less than 1" thick.

**TEXTILE**  
Flexible and thin, made of assembled fibers, with openings smaller than 0.25." **Fabric** woven, knotted or similar, and 1/16" thick or less. **Mats** more than 1/16" thick, woven, knotted or similar. Felts matted fibers, neither woven, knotted, nor similar

**MESH**  
Thin with uniform, small rectilinear openings visible to the eye. **Rigid** or **Flexible**

**HONEYCOMB**  
Sheets formed into a hexagonal cell structure with openings visible to the eye. **Rigid** or **Flexible**

## LINEAR

**CORD**  
Twisted or formed flexible linear pieces composed of one or more single or plied filaments, strands, or yarns. **Ropes** more than 0.15" diameter. **Threads** less than 0.15" diameter. **Tapes** flat, thin and wide, more than 0.15"

**PROFILE**  
Rigid linear pieces long in relation to their cross-section.

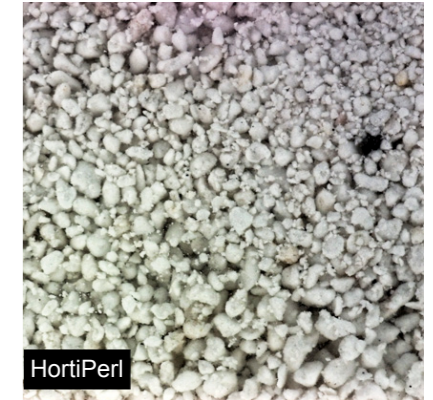
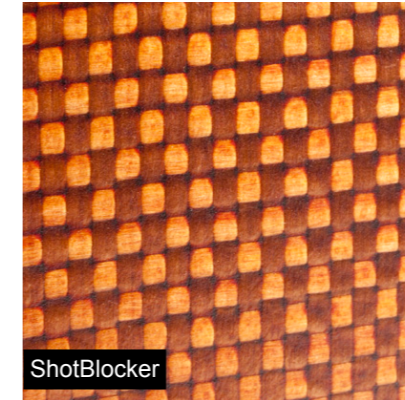
## VOLUMETRIC

**BLOCK**  
Volumetric, solid, dimensionally-stable units. Thicker than 1".

**GRANULES**  
Solid, small particles or grains. **Irregular** variable size and shape, larger than 1/32" diameter. **Regular** similar size and shape, larger than 1/32" diameter. **Powder** any solid, granular material smaller than 1/32" diameter

**FLUID**  
Fluids with a constant density. **Liquid** aqueous. **Spray** liquid in suspension. **Foam** liquid with bubbles; it can flow, expand, and eventually solidify. **Gas** any substance in a gaseous state

**SEMISOLID**  
Any material in gaseous state, including compressed gases. **Gel** jelly-like semi-solids. **Paste** spreadable semi-solids that harden after a defined procedure



**MECHANICAL**

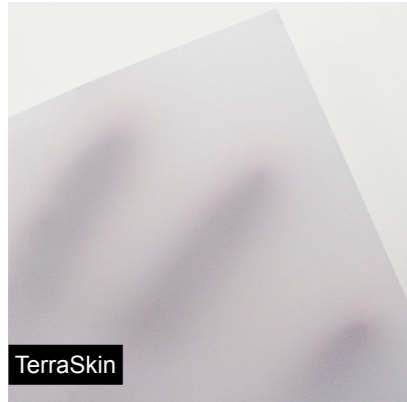
- DENSITY**  
Mass per unit of volume (kg/m<sup>3</sup>)
- COMPRESSION STRENGTH**  
Stress at which it first suffers permanent (inelastic) deformation in compression (MPa)
- TENSILE STRENGTH**  
Stress at which a round bar of the material, loaded in tension, separates (MPa)
- YIELD STRENGTH**  
Stress at which it first suffers permanent (inelastic) deformation in tension (MPa)
- BENDING STRENGTH**  
Stress at which it first suffers permanent (inelastic) deformation in bending (MPa)
- SHEAR STRENGTH**  
Stress at which it first suffers permanent (inelastic) deformation in shear
- ELONGATION**  
Extension in the length of a tensile specimen at fracture (%)
- HARDNESS**  
Resistance to permanent fracture or plastic deformation due to a force applied with a sharp object (HV)

- YOUNG'S MODULUS**  
Ratio of the uniaxial stress over the uniaxial strain. Used to measure the stiffness of an elastic material.
- FATIGUE LIMIT**  
Range of cyclic stress that can be applied to the material without causing failure

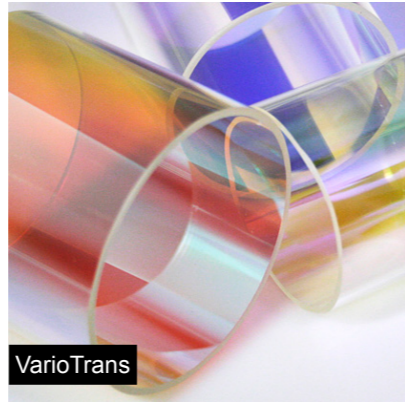
**HYGRO-THERMAL**

- THERMAL RESISTIVITY**  
The reciprocal of the rate at which heat is conducted through a solid (m<sup>2</sup>C/W)
- THERMAL EXPANSION COEFFICIENT**  
The degree of change in volume in response to a change in temperature (ustrain/°C)
- MELTING POINT**  
Temperature at which a material turns abruptly from solid to liquid (°C)
- SPECIFIC HEAT**  
Amount of heat required to raise the temperature of 1 kg of material by 1°C (J/kg °C)
- EMISSIVITY**  
Measure of the heat radiation emitted by a material
- WATER ABSORPTION**  
Increase in mass as a result of moisture absorption when a major surface of a specimen is placed in contact with liquid water (%)
- POROSITY**  
Fraction of the volume of voids over the total volume

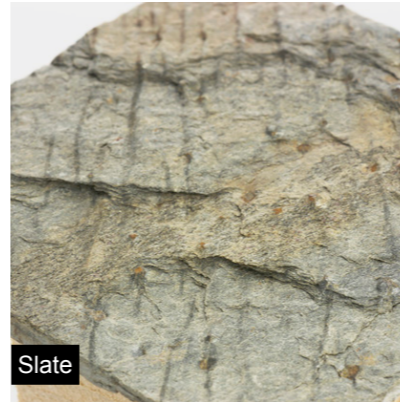
- FLAMMABILITY**  
Degree of difficulty required to cause ignition or burning
- VAPOR PERMEABILITY**  
Measure of the passage of water vapor through a substance



TerraSkin



VarioTrans



Slate



Basaltex Non Woven Mats



EL (Electroluminescent) Wire

**ELECTRICAL**

**ELECTRICAL RESISTIVITY**

Capacity of a material to oppose to the flow of electric current. The reciprocal of Electrical Conductivity (conductor, semiconductor, insulator)

**OPTICAL**

**TRANSPARENCY**

Capacity of a material to transmit light through it (opaque, translucent, transparent)

**REFLECTANCE**

Capacity of a material to reflect light incident on its surface (specular (glossy), medium (satin), diffuse (matte))

**ACOUSTICAL**

**SOUND ABSORPTION**

Capacity of a material to change the acoustic energy of sound waves into another form, reducing the amount of reflected and transmitted sound (reflective, neutral, absorbent)

**SOUND ISOLATION**

Capacity of a material to prevent the transmission of sound through it (insulator, neutral, conductor)

**DURABILITY**

**FIRE RESISTANT**

Resists combustion for a specified time where the material will not fail structurally or allow transit of heat

**WATER RESISTANT**

Not easily harmed or affected by water or does not allow water to pass through easily

**FREEZE/THAW RESISTANT**

Solids that can resist cyclic freezing and melting without disintegration

**CHEMICAL RESISTANT**

Resists damage by chemical reactivity or solvent action

**CORROSION RESISTANT**

The capacity of a metal or alloy to resist the corrosive action of a medium. Determined by the rate of corrosion under given conditions

**UV RESISTANT**

Ability to withstand decay due to the damaging effect of the ultraviolet rays of the sun

**FUNGAL / BACTERIA / ANIMAL RESISTANT**

Ability to resist fungal or bacterial growth, or deter specific animal species on its surface

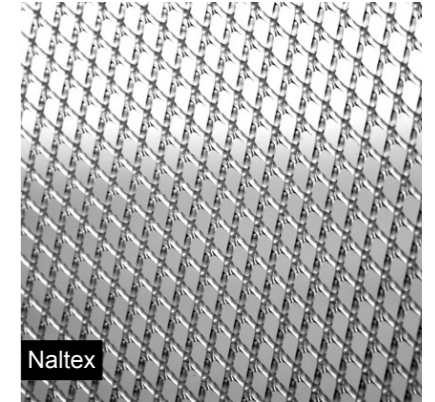
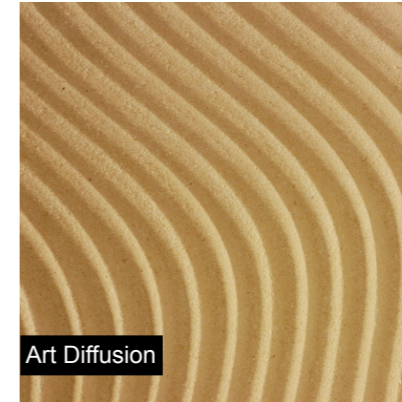
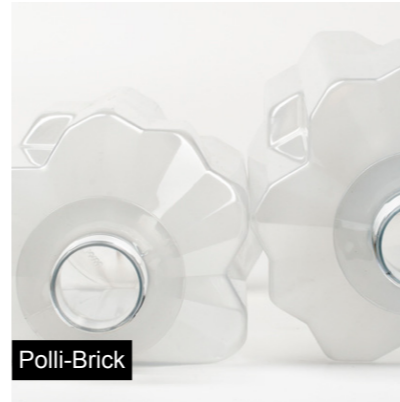
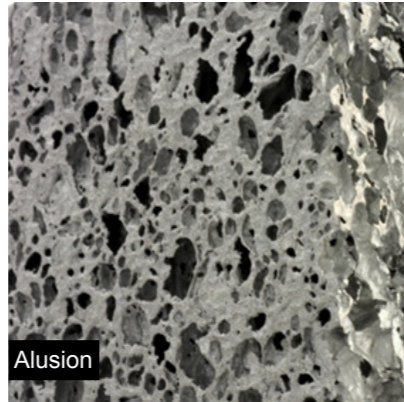
**RADIO FREQUENCY SHIELDING**

Prohibits electromagnetic radiation from penetrating the material

**ELECTROMAGNETIC INTERFERENCE (EMI) SHIELDING**

Reduces the electromagnetic field with barriers made of conductive or magnetic materials





**CASTING**

Processes based on the pouring of curable fluids into molds

- Centrifugal casting
- Die casting
- Investment casting
- Sand casting
- Slip casting
- Slumping

**MOLDING**

Processes based on the deformation of solid and semisolid materials applying high pressure against molds

- Autoclave molding
- Back-pressure forming
- Blow molding
- Bubble forming
- Cavity forming
- Cold isostatic pressing (cip)
- Compression molding
- Contact molding
- Diaphragm molding
- Dip molding
- Electroforming
- Explosive forming
- Foam molding
- Hot isostatic pressing (hip)
- Hydroforming or fluid forming
- Injection molding
- Powder molding
- Rotational molding
- Thermoforming
- Transfer molding
- Vacuum forming
- Vacuum infusion process (vip)

**MACHINING**

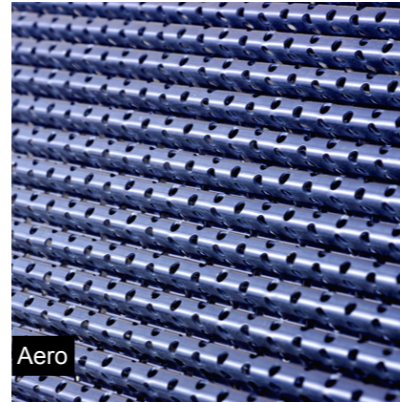
Processes based on the subtraction of material mainly by mechanical methods

- Blanking
- CNC cutting
- Drilling
- Electron-Beam Machining (EBM)
- Grinding
- Laser-beam cutting
- Lathing
- Milling
- Nibbling
- Oxyacetylene cutting
- Plasma-arc cutting
- Punching
- Water-jet cutting
- Water-jet abrasion
- Wire cutting
- Wire Electrical Discharge Machining (W-EDM)

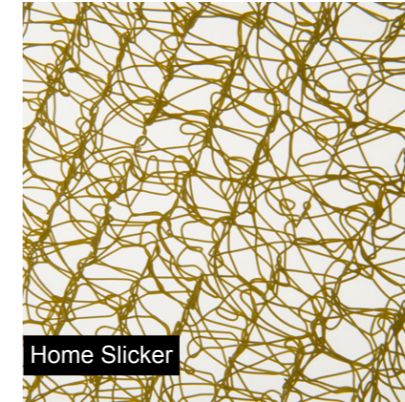
**DEFORMING**

Processes based on the deformation of solid materials using mechanical devices

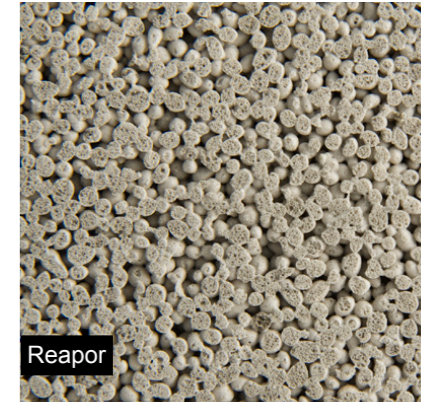
- Bending
- Blowing
- Die cutting
- Embossing
- Extrusion
- Forging
- Inflating
- Jiggering
- Jollying
- Pressing
- Pultrusion
- Rolling
- Rotary swaging
- Shearing
- Stamping



Aero



Home Slicker



Reapor

**SURFACING**

Processes based on the application of thin layers of fluids on the surface of a material

- Anodizing
- Calendering
- Coating
- Cubic printing
- Flame hardening
- Galvanizing
- Inkjet printing
- Laser hardening
- Over-mold surfacing
- Pad printing
- Photo-etching
- Silk screen printing
- Spray painting

**JOINING**

Processes based on the connection of two or more parts to form a single unit of form

- Bonding
- Doweling
- Fastening
- Filament Winding
- Flexible adhesives
- Knitting
- Rigid adhesives
- Soldering
- Weaving
- Welding

**RAPID PROTOTYPING**

Processes based on the automated fabrication of products using additive techniques

- 3D printing
- Contour crafting
- Fused Deposition Modeling (FDM)
- Laminated object manufacturing
- Laser Sintering
- Selective Laser Sintering (SLS)
- Selective Laser Melting (SLM)
- Stereolithography (STL)

## MATERIALS COLLECTION PRIMER

## AUTHORS

Anya Domlesky + Jane Hutton

## DESIGNERS

Anya Domlesky + Jacqueline Park  
And assistance by Jina Kim + Ambrose Luk

## EDITORS

Jane Hutton + Johanna Kasubowski

## ADVISOR

Alix Reiskind

## BIBLIOGRAPHY

A Green Vitruvius : Principles and Practice of Sustainable Architectural Design (London: James & James, 1999)

Amato, Ivan, *Stuff : the Materials the World Is Made Of*, 1st edn (New York, NY: BasicBooks, 1997)

Ashby, M. F., *Materials and the Environment : Eco-informed Material Choice* (Amsterdam ;: Butterworth-Heinemann/Elsevier, 2009)

Berge, Bjørn, *The Ecology of Building Materials*, Second Edition, 2nd edn (Taylor & Francis, 2009)

Borch, Ine ter, *Skins for Buildings : the Architect's Materials Sample Book* (Amsterdam: BIS, 2004)

Construction Industry Research and Information Association, *Environmental impact of materials*. (London: Construction Industry Research and Information Association, 1995)

Dent, Andrew, Anita Moryadas, and George M. Beylerian, *Material ConneXion : the Global Resource of New and Innovative Materials for Architects, Artists, and Designers* (Hoboken, N.J.: J. Wiley, 2005)

Deplazes, Andrea, ed., *Constructing Architecture: Materials, Processes, Structures*, trans. by Gerd H. Söffker, 2nd ed. 2008. 2nd printing (Birkhäuser Architecture, 2008)

Harris, Charles W., Nicholas T. Dines, and Kyle D. Brown, *Time-saver Standards for Landscape Architecture : Design and Construction Data*, 2nd edn (New York: McGraw-Hill, 1998)

Jester, Thomas C., *Twentieth-century Building Materials : History and Conservation* (New York: McGraw-Hill, 1995)

Rand, Patrick, and Victoria Ballard Bell, *Materials for Architectural Design* (London: Laurence King, 2006)

Schwedt, Georg, *The Essential Guide to Environmental Chemistry* (Chichester ;: John Wiley, 2001)

Sovinski, Rob W., *Materials and Their Applications in Landscape Design* (Hoboken, N.J.: John Wiley & Sons, 2009)

## IMAGE CREDITS

Images used to represent materials in use are for demonstration use only in an educational context.

Materials in Use, Biocomposites, page 4

**Railroad tie wood, reclaimed**

Biblioteca Municipal de Azkoitia, 2006  
Estudio Beldarrain  
© Jon Cazenave  
<http://places.designobserver.com/slideshow/rematerial-from-waste-to-architecture/13838/848/>  
accessed on 03/06/2014

**Brazilian Ipe hardwood**

Yokohama Ferry Terminal, 2002  
FOA (Foreign Office Architects)  
© Lise Laurberg  
<http://www.arospace.com/image-library/yokohama-international-port-terminal/>  
accessed on 03/07/2014

**Unbleached Kraft paper or tissue paper**

Softwall  
Molo Design  
© Molo Design  
<http://molodesign.com/products/softwall-softblock-modular-system-%C2%B7-led-lighting/#>  
accessed on 03/07/2014

**Gluelam scotch pine**

Corolle: high tension electricity pylon, 1994  
Martin Szekely  
© Alain Dovifat  
<http://www.martinszekely.com/niveau4-industrie.php?ty2=ma&ty=de&id=15&id2=52>  
accessed on 03/07/2014

Materials in Use, Polymers, page 6

**Nylon fabric**

Wendy, 2012  
HWKN  
© Michael Moran  
<http://www.architectmagazine.com/cultural-projects/construction-complete-on-hwkns-wendy-at-moma-ps1.aspx>  
accessed on 03/07/2014

**Polycarbonate panels**

Model Workshop, 2002  
Almann Sattler Wappner Architekten  
© Florian Holzherr, Stefan Müller-Naumann  
<http://www.allmannsattlerwappner.de/en/#/en/projects/detail/88/pics/?page=6>  
accessed on 03/07/2014

**Acrylic rods**

Seed Cathedral, 2002  
Heatherwick Studio  
© Daniele Mattioli  
[http://www.yatzer.com/2173\\_seed\\_cathedral\\_for\\_the\\_uk\\_shanghai\\_pavilion\\_by\\_heatherwick\\_studio](http://www.yatzer.com/2173_seed_cathedral_for_the_uk_shanghai_pavilion_by_heatherwick_studio)  
accessed on 03/07/2014

**PET**

United Bottle, 2006  
Instant Architects  
© Van Alen Institute  
[http://www.vanalen.org/fellowship/fellows/03\\_2008\\_hebelstollman#related\\_photos\\_content%3Dtrue](http://www.vanalen.org/fellowship/fellows/03_2008_hebelstollman#related_photos_content%3Dtrue)  
accessed on 03/07/2014

**GRP, ETFE**

Chanel Mobile Art Pavilion, 2008  
Zaha Hadid Architects, ARUP  
© Stefan Tuchila  
[http://www.archdaily.com/144378/chanel-mobile-art-pavilion-zaha-hadid-architects/\\_k5\\_5077/](http://www.archdaily.com/144378/chanel-mobile-art-pavilion-zaha-hadid-architects/_k5_5077/)  
accessed on 03/07/2014

Materials in Use, Metals, page 8

**Steel structure and cables**

MFO Park, 2002  
Burckhardt + Partner AG  
© Burckhardt + Partner  
<http://www.burckhardtpartner.ch/en/references/items/new-mfo-park.html>  
accessed on 03/07/2014

**Steel shipping containers**

Nomadic Museum, 2005  
Shigeru Ban Architects  
© Shigeru Ban Architects  
[http://www.dma-ny.com/site\\_sba/?page\\_id=307](http://www.dma-ny.com/site_sba/?page_id=307)  
accessed on 03/07/2014

**Stainless steel woven curtain**

Princeton Parking Garage, 2000  
TEN Arquitectos  
© TEN Arquitectos  
<http://www.ten-arquitectos.com/proyecto.php?ip=121>  
accessed on 03/07/2014

**Articulating aluminum panels**

Technorama Façade, 2002  
Ned Kahn  
© Ned Kahn Studios  
<http://nedkahn.com/portfolio/technorama-facade/>  
accessed on 03/07/2014

**Cast tombasil (white bronze) and copper panels**

American Folk Art Museum, 2001  
Todd Williams Billie Tsien Architects  
© Michael Moran  
<http://blog.archpaper.com/wordpress/archives/16891>  
accessed on 03/07/2014

Materials in Use, Minerals, page 10

**Concave natural stone**

Weather Garden (Stone Yard, Park Hyatt Hotel), 2004  
Voft Landschaftsarchitekten  
© Vogt  
<http://www.vogt-la.com/en/project/hotel-park-hyatt>  
accessed on 03/07/2014

**Earthen facades and floors**

Aomori Museum of Art, 2006  
Jun Aoki & Associates  
© Daici Ano  
<http://www.archdaily.com/126728/aomori-museum-of-art-jun-aoki-associates/amoano002/>  
accessed on 03/07/2014

**Earth**

Storm King Wavefield, 2009

Maya Lin Studio  
© Librado Romero  
[http://www.nytimes.com/2010/09/07/arts/design/07storm.html?\\_r=0](http://www.nytimes.com/2010/09/07/arts/design/07storm.html?_r=0)  
accessed on 03/07/2014

**Rock-filled gabions**

Dominus Winery, 1998  
Herzog and de Meuron  
© Jos Driessen  
<http://www.fotopedia.com/items/NVzlgfk-DZM-AP00r4ljfRc>  
accessed on 03/07/2014

**Greek marble**

St. Pius Church, 1966  
Franz Feug  
© Frank Kaltenbach  
<http://www.detail-online.com/inspiration/discussion-taking-a-second-look-%E2%80%93-st-pius-catholic-church-in-meggen-108891.html>  
accessed on 03/07/2014

Materials in Use, Ceramics, page 12

**Tile and stone, wapan tiling, ceramic rubble**

Ningbo Historical Museum, 2009  
Amateur Architecture Studio  
© Iwan Baan  
[http://www.iwan.com/photo\\_Wang\\_Shu\\_Ningbo\\_Historic\\_Museum.php?plaat=Wang-Shu-Ningbo-Museum-4405.jpg](http://www.iwan.com/photo_Wang_Shu_Ningbo_Historic_Museum.php?plaat=Wang-Shu-Ningbo-Museum-4405.jpg)  
accessed on 03/07/2014

**Bichroic, anti-reflective, clear glass**

Harpa Concert Hall, 2011  
Henning Larsen Architects  
© Henning Larsen Architects  
<http://www.archdaily.com/153520/harpa-concert-hall-and-conference-centre-henning-larsen-architects/harpa-concert-hall-and-conference-centre-in-reykjavik-11/>  
accessed on 03/07/2014

**Glazed terracotta rods**

The New York Times Building Sunscreen, 2007  
Renzo Piano Building Workshop  
© Renzo Piano Building Workshop, FXFOWLE  
[http://www.iwan.com/photo\\_Wang\\_Shu\\_Ningbo\\_Historic\\_Museum.php?plaat=Wang-Shu-Ningbo-Museum-4405.jpg](http://www.iwan.com/photo_Wang_Shu_Ningbo_Historic_Museum.php?plaat=Wang-Shu-Ningbo-Museum-4405.jpg)  
accessed on 03/07/2014

**Rammed concrete**

Bruder Klaus Kapelle, 2007  
Peter Zumthor  
© Samuel Ludwig  
<http://www.samueltludwig.com/peter-zumthor/n0imxh2kzl54qc44obm671fxnwielt>  
accessed on 03/07/2014

**Pre-cast concrete pavers**

Southeast Coastal Park, 2007  
FOA (Foreign Office Architects)  
© FOA  
[http://www.cyberarchi.com/dossier/zoom\\_article\\_v2.php?dossier=75&article=13710&photo=37578&modal=true&keepThis=true&height=900&width=800&TB\\_iframe=true](http://www.cyberarchi.com/dossier/zoom_article_v2.php?dossier=75&article=13710&photo=37578&modal=true&keepThis=true&height=900&width=800&TB_iframe=true)  
accessed on 07/12/2013