which minimizes wastage. Triple rolls are also available. There are two width alternatives, the narrower type is called European rolls are 20.5" wide with 33' double roll length, covering approximately 55 square feet. And the alternative is the American roll that is 27" wide with 27' double roll length, covering approximately 60 square feet.

WALLCOVERING APPLICATION

Wallcovering application is a fairly straightforward and relatively less messy application, one of the final tasks on a construction site. Similar to paint application, the ***irregularities on the substrate would be amplified*** *on the wallcovering surface, including minor imperfections.* This, however, is also tied to the backing type used. Wallcoverings with thicker backing are slightly more forgiving. The substrate needs to be fully sealed before the application, and the seal needs to be fully cured before moving forward. Especially for gypsum board applications, a sealer application underneath the wallcovering is beneficial in the sense that *when torn down, wallcovering can* ***damage the paper facer*** *of gypsum.* The sealer improves strippability of the wallcovering. Wallcovering primer works with the same principles as paint primer, though the formulations are different. Smoothing out the wall, increases the adherence to difficult surfaces, hides the previous colors and stains, makes removing the wallcovering easy.

Wall liner, *also known as paper liner or liner paper, is a useful barrier for hiding flaws and imperfections on the substrate while providing a smooth surface.* It comes in various thicknesses, thinner wall liners are not able to hide flaws. Wall liners, as well as wallcoverings, can be ***pre-pasted,*** *meaning the backing of the wallcovering features an adhesive layer off the factory, that is activated when in contact with water.* Liners are applied horizontal to the wall, underneath the vertical wallcovering strips. Wall liners can also provide a surface to paint on, it is possible to omit the wallcovering layer altogether. Sizing a wall means applying wall size on plaster or over primer. ***Sizer*** *application creates a somewhat slippery layer, helps with sliding and adjusting the wallcovering during installation, also helps with grip and peelability.* Before hanging the wallcovering, the stock should be carefully examined for defects such as color bleeding, shading errors, out-of-register colors, ink spots, delamination, etc. The overall job should follow a consistent direction or orientation that complements the space's natural flow and architectural features; patterns should not be clashing architectural details, rather enforce them. There should be no adhesive drips or smears on the wallcovering facing. There shouldn't be any visible air pockets, creases, or wrinkles.

Fig.05/23 Adhesive is being applied on cut strips of wallcovering.

Vid.05/07 Video on practical wallcovering application tips.

06

CONCRETE & MASONRY

- *Vocabulary for concrete*
- *Concrete types and application*
- *Terrazzo and installation*
- *Brick types and installation*
- *Vocabulary for natural stone*
- *Quarrying and environmental impact*
- *Stone types and finishes*
- *Stone installation and maintenance*

Concrete is a ubiquitous building material that a mixture of a cementing component, such as Portland cement, fly ash, slag, or silica fume; a mineral aggregate of different fineness such as sand or gravel as filler, and water. The mixture is initially viscous, however, *water causes the cement to harden through an exothermic reaction called **hydration** – not the same as drying by evaporation.* This is also called the curing process, ultimately causing the mixture to harden around aggregates. A key concrete ingredient, ***Portland cement** is made by heating limestone and clay to form clinker in a rotary kiln, which is then ground with gypsum into a fine powder. **Fly ash** is a pre-consumer recycled waste of coal-burning process;* less common, the manufacturing process unknowns can cause quality variations and unpredictability. Ancient Romans were the first to utilize cement in construction, as early as the 3rd century. Written in the 1st century BC, Vitruvius talks about concrete and mixture proportions in his treatise

Fig.06/01 The dome of Pantheon showcases the capabilities of concrete as a construction material.

Fig.06/02 Portland cement factory. The long tube diagonally running left to right is the kiln.

on architecture. Roman concrete is also known by the name Opus Caementicium. ***Reinforced concrete****, a composite material involving a steel rebar lattice embedded in a concrete matrix,* is the most common application in construction and featured in virtually all modern construction projects.

The high temperatures, approximately 2700ºF, required to manufacture cement cause ***substantial environmental impact****.* In addition, the calcination process releases CO_2 as a substantial byproduct. The total output from the process accounts for almost 8% of total man-made CO_2 production per year. The limestone and aggregate used to produce concrete needs to be quarried in large quantities. ***Quarrying rock*** *results in significant environmental degradation through air and noise pollution, water depletion, soil eroison, and biodiversity loss.* Since concrete is such a common building material, it accounts for a substantial portion of the construction waste, worldwide. Even though rebars can be fully recycled, only a small percentage of concrete is generally recycled as filler. ***Uncured cement*** *is a known irritant; due to high alkalinity it is corrosive to human tissue.* However, after curing it is chemically inert and non-toxic.

On grade *refers to the ground level of the building;* ***below grade*** *refers to any level below the ground level.* Concrete is highly susceptible to moisture absorption and transfer, if the material is in contact with a source of moisture, such as soil, it needs to be carefully insulated, especially if situated below grade. The typical concrete is hydrophilic, meaning it will readily suck any moisture present in the environment. Even slight insulation failures would result in carbonation as well as rebar corrosion over time; causing a reduction in concrete's strength, inducing cracking and spalling. ***Efflorescence*** *refers to the white-colored salt streaks and spots on the*

Vid.06/01 Video on the cement manufacturing process.

Vid.06/02 Video on concrete, cement, and mortar.

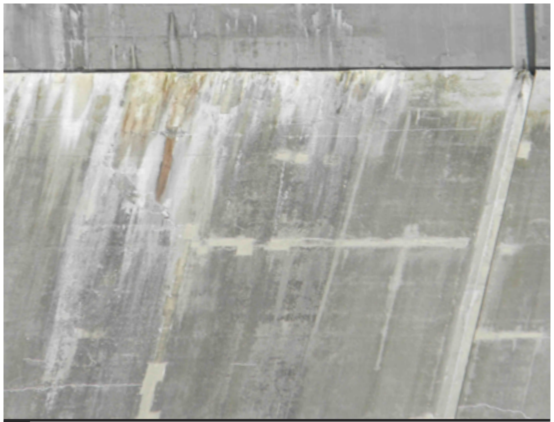

Fig.06/03 Efflorescence refers to the white salt stains indicating significant moisture exposure.

concrete surface, indicating moisture exposure.

Concrete can and should be ***tested for the presence of moisture*** *before any finish application; there are multiple convenient tests are available such as on-site humidity probes, calcium chloride test, and digital moisture meters.*

There are two common methods for concrete subfloor preparation. ***Screed*** *is a method of topping a horizontal concrete application with a finer coat and leveling the surface either with a flat board or a mechanical tool.* This thin top layer features either very fine or no aggregate for a smooth result, as opposed to the thicker base layer, which features larger aggregate size and the outcome is coarse but much stronger. ***Floating screed*** *is laid on top of a layer of insulation and does not directly bond to the floor slab underneath.* Even though expensive, it mechanically separates two layers and minimizes cracking. ***Self-leveling concrete*** *is another method of achieving a smooth, level finish; this application features a polymer-based additive in the concrete mix and it is less viscous and runnier than the typical screed concrete.* The mix is lightly spread with a flexible blade smoother

Fig.06/04 Digital hygrometers are very convenient, though the measurements can be up to 5% off.

while the application slowly levels itself out. Self-leveling concrete is relatively expensive, however, it can be applied as a thinner layer.

Concrete aggregate is fairly brittle when cured and it is subject to dimensional change with shifting moisture and heat conditions. Before the concrete is poured resilient ***expansion joints*** *are placed 10' to 15' apart, around 20 to 30 times the thickness of the slab.* It is also possible to saw-cut joints, which should be

Fig.06/05 The screed is a flat board used to straighten freshly poured concrete.

Fig.06/06 *Expansion joints are crucial for protecting the integrity of the concrete for extended periods.*

Fig.06/07 *Concrete polishers, or floor grinders, feature rotating abrader pads underneath.*

done within 12 hours of concrete application. Otherwise, concrete will crack while curing due to contraction.

Besides being commonly used as a structural element and flooring substrate, concrete is also regularly specified as a finish in commercial as well as residential settings. ***Polished concrete,*** *involves sanding the screed or self-leveling concrete overlay with abraders of incrementally higher grit.* Before polishing, concrete needs to be fully cured. This happens typically 10 days after application but in some conditions, up to 28 days are needed. Polished concrete finish has high mechanical and chemical resistance and appropriate for environments with high traffic loads, including forklift traffic. The gloss level can be adjusted; high gloss providing around 0.50 slip resistance and low glass around 0.60. It is possible to apply polymer coating for higher slip resistance. It is an inert finish that does not degrade and can last many years. ***Cement overlays*** *a thin layer of cement-based product used for repairing, strengthening, and enhancing the look of existing concrete surfaces.*

Concrete is a viscous material, before it is cured and needs to be poured in a watertight mold, which is commonly referred to as ***concrete formwork.*** In order to prevent sticking and ensure separation while removing a release agent, also known as a parting compound, should be applied inside the formwork. After 2 to 4 days the formwork is removed to let the concrete continue curing. It is possible to use *various* ***admixtures*** *to enhance or modify concrete's properties.* The setting rate can be slowed or curing time can be reduced, possible rebar corrosion can be inhibited, or with plasticizers, concrete can be molded without vibration or compaction, ensuring homogeneous dispersion.

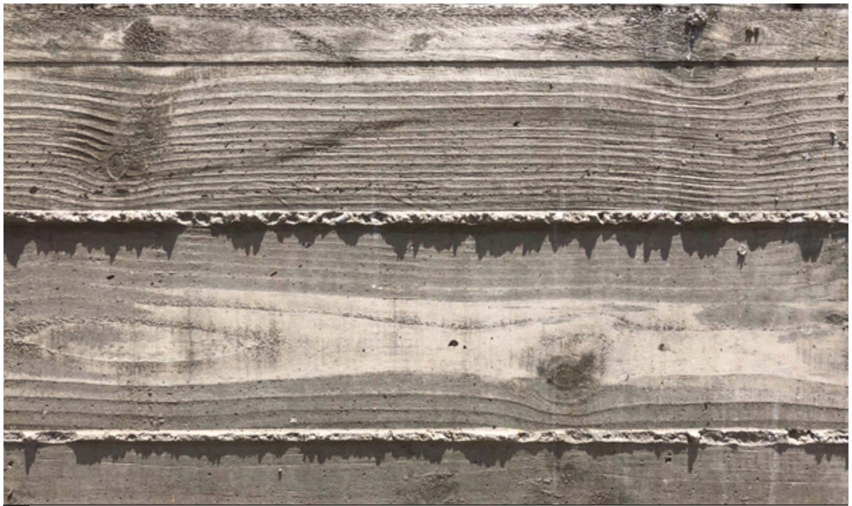

Fig.06/08 *Board formed concrete is imprinted with the grain texture of the formwork.*

Vid.06/03 Video on creating board-formed concrete mock-ups.

Vid.06/04 Video on a complex terrazzo installation.

Board-formed concrete *refers to the process of pouring concrete into a wooden formwork to achieve a characteristic striated look, with the imprint of wood grain.* ***Wall ties*** *hold the formwork together while concrete is cured, when removed leaves circular imprints.* Glass Fiber Reinforced Concrete allows for the creation of intricate sculptural forms; widely used for DIY furniture. *Concrete can be* ***precast*** *for rapid construction, reduced labor and waste, and high quality control*; can be structural elements, or they can be countertops, furniture, fixtures, or tiles. ***Pre-stressed*** *concrete is great for attaining higher tensile resistance and structural stability.*

Terrazzo *is a cementitious material that substitutes typical gravel aggregate with chips of granite, glass, porcelain, or any other suitable material of varying sizes.* Typically the material receives a polished finish. Cement can be substituted with polymer resin. Terrazzo can be applied either as cast-in-place or sold as precast panels that can be cut into any required shape. Terrazzo tiles are also available in the market.

Cast-in-place *or poured terrazzo is set with brass, aluminum, zinc, or vinyl divider strips, which also function as expansion joints.*

Polymer-based terrazzo can be as thin as 1/4" applied directly over the prepared subfloor, a moisture membrane or crack suppression membrane may be required. Monolithic terrazzo is applied at 1/2" thickness, directly over the prepared concrete subfloor. Bonded terrazzo is also 1/2" thick, however, sits on a 3/4" to 1-1/4" mortar underbed. Unlike monolithic terrazzo, bonded terrazzo does not require meticulous subfloor preparation. Lastly, sand cushion terrazzo features a wire reinforcement, sheet insulation, as well as a thick sand layer under the mortar underbed, totaling at 3" application thickness. *The* ***mechanical separation*** *from the subfloor ensures that building settling or deflection of structural elements won't fracture the brittle terrazzo application.*

Terrazzo is renowned for its durability and longevity, and it requires minimal maintenance. It is a popular material for countertops, stairs,

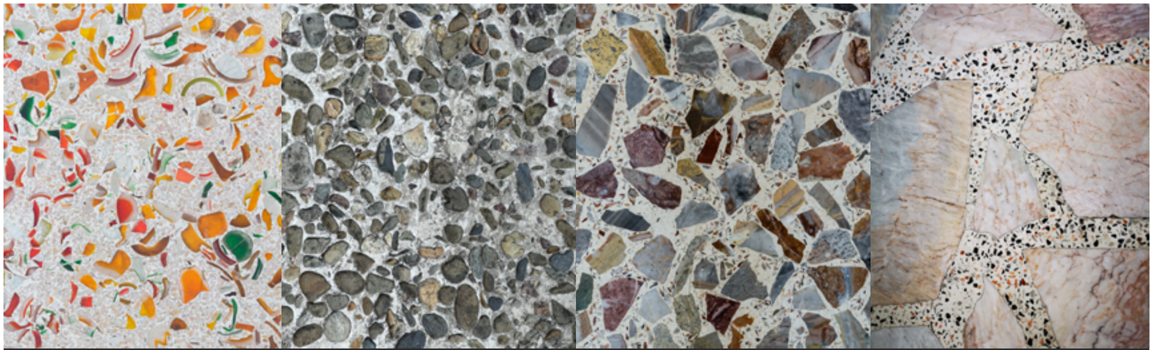

Fig.06/09 Four different terrazzo aggregates: (a) broken glass bottles, (b) unfinished pebble, (c) varying aggregate sizes, (d) large marble pieces.

outdoor furniture, etc. *Terrazzo is an upcycled and relatively environmentally friendly product* as ***the aggregate chips are repurposed waste or by-products.*** Cementitious finishes such as polished concrete and terrazzo are stain-resistant, as long as spills are cleaned and dried quickly. ***Highly acidic or alkaline cleaners*** *can damage concrete and terrazzo, nevertheless, diluted hydrogen peroxide or ammonia can still be utilized.*

BRICK

Masonry *is a method of building structures or surfaces with units or blocks, such as brick, concrete, or stones, bonded together with mortar, a relatively fine cementitious paste.* Masonry units typically manufactured in standard sizes. ***Brick*** *is a common masonry unit manufactured by molding clay into forms, drying them, and then firing them in a kiln at high temperatures.* The standard brick size is 2-1/4" by 3-5/8" by 8" and weighs around 4.5 pounds. There are many shapes and sizes of brick available such as solid, utility, norman, frogged, hollow; some are for decorative purposes others solve unique masonry problems, such as cornering at a specific angle.

First examples dating back to 7000 BCE, bricks have been a staple building material throughout the world with countless local variations in size, color, and composition. Mud bricks were among the oldes building materials, hand mixed, molded, and sun dried. ***Brick veneer*** *became popular in the 1920s. It is still available in 5/8" thick "flat back" units and 3/4" thick with back geometry.* This enabled lightweight decorative applications on wall substrates that appeared

Vid.06/05 Video on working as a bricklayer in the 1940s.

Fig.06/10 Constructed in 1420, the masonry dome of Santa Maria Del Fiore in Florence, Italy spans 144 feet.

like load-bearing masonry walls. Frank Lloyd Wright used the material and exploited the effect in many of his projects.

The general use ***common brick****, also known as burnt clay brick with an untreated surface.* It has a reddish-brown color with a porous but flat facing. Common brick is often used for non-structural masonry work. There are many other versions available, one being the ***engineering brick*** *which is used for demanding applications where strength, durability, moisture, and frost resistance are required. A highly versatile option,* ***face brick,*** *is manufactured for visual exposure and features a wide range of colors and finishes, including blues, greens, glazed, or distressed options.* ***Concrete brick*** is not the same as cinder block, features two hollowed-out gaps and an aesthetic finish; more appropriate for interior applications. Due to its porousness. ***Concrete masonry unit (CMU)*** *is highly versatile, more strong and durable than concrete brick, and commonly used as a construction material for load-bearing*

Fig.06/11 *Frank Lloyd Wright's Xanadu Gallery entrance showcases brick's versatility.*

Fig.06/12 *Reclaimed brick features a unique character.*

masonry. ***Compressed earth block (CEB)*** is manufactured by compacting damp soil under high pressure into the shape of a brick. It is an environmentally friendly manufacturing method, however, the unit output is fairly low and the end product has fairly low abrasion and moisture resistance. ***Rammed earth*** involves the same technique, the resulting product is large blocks or entire floors and walls.

*Brick boasts have **significantly lower embodied energy** than glass, steel, or aluminum.* Brick is a brittle material and there's always some broken ones in every transported batch, on the other hand, thanks to its modular nature breakage is limited to individual units and construction waste is minimized. *Also, its **modular nature** enables expressivity and creative visual statements.* Even though they are not as durable as new bricks, ***reclaimed or antique bricks** can be used for their distinctive character.* They are slightly more expensive and significant visual variability should be expected.

*Brick can be **bonded in many different ways**; every single one providing different structural properties as well as visual character.* Certain bonding methods are associated with different cultures, regions, or eras. ***Stretcher** is the long side of the brick, and the bond featuring bricks laid in stretcher courses with only their long sides showing is called the stretcher bond or a running bond.* Each course is staggered to the half-length of the brick face. *Similarly, **header** is the short side of the brick and only the short side is seen in the header bond. **English bond** is a very strong bricklaying method featuring one stretcher course and one header course in alternation. **Common bond**, or American bond involves a header course between three to five stretcher courses.* Flemish bond, involves courses made up of a stretcher and a header in alternation. These are staggered so that the center of the header in one course meets the center of the stretcher on the course above and below. ***Stack bond** is somewhat weak and can only be used for decorative purposes, features completely aligned stretcher faces with no staggering.*

Brick provides unique texture, pattern, and relief effects when interacting with light and mortar lines can further elevate the efect. ***Mortar lines*** *can be shaped to influence water-shedding behavior besides the aesthetics; they can be concave, flush, angled, recessed, or extruded.* Brick can be painted over for decorative purposes and protection, which can be removed through pressure washing.

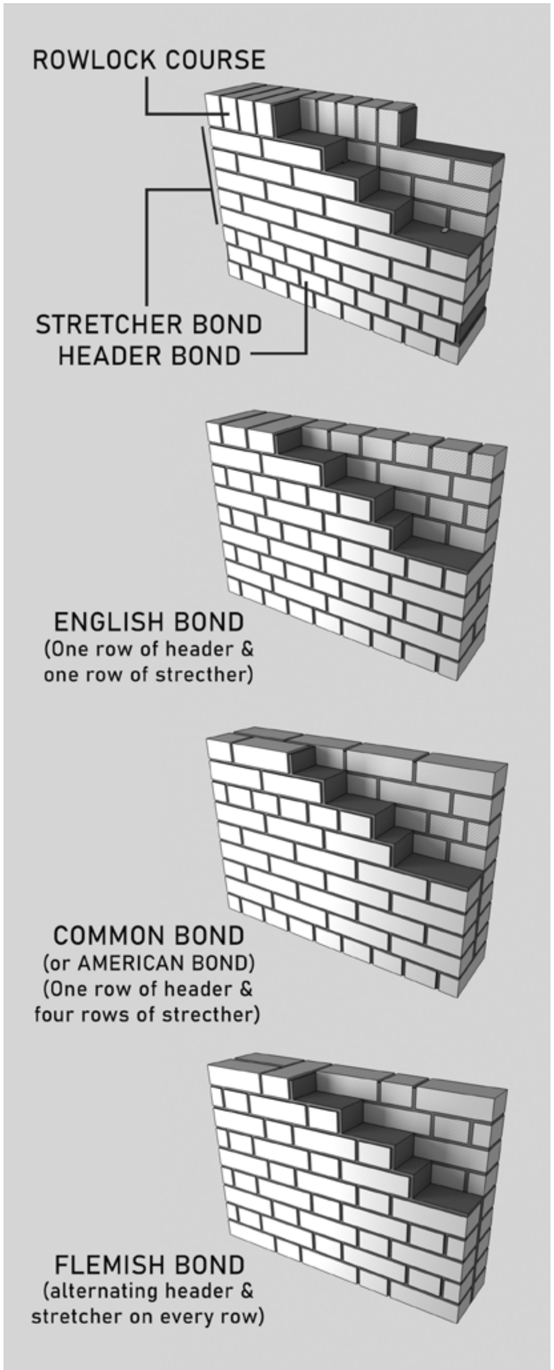

Fig.06/13 A selection of important brick bonding techniques.

Fig.06/14 Brick can be painted over to achieve a more contemporary feel.

STONE

***Rock** is a naturally occurring mineral aggregate. When rock is removed from its bed for various purposes, it is referred to as **stone**.* Stone can be directly used without any processing, or it can be cut, shaped, and, dressed (cut, worked) to create dimensional stone. Stone, alongside wood and mud, shaped early architecture. The earliest constructions often utilized unprocessed stone, boulders, and rubble instead of quarried stone. One of the earliest examples, Skara Brae is a cluster of eight stone houses in a Neolithic village located in Scotland. The Great Pyramid of Giza, built 4600 years ago, is the biggest stone monument today, a testament to the material's strength and durability. Furthermore, natural stone is also highly desirable when aesthetics is a concern, owing to their rich and complex color and texture features. Pietra dura, a technique involving inlaying finely cut, polished colored stones into a stone base, was used extensively in Renaissance Italy.

Natural stone is extracted through quarrying, which involves cutting and removing large blocks of stone from the earth. With the ***diamond wire** technology operations sped up and rapidly expanded to previously hard to quarry areas. Diamond wire technology replaced the **feather and wedge** technique, which involves inserting metal tools called feathers into periodically drilled holes on a line on the stone and pushing wedges into the feathers, to force the stone to split.* This technique is time-consuming, expensive, and the results could be unpredictable as the stone is essentially split instead of cut.

Vid.06/06 *Video on how marble is quarried and finished.*

Depending on how difficult it is to remove natural stone from its bed, its embodied energy can be higher or lower. However, *this is only true for locally sourced stone, as imported stone requires very heavy material to be transported from thousands of miles away,* as some desirable colors and textures can only be quarried in specific locations over the world. For instance, Lava Jewel is quarried in India, or Blue Bahia is quarried in Brazil. ***Quarrying** has a significant negative environmental impact.* Besides scarring an established landscape possibly causing erosion and destruction of habitat, deeper quarries may affect groundwater flow patterns and quality.

Fig.06/15 *Skara Brae is one of the first stone settlements featuring only 8 dwellings.*

Fig.06/16 *The pietra dura technique, developed by Venetians, was extensively utilized in the Taj Mahal.*

Fig.06/17 A 1936 photograph from a Maine quarry depicting how the stones were manually processed.

Fig.06/18 The diamond wire needs to be constantly sprayed water to provide lubrication and manage heat build-up.

Depending on a quarry's proximity to various radioactive elements deep underground, radioactive contamination can occur. Consequently, there's a possibility that natural stone used in interiors might emit radon, as well as beta and gamma rays, however, *the* ***radiation is fairly negligible*** *and does not present any danger to the occupants, according to the EPA.*

Petrology is the study of the composition and structure of rocks, their formation, and transformation. Stone is categorized based on how it was formed. This also determines the hardness of the material. Stones from igneous formations are harder than metamorphic formations which are harder than sedimentary formations. ***Igneous rocks*** *are simply solidified molten magma.* Examples include granite, andesite, basalt, pumice, etc. ***Sedimentary rocks*** *consist of tightly compacted sediment* such as limestone, sandstone, gypsum, and travertine. ***Metamorphic rocks*** *are formed when the pressure and heat conditions around existing igneous or*

Fig.06/19 The Rock of Ages granite quarry is located in Vermont. It is the largest deep-hole quarrying operation in the world, measuring at 600 feet.

Vid.06/07 *Video on rock formations.*

metamorphic dramatically change and force the rock formation to transform. This last group includes marble, soapstone, and slate.

Fieldstone refers to naturally occuring rocks found on the surface of the soil, rather than being quarried. Requires minimal processing, though labor-intensive to construct with due to random shapes and sizes. Broken bits of stone are referred to as ***rubble***. ***Pebbles*** are small rounded stones. ***Tumbled stones*** are processed to have rounded edges and a smooth, weathered appearance, mimicking natural wear over time.***Flagstone*** is flat stone with naturally split layers commonly used as paving material. ***Stone Mosaics*** are decoratively arranged small colored stone pieces. ***Engineered stone****, or commonly referred to as quartz, is mixture of stone aggregate and resin intense heat and pressure, resulting in a highly durable and non-porous surface.* Thanks to its homogeneous resin matrix, it does not require periodic sealing of the surface, unlike its natural counterparts.

The hardness of any stone is expressed by the ***Mohs hardness scale****, which is a comparative abrasion resistance test for minerals.* The hardness rating ranges from 0 to 10. Materials from

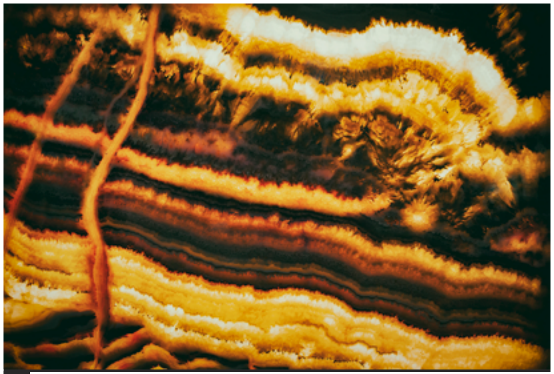

Fig.06/20 The vein structure on onyx results in varying levels of translucency and illumination patterns.

each subsequent hardness rating can scratch the surface of materials belonging to the previous rating. A higher rating means the material is more resistant to abrasion.

Vid.06/08 *Video on quartz manufacturing and properties.*

Natural stones can be specified for countertops and furniture, panels and tiles are used for finishing floors, walls, and many other architectural elements. *Natural stone is* ***heavy and brittle****, consequently, breakage is a common occurrence.* The designer should think about

Tab.06/01 Hardness ratings of various natural stones in accordance with Mohs hardness scale.

Rating	1	2	3	4	5	6	7	8	9	10
Material	**Talc**	**Gypsum**	**Calcite**	**Fluorite**	**Apatite**	**Feldspar**	**Quartz**	**Topaz**	**Corundum**	**Diamond**
Slate		■	■	■						
Marble			■	■						
Travertine				■	■	■				
Granite						■	■			
Engineered Stone							■	■		
Basalt					■	■	■	■	■	

Fig.06/21 Vein cut texture is linear and layered.

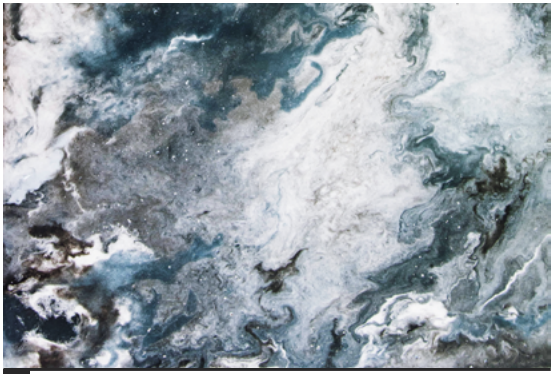

Fig.06/22 Cross cut texture is swirly and cloudy.

how components will be handled and transported to the building site as well as how they will be installed. Natural stone can contain voids, fissures, separation lines that significantly affect workability. The ***Marble Soundness Classification*** *published by the Natural Stone Institute categorizes marbles and granites into 4 groups in relation to the number of holes, voids, and fissures:* “rating A” with minimal proportion of geological faults and highest quality, whereas on the other end, “rating D” with the largest proportion of geological faults. Such holes may be repaired by waxing, sticking, or filling with a polymer resin.

Stone slabs are sawn from larger blocks. Typical slab size is around 5’ by 10’, but the actual usable area depends heavily on the source block shape and it is often assumed to be approximately 45 square feet. The typical slab cuts have 2cm (3/4”) and 3cm (1-1/4”) thickness, custom thicknesses are also possible. Stone slabs can be cut in different ways to achieve different visual effects. ***Vein cut*** *is when the slab is cut parallel to the vein, featuring parallel lines and layers.* ***Cross cut*** *is when the slab is cut against the vein, provides a cloudy complex look.*

When a block of natural stone is cut, it generates a series of slabs with similar color and texture features. Very similar to how wood veneers are matched, in order to cover large surfaces while maintaining a coherent and pleasing visual whole, various matching techniques can be employed. ***Slip matching***, or side slip, involves repeating the same pattern without changing the orientation of the tiles. A very common method, ***book matching*** involves reversing

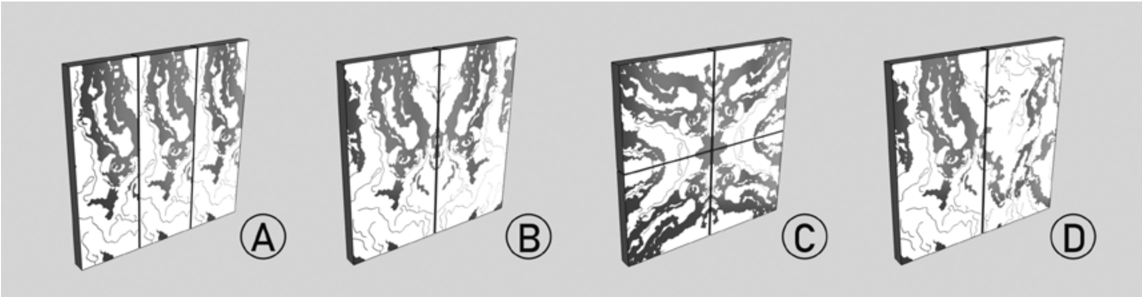

Fig.06/23 Four granite pattern matching techniques are slip (A), book (B), diamond (C), and pattern (D) matching.

one tile to mirror the adjacent tile, resembling an open book. ***Diamond matching***, or quarter match, involves 4 tiles mirrored on two axes creating an impression of a diamond shape with their linear vein structure. ***Pattern matching***, or blend pattern, involves carefully aligning visual features to create a consistent and continuous visual composition.

Even though it can create a lot of wastage, for smaller-sized pieces, such as countertops or furniture components, a ***specific section of the stone slab can be identified and cut*** *based on desired vein structure.*

Also referred to as ***sawn finish***, *stone slabs can be left unfinished after they are cut, which creates a raw, rough, and irregular look.* Or, slabs can be further processed to create polished, honed, leathered, etched, frosted, or flamed finishes. A ***high-gloss polished surface*** *can be attained by grinding, honing, polishing and buffing with progressively finer grit abraders.* Denser stones such as marble and granite can achieve a higher sheen compared to sedimentary stones such as limestone or sandstone. Polished granite is high maintenance, requires daily mopping, and regular waxing and buffing. The polish wears off with traffic exposure. Polished stone is often less expensive and readily available. It has poor slip resistance, not appropriate for exterior applications without surface treatment or walk-off mats. Moreover, the reflective polished surface can cause significant glare, especially for darker colored stones. Installation requires extra care as loose sand and grout smears are capable of scratching the polished finish. ***Honing*** *is another type of smooth, yet not glossy finish achieved through grinding and sanding, but with lesser grit abraders.* Visually, it is more understated than a polished finish, though it can hide dirt and smudges; performs well under heavy traffic where cleaning and maintenance is a concern; provides better slip resistance. It is possible to

Vid.06/09 Video on refinishing polished granite back to honed.

rebuff already polished stone to get a honed finish. ***Leathering*** *is similar to honed granite; it has smooth appearance, but the surface is somewhat coarse and textured.* This finish can hide dirt and smudges slightly better than a honed finish but cleaning and maintenance is harder. Requires additional processing therefore slightly more expensive than honing. ***Flaming*** *involves the application of high heat, typically with a blowtorch, to the granite surface, causing the outermost grains to pop and create a rough, weathered texture.* Thanks to its prominent texture, this finish hides soiling well and provide slip resistance, though it can affect the natural color of the stone resulting in a darker and duller appearance.

There are two common types of masonry, ashlar, and rubble. ***Ashlar*** *masonry involves finely*

Fig.06/24 Ashlar masonry (left) is a stark visual contrast against rubble masonry (right).

Fig.06/25 *Natural stone veneers are being thinset on CMU (Concrete Masonry Unit) wall.*

dressed stones laid in regular patterns with fine mortar joints. The term ashlar also refers to each of the rectangular masonry units. ***Rubble*** *masonry involves undressed or roughly dressed masonry units,* arranged in a seemingly random pattern.

Natural stone can be ***placed in mortar,*** *cement- or polymer-based; or* ***anchored*** *to a concrete or masonry substrate.* Natural stone is very heavy, between 6 to 10 pounds per square foot, depending on tile thickness. The substrate must be capable of supporting the weight without deflection over time. Depending on the extent of the application consultation and site visit with a structural engineer might be needed. *Natural stone tiles are cut with a* ***waterjet****, ensuring minimal dimensional difference between each tile.* This enables the grout lines to be very thin, down to 1/16".

Similar to ceramic and porcelain natural stone can be installed on a substrate with a thinset and thickset method. ***Thinset*** *installation requires consistent and meticulous subfloor preparation,*

Vid.06/10 *Video on granite cutting with waterjet.*

Fig.06/26 *When left to dry, acidic liquids such as lemon juice damages the granite surface.*

especially important for polished finishes for consistent reflections. On the other hand, the mortar bed created with ***thickset*** *installation is appropriate when substrate and slab variations are present.* Stone slabs can be anchored to gypsum board, masonry, or concrete walls with wire ties or it is possible to install with an epoxy-based thinset adhesive for reliable bonding.

Even though the surface of natural stone appears dense and impenetrable, it is actually porous, especially for the rougher finishes, and it is absorptive. Leftover moisture and food is trapped within the tiny crevices and pores, facilitating bacteria growth. Consequently, there is a need for periodical sealant application. Sealers can be topical or penetrating. ***Topical sealers,*** *such as polyurethane (PU) and acrylic, sit on the surface and wear out quickly and require frequent reapplication.* ***Penetrating sealers*** *include silicone and fluoropolymers, which create a stronger bond, however, the finish appears matte, dull, or even foggy if applied improperly.* Acids in common food such as dairy, carbonated drinks, alcohol, or even meat can permanently damage the stone if not cleaned immediately. Natural stone with calcite in their composition, such as marble and travertine can stain and etch by acid exposure more readily, especially if its color is lighter.

07

WOOD

- *Vocabulary for wood products*
- *Forest management*
- *Performance properties and behavior*
- *Prominent wood species*
- *Processing and finishing*
- *Wood veneers*
- *Engineered woods*

Within the context of materials and finishes, wood is often used to reference solid wood, however, wood can come in various forms to suit multiple needs of the designer, such as veneer, engineered wood, or it can be processed into thin layers of paper, impregnated with resin, and bonded to form strong dense boards. ***Solid wood*** *is simply lumber cut from trees into boards, planks, studs, or any regular form, which are called dimensional lumber.* Lumber is dried in kilns, naturally, or in combination to remove the excess moisture so that when transformed into a structure, furniture, or decorative component, the wood won't distort in response to the environmental moisture. ***Veneers*** *are very thin sheets of wood sliced from lumber,* used to laminate other, often more stable or cheaper substrates to incorporate the desirable wood texture without consuming substantially more valuable wood, all the while ensuring high workability and visual consistency. ***Engineered wood*** *refers to veneers, wood dust, chips, or various* *mill yard waste bonded together with polymer resin to create a composite product,* such as plywood, medium-density fiberboard (MDF), particle-board, oriented strand board (OSB), and cross-laminated timber (CLT).

An important classification for solid woods is the ***hardwood vs. softwood*** *distinction, which simply identifies if the source tree was deciduous or evergreen, respectively.* Even though the words hard and soft are mentioned, the classification has little to do with the actual hardness or softness of the wood. For example, Pacific Yew, a softwood, is harder than some hardwoods and Balsa Wood, a hardwood, is softer than many softwoods due to its very low density porous structure. Bamboo is categorized as grass and depending on how it is processed, it can also be harder than some hardwoods.

Like any other category of materials, sustainability is an important consideration when specifying wood. Similar to other materials the overall environmental impact should be considered. Wood has very low embodied energy, easy to process, and local sourcing is often possible as there are many alternative species available for virtually every use. Locally sourcing wood lowers initial energy costs and carbon footprint typically associated with transportation. Designers *should avoid contributing to deforestation by* ***reducing, reusing, and recycling*** *wood and wood products.* Despite having superior performance features and unique textures, exotic woods often encourage deforestation, habitat destruction and loss of biodiversity. Designers should be especially wary of rainforest species from Africa, South America, and Southeast Asia.

Wood is a renewable resource as long as good forest management practices are employed. ***Forest management*** *refers to maintaining forest health and growth, protecting associated ecosystems while reducing hazards such as wildfires or landslides.* Forest management is primarily about conserving the balance of a very complex system, involving activities like controlling various invasive species of trees as they threaten forest integrity, or cultivating younger trees as they sequester CO_2 much efficiently than older trees. Additionally, older trees become more susceptible to disease and rot. *The* ***Forest Stewardship Council (FSC)*** *is a non-profit organization focusing on sustainable forest management operating throughout the world.* If a wood product features a ***Chain-of-Custody*** *certification, it means that from sourcing, to handling, processing, and delivery the wood product meets the standards set by FSC.* An FSC label on a wood product should be sought as it means the material is responsibly

Fig.07/01 Oak is a deciduous tree that supplies hardwood lumber.

Fig.07/02 Good forest management practices ensure that deforestation does not happen.

sourced without compromising the integrity of any forests, ecosystems, or local communities. ***Programme for the Endorsement of Forest Certification*** is another widely acknowledged independent organization promoting sustainable forest management, claimed to be more appropriate for small forest management.

Link 07/01 Link to FSC's public certificate search.

Fig.07/03 Heartwood (cracked core) and sapwood (outer yellowed area) seen on a trunk cross-section.

GENERAL PROPERTIES

The financial and emotional value of solid wood, as well as its usefulness and desirability are linked to the following characteristics: (1) natural grain formation, (2) dimensional stability, (3) abrasion resistance, (4) workability and finishability, (5) weathering.

Visual characteristics, such as the color, texture, and definition of the natural grain formation can vary between different species, between the same species growing in different soil and climate conditions, also, within the same tree between sapwood and heartwood. *The changes in **growing conditions** year over year determine grain formation, introduces a lot of visual variation.* Lighter rings are called *earlywood or springwood* representing fast growth at the beginning of the season and darker rings are called *latewood or summerwood* and they are typically denser. The transition between them can be gradual or abrupt affecting performance and workability. Overall, *slow-growing trees with narrower and denser growth rings tend to be harder and stronger than fast-growing trees with wider and more juvenile growth rings.* Another important distinction is the sapwood and heartwood. ***Sapwood** is the actual growing part of the tree*, usually has lighter color and features. As the tree grows, inner sapwood layers go through a chemical transformation and become heartwood, providing structural support for the tree. ***Heartwood** is often denser, stronger, and has less moisture content.* Trees can endure various outside effects disturbing their natural growth, ultimately creating some unique grain figuring. *This **deformed growth** is commonly referred to as burl.* The cause may be injuries or virus infection. Insect and animal intervention can cause various figuration as well. *There are also various **types of decay** that can produce desirable visual results,* such as spalting which is the formation of black lines caused by fungal decay. The visual quality of such deformations is desirable and they are often used as wood veneer. Due to their rarity they are typically expensive.

*Being a **hygroscopic** material, in other words, reactive to environmental humidity, solid wood responds to moisture by expanding and contracting.* Wood shrinks or swells most on the tangential direction (across the grain), less on radial direction (approx. 50% less), and neglectable on the longitudinal direction (along the grain). Finished wood will still acclimate and move, and this movement can happen multiple

Fig.07/04 *Despite being a growth anomaly, burls have highly desirable visual character and are expensive.*

Fig.07/05 *Spalting is not a defect but a fungal decay that forms colored streaks.*

times within a year as environmental humidity changes. The movement is highly dependent on the species of wood, how it was cut, and if it was dried and acclimatized appropriately or not.

> *Bigger lumber pieces are* ***subject to more movement****, which is one of the reasons for the cracking of lacquers and polyurethane coatings on larger wood planks.*

A log is, in the most basic sense, a cylindrical object that is made up of conical layers of slightly undulating growth rings. Lumber, on the other hand, is a planar product. The sawing direction of the lumber determines the visual and performance properties of the resulting wood product. There are three common sawing methods to extract lumber: Plain sawing, quarter sawing, and rift sawing. ***Plain sawing****, the least wasteful and cheapest cut, involves cutting the log into parallel slices along its length.* This method creates the characteristic elliptical grain lines, in some sources referred to as cathedral peaks. The biggest disadvantage, aside from inconsistent grain structure, is that the resulting tangential grains are more susceptible to moisture change, causing further warping. *In* ***quarter sawing****, the log is sawed into quarters, then each quarter is sawn towards the log's center.* Grains are parallel on the longitudinal axis, hence there is more dimensional stability and little chance of shrinking and swelling. Lastly, ***rift sawing*** *involves cutting the log perpendicular to the growth rings creating the most consistent parallel grain*

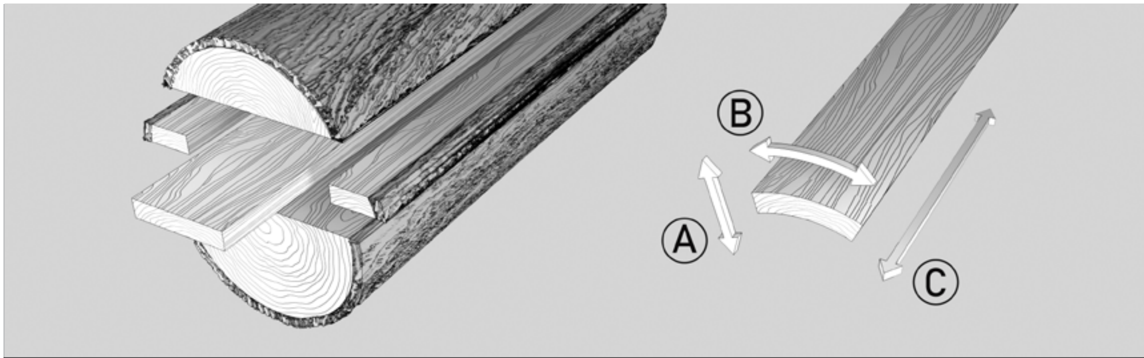

Fig.07/06 *Radial (A), tangential (B), and longitudinal (C) dimensions of lumber and warping tendency on radial dimension.*

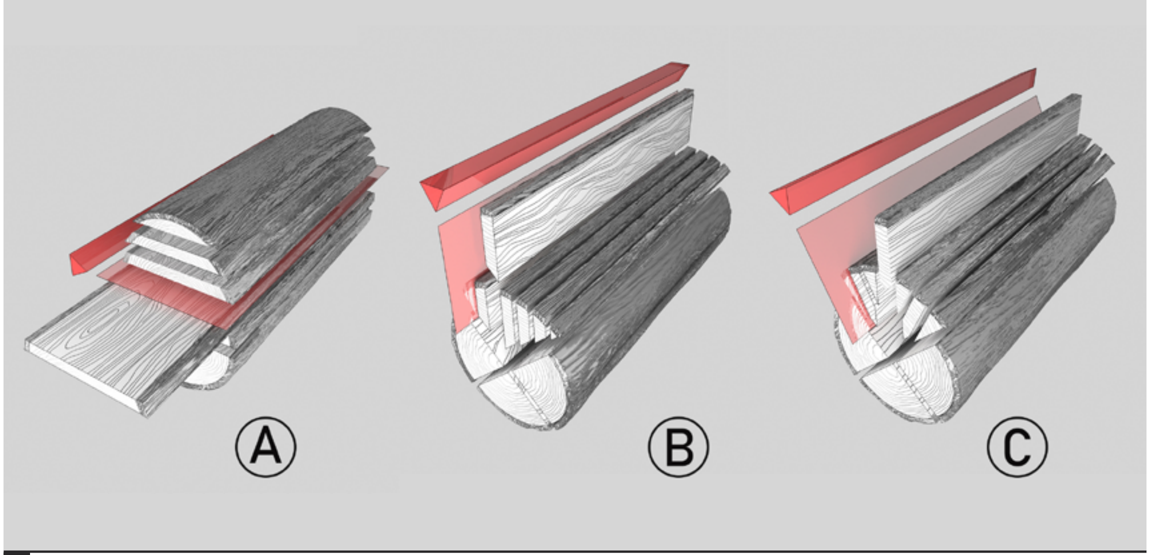

Fig.07/07 *Common lumber sawing methods include plain sawing (A), quarter sawing (B), and rift sawing (C).*

texture as well as minimizing the possibility of dimensional movement. Rift sawing is often a byproduct of other sawing methods as it causes low yield and relatively useless wedge-shaped wastage between each plank.

The cuts are made in order to obtain wood products useful for a variety of purposes, so it is possible to see multiple types of cuts employed on a single larger log. As an example, for flooring planks (wider than 3”), strips (narrower than 3”), and parquet strips (narrower than 1”, arranged in geometric patterns) are used. *Sawmills cut hardwood to obtain the **best yield at a specified thickness**, as a result, pieces of lumber won’t have a consistent outline.* Hardwood lumber thickness is expressed in quarters – 4/4 means 1” thickness, and 6/4 means 1-1/2” thickness. These are nominal values and actual value depends on if the lumber is rough sawn or planed. In dimensional lumber manufacturing, *the word **nominal** means “in name”, which is different from the real value.* a 2-by-4 wood stud actually measures 1½ inches by 3½ inches. The principal reason is, when the wood product is ***dried, planed, sanded, cured, etc.***, its dimensions become smaller and smaller.

The working properties of different species of solid wood can be found and compared in categories such as machinability, stability, gluing, sandability, nailability, stainability, and paintability. These are often approximations and can vary based on the sub-species, growing conditions, lumber grade, etc. ***Hardness and density** of a solid wood is also a determining factor for its workability.* The harder the wood is the harder it will be to cut and mill, the blades and tooling

Fig.07/08 *A pine log being processed on a modern automated milling machine.*

bits will be blunted very quickly. Another important parameter for workability is the ***consistency of grains*** *and the presence of knots, streaks, spots, and other blemishes. These might cause some lumber to split and check during sawing.*

The cellular structure of the wood is a significant determining factor in finishability. Some wood species with *larger cells have open pores, broad rays, and an* ***open grain****, has an ability to soak up stains,* though in order to achieve a truly smooth finish a filler application may be needed before the topcoat. On the other hand, some wood species have *smaller cells, fewer pores, thinner rays, and an overall* ***tight grain****.* These woods are harder to stain, especially when sanded too finely, and pre-stain conditioning might be necessary to prevent an uneven look. *The presence of* ***knots and other blemishes*** *can be problematic as these can bleed resin or simply create an uneven surface that is harder to finish consistently.*

The abrasion and denting resistance of the solid wood product depends on its hardness. When hardness is mentioned in the context of materials and finishes, it refers to the ability of a material to resist deformation under stress or impact. The hardness of various wood species is measured by the ***Janka Hardness Rating****, which involves embedding a .44 inch diameter steel ball halfway into a piece of wood and measuring the deformation.* This rating is very useful for making comparisons. For instance, when specifying flooring for a high-traffic area, a wood species with a higher hardness rating would perform better against the expected wear and tear.

The species at the top of the hardness scale are usually ***exotic woods****, which are expensive and slow-growing but more importantly specifying them would possibly encourage unsustainable wood sourcing practices.*

Vid.07/01 Video on the Janka hardness test.

Wood can weather, oxidize, develop a patina, and fade. UV exposure affects each species differently. Some wood species develop a desirable tint in a matter of months, and others can bleach and turn gray over the course of a few years. Using UV/Fade resistant protection, such as acrylic-based finishes, would slow the process, but in some cases fails to completely eliminate it. *The designer should always be mindful of how* ***UV exposure*** *will affect a material, as it is possible to cause visual inconsistencies over time.* For instance, the wood flooring underneath an area rug won't fade at the same rate as the flooring around it. When the rug is removed, the resulting visual inconsistency might be jarring and undesirable. ***Surface finishes can also age and weather.*** *In general they dry out and harden in time, cracking and peeling, in addition to darkening or yellowing with dust and UV exposure.*

The National Oak Flooring Manufacturers Association (NOFMA) or currently known as ***Wood Flooring Manufacturers Association*** *has*

Fig.07/09 Wood shingles on different facades clearly depict the weathering effect of UV exposure.

established wood quality grades, to help with solid wood specification. There are ***4 grades available****, from higher to lower: First and Second (FAS), Select, No 1 and No 2 Common (1C and 2C).* ***First and Second (FAS) grade*** features minimal defects and grain variations, and comes in as longer and wider boards. On the other end, in ***No. 2 common grade***, there is considerable visual variation and defects throughout. Common grade is appropriate for utility applications where appearance is less critical, or the design calls for a more rustic look.National Hardwood Lumber Association (NHLA) also publishes a rulebook that contains guidelines for inspecting and grading solid wood products. The identification rules are numerous and complicated, however, the logic is similar to the NOFMA quality grading method.

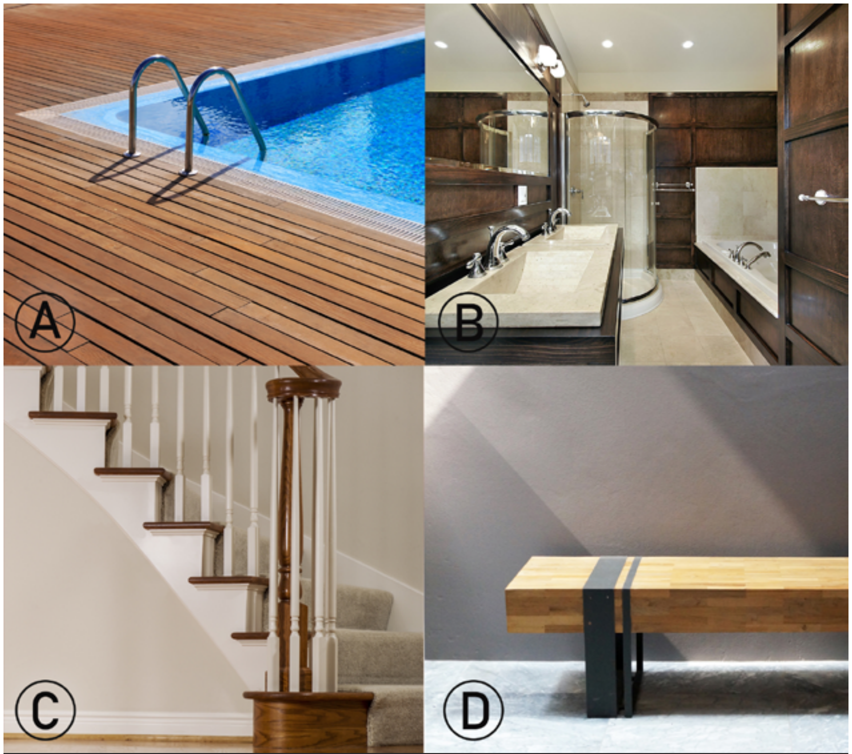

Fig.07/10 Common solid wood applications: flooring – teak hardwood decking (A), paneling - American walnut paneling (B), trims and details - oak stair trims (C), furniture - hickory blockboard (D).

Vid.07/02 Video on hardwood lumber grades.

The cost factors for wood are diverse and pricing is determined based on ❶***the type of wood*** (type, rarity, supply and demand, transportation), ❷***quality/grade*** (official grade, size and thickness, treatment and finishes), and lastly, ❸***the size/complexity of the job*** (includes quantity, skill level, prepwork, installation, maintenance, etc.). *Lumber prices can fluctuate based on various bottlenecks in the supply chain*, a %300 increase was observed following the COVID-19 pandemic, in the span of only 6 months.

Beyond solid wood lumber, the trunk of a tree can supply additional wood resources. The outer bark of the tree is a protective tissue surrounding the vital outer layers of the woody core, which transports water and nutrients along the length of the tree. Besides forming a protective barrier, bark has antimicrobial properties, resistant to decay, especially strong against outdoor conditions, water and moisture, due to its waxy constitution. ***Cork*** *is actually the bark of a species of tree known as the cork oak, mainly grown in Southern European countries such as Spain and Portugal.* Properly removing bark requires skill. It is usually done manually, as damaging the inner bark can be fatal for the tree.

Cork is a great thermal and sound insulator, and being naturally impact-resistant, it prevents transmission of vibrations, making it a great underlayment. *Cork is a* ***rapidly renewable*** *material; after harvesting, it regrows within around 10 years.* Owing to its structure of millions of microscopic closed air pockets it is resilient, it returns back to its original shape after the pressure is removed. *Furthermore, cork cell walls contain a waxy substance, making it* ***hydropho-***

Fig.07/11 The laborious traditional methods of cork extraction are still widely employed today.

***bic**, meaning it does not absorb water.* The cork panels commonly used in construction are actually grounded and agglomerated cork, whereas the highest quality cork is used as wine bottle stoppers. Cork is antistatic and antimicrobial; it would inhibit mold growth. Cork can have somewhat random and unpredictable visual features, which can be a blessing and a curse. There are some significant disadvantages to the material, such as heavy objects may leave marks, when subpar binders are used it tends to break into pieces, and sunlight causes fading. When specifying cork under heavy traffic the designer should consider that it is porous and uncleaned spills can cause staining, furthermore, it cannot endure the harsher cleaning products such as ammonia or bleach.

SPECIES

Every piece of lumber features several properties making them suitable for some tasks and unsuitable for others. It is likely to observe property differences ***between sub-species*** and even between the ***heartwood and sapwood*** of the same exact tree. There are also many examples of referring to different species with a single name. Such as, oak which actually refers to 30 to 60 different tree species with similar properties, each available in multiple different regions. When considering a wood species, the designer should consider factors such as hardness, strength, dimensional stability, resilience, grain and pore structure, color and texture, workability, maintenance, and of course price range and availability.

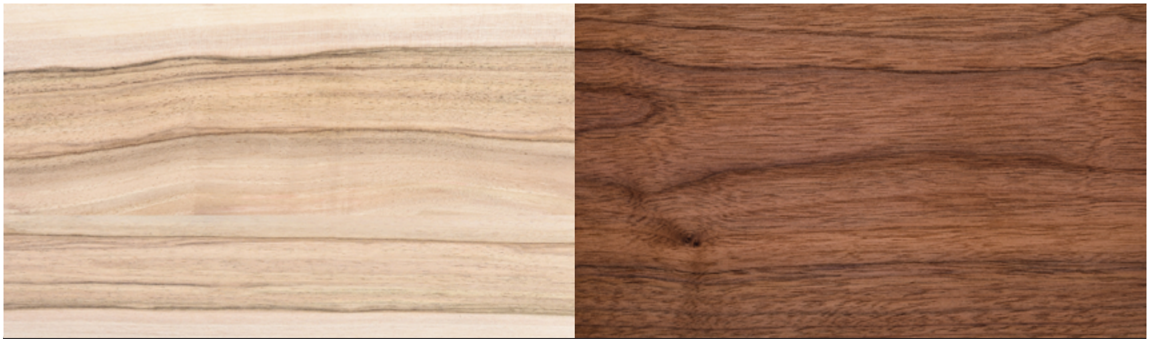

Fig.07/12 The color difference between Walnut sapwood (left) and heartwood (right) is dramatic.

Fig.07/13 *Hickory heartwood.*

Fig.07/14 *Maple sapwood.*

HICKORY ● Hickory is a hard, heavy, and strong species, often considered a utility hardwood. The color difference between heartwood and sapwood is distinct, ranging from pale-yellow to dark brown. The texture is uniform and the grain is fairly straight. High bend strength enables shaping around tight curves. Its hardness and density provide resistance against crushing and denting, however, workability is relatively low. Requires sharp tools and quickly dulls edges, though it can be smoothened well and can hold fine details. Hickory is widely available and priced in the low to mid-range.

MAPLE ● Maple is a hard, dense, and strong wood, resistant to wear. Commonly used for flooring. Sapwood is pale yellow-cream and more commonly utilized. Heartwood is reddish-brown, almost mimic more expensive cherry and mahogany, especially with darker staining. It has a fairly consistent texture with faint and closed grain, as a result it stains unevenly. Abundant and moderately priced. There's a hard and a soft maple distinction, which is based on surface hardness difference of around 60% to 100%.

OAK ● Oak is a highly versatile and widely used hardwood species, commonly seen in many residential interiors, making up almost 70% of all hardwood flooring. Sapwood is white to light brown and heartwood is light to medium brown. It has consistent texture and coloration. Owing to the very characteristic open pores, it stains and finishes very well. It features high workability, and moderate dimensional stability. There are two common types, white and red oak. White oak grows slower than red oak, slightly heavier, denser, and durable. Red oak has a slightly reddish-pinkish tint; lighter, cheaper, and more workable than white oak. Northern red oak is commonly used as a comparison standard in the construction industry.

ASH ● Ash is a family of multiple species with similar properties. It features nearly white sapwood, and depending on sub-species, the heartwood can be grayish, creamy, or brown. The grain is straight and open. Black ash has more contrast in grain coloring, tighter grain spacing compared to white ash. Highly workable and steam bend-

Fig.07/15 *White oak.*

Fig.07/16 White ash.

able. It has relatively high density and hardness. Relatively inexpensive alternative to hickory.

BEECH ● Beech is a dense and hard species with great workability. Commonly used in plywood manufacturing. The texture is somewhat plain with pale tan sapwood and pinkish-brown heartwood. Its grain is straight and moderately tight, however, it is also porous, takes surface treatments well. Somewhat resistant to abrasion and finishes well. Highly suitable to steam bending, used in the construction of famous Thonet chairs. Darkens when steamed. Dimensional stability is problematic and there's considerable shrinking. Widely available and relatively cheaper. Comparable to birch, beech is slightly stronger with more texture definition.

Fig.07/17 Beech sapwood.

Fig.07/18 Yellow birch.

BIRCH ● Birch features a similar appearance to beech, its texture is more subdued and uniform. The sapwood is white to yellow, and heartwood is light to golden brown. Porous, stains and finishes well. It has high workability but due to grain figuring it is also prone to splitting. Carvable and turnable. Relatively flexible with high bendability. Commonly used as veneer, often in plywood manufacturing. There are many iconic pieces of furniture featuring birch plywood. Abundant, widely used, and relatively cheap.

ALDER ● Alder is the softest among widely available hardwoods. Dents very easily, has a smooth and consistent texture. There isn't much distinction between sapwood and heartwood. Normally white to pale-tan, oxidizes to golden-tan or brown

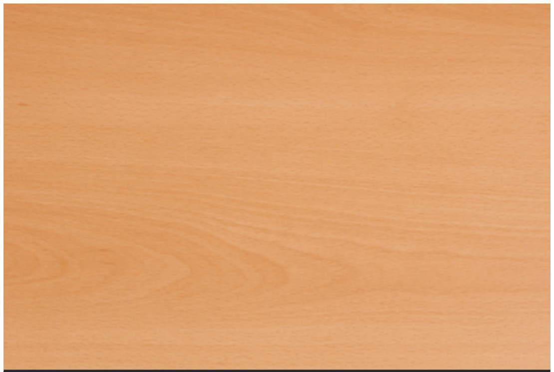

Fig.07/19 Alder.

Fig.07/20 Black walnut.

during the drying process. Knots and mineral streaks are not uncommon. Highly workable and machineable. Planes, sands, and finishes well. Commonly used for kitchen utensils, toys, and millwork.

WALNUT ● Walnut sapwood is cream to light brown and heartwood is brown to dark brown with blackish streaks. The very unique and highly desirable color is fairly uniform for sapwood and heartwood separately but there's a dramatic jump in between. It has an open grain structure, the sapwood can be steamed and stained to darken. Dense, hard, with medium to high workability. Carvable and turnable. Planes, sands, and finishes exceedingly well. Resistant to warping and shrinkage. Resistant to decay and weathers well. Even though a domestic species, considered premium hardwood and relatively expensive. Consequently, popular in veneer form.

CHERRY ● Cherry is another popular premium hardwood. A domestic species, slightly less expensive than walnut. Highly figured and defined grain. Sapwood is pale yellow to light brown and heartwood is reddish-brown. Oxidation and UV exposure causes the wood to quickly develop a darker orange-amber tint. The tree itself is already small, but, due to over-specification only small pieces of lumber available. Fairly stable after drying. Medium to low workability, difficult to stain evenly. Can finish well, though requires significant skill.

MAHOGANY ● Mahogany is a premium hardwood, available only as import. It is listed among vulnerable species. Desirable due to unique visual features; has a tight and interlocked grain structure and shifts color based on viewing angle. Its sapwood is pale pink and the heartwood is reddish-brown. Stains well due to the presence of large pores, finishes exceedingly well. Highly stable, rarely warps or checks. Lighter and softer than walnut and highly workable. Despite being an imported wood it is cheaper than walnut yet more expensive than cherry.

Fig.07/21 Cherry.

Fig.07/22 Mahogany.

Vid.07/03 Video depicting the color shift (chatoyancy) of mahogany.

PINE ● Pine is a softwood with very good performance properties, commonly used as construction lumber. Easy to cultivate, abundant, and relatively cheap. Sapwood is pale yellow and heartwood is golden brown, referred to as heart pine. It has medium contrast in grain texture, and it is fairly recognizable. Depending on the cut it can feature characteristic knots. It has high workability and it can last very long with good protective finish.

DOUGLAS FIR ● Douglas Fir is a softwood obtained from a large growing evergreen/coniferous tree. Due to the size of the tree high-quality knot-free timber can be obtained in long lengths. Moderately resistant against elements, infestation, and rot. It features high workability and dimensional stability. Widely used in construction and can meet demanding performance requirements. Its appearance is distinctive, the heartwood is yellowish-to reddish-brown, and the sapwood is cream, with very pronounced straight grain when quarter sawn. Finishes well.

Fig.07/24 Douglas fir.

RED CEDAR ● Red Cedar is another evergreen/coniferous tree that is renowned for its natural resistance to moisture, decay, and insect infestation. It is low density, light, and workable. Commonly used in the exterior for decking, siding, and roofing. It is a fairly small tree and the lumber can feature knots, streaks, and other blemishes. Straight grain, pinkish to yellowish in sapwood, purple-red color in heartwood. Has a very distinctive smell.

EXOTIC WOODS ● There are a plethora of exotic wood species available with very unique visual features and outstanding performance properties. Ebony, Rosewood, Zebrawood, Wenge, Teak, and Iroko are some vulnerable and endangered species that have been over-specified and extensively logged. Before specifying an exotic wood, the designer should consult with the lumber

Fig.07/23 Eastern white pine.

Fig.07/25 Red cedar.

Fig.07/26 *Zebrawood.*

Fig.07/27 *Reclaimed wood.*

supplier and consider possible alternatives first. *For visual features, **engineered veneers** can be a good, environmentally friendly substitute.*

RECLAIMED WOOD ● Reclaimed Wood refers to the wood obtained from dismantled structures or products, often old barns, old casework, shipping crates, or ships themselves. Features a highly desirable weathered look. Even though essentially discarded lumber, reclaimed wood is relatively expensive due to the labor required for sorting, cleaning, de-nailing, planing, sanding, refinishing work. Aside from trusted resellers, it is also possible to directly source unprocessed reclaimed wood, which might have significant defects such as termite damage, warping, dirt, rusted fasteners, and overall inconsistency in quality. Reclaimed wood can be dimensionally stable due to the long time spent acclimatizing. White oak is commonly available as reclaimed wood, however, it is possible to find some wood species that are rare and expensive, such as chestnut. It is possible to find some larger-sized lumber that are not readily available today.

Vid.07/04 *Video on working with reclaimed wood.*

PROCESSING

All lumber need to go through an initial drying process so that the excess moisture content can be expelled and a balance can be reached. There are two wood drying methods. ***Air drying** involves stacking the wood in the open in a way that allows air flow.* This is a slow process sometimes taking years, and there's a limit to how much moisture can be expelled. *The other method involves drying lumber in large kilns. Known as **kiln drying**, this method is faster and the wood can be dried further,* however, it is expensive and various deteriorations such as

Fig.07/28 *Lumber drying kiln.*

warping and checking may occur depending on lumbers position in the kiln. It is also possible to utilize a combination of both. *Surface moisture content for solid wood has to be **6-9% for interior use**, and **9-14% for construction and exterior use**.* For different regions, the average equilibrium moisture content differs based on relative humidity. Coastlines such as parts of Florida and California (11%) demand higher moisture content than inland areas (8%), and then there are the arid areas such as parts of Arizona, Nevada, and Utah (6%).

Wood responds to the relative humidity of the environment, and while doing so the material expands and shrinks. This should be considered when specifying solid wood for various uses. Seams, gaps, or kerfing can be provided to accommodate movement, or miter joints might be avoided with wood species that are more susceptible to movement, such as beech or birch.

*When joining wood from different sources (species, heartwood/sapwood, kiln/air dried, reclaimed, etc.) it should be considered that both will **respond differently to moisture** and dimensional change might vary, straining the assembly.*

Fig.07/29 Moisture content of the environment causes the wood to expand and contract.

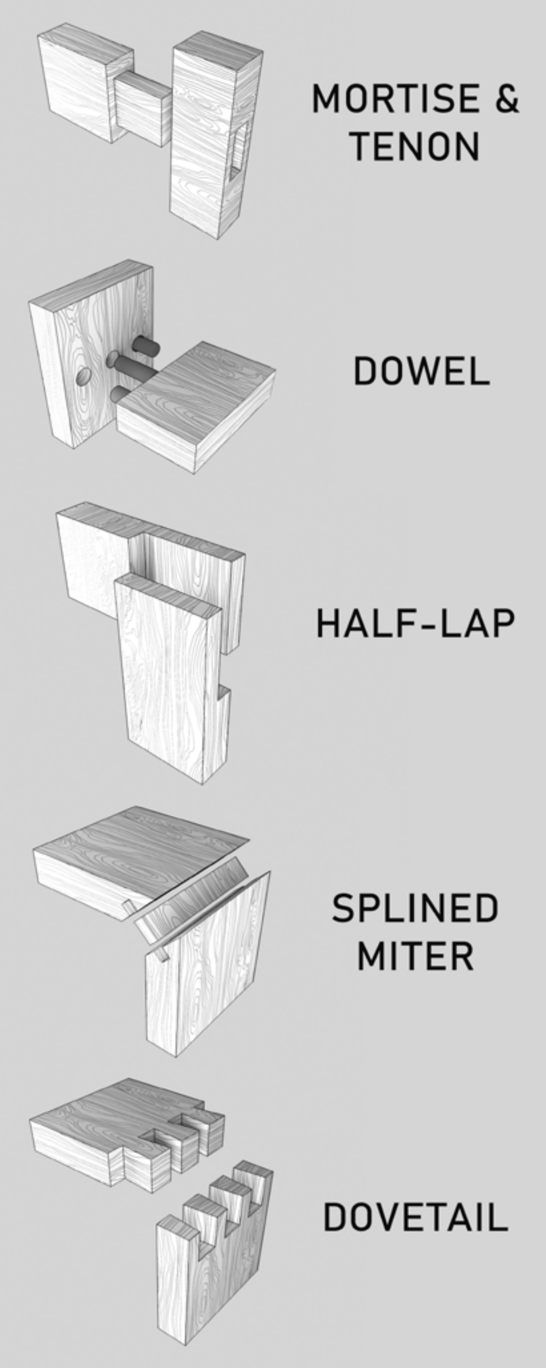

Fig.07/30 Common wood joinery types.

Vid.07/05 *Video on the intricacies of drying lumber.*

Type of joinery can allow for expansion and contraction without damage to components. An additional important consideration is the ***sources of moisture** surrounding the wood component.* For instance, when planning to apply wood flooring on concrete, the designer should be wary of the likely moisture draw and should specify details to minimize moisture transfer, such as pads or sleepers. There are various ways to measure moisture in materials, both from the surface and through probing. It is better to write down the required conditions in the initial specification document than dealing with weeks of re-flooring later.

***Acclimatization** involves placing and aerating the wood in the environment in which it will be installed, so that the moisture content is at an equilibrium before the installation.* The time to acclimatize can be between 3 to 7 days, depending on the species of wood and how it will be finished. Before attempting acclimatization, the moisture content of the surrounding environment should be already stable. For example, if there's wet paint, it needs to dry or the concrete needs to completely cure first.

*It is possible to **treat the lumber** with pressure and heat to achieve protection against moisture-induced deformation, rot, insects, and decay.* It is also possible to infuse fire-retardant chemicals to the lumber during the process. It should be noted that pressure treatment and thermal modification are two different processes with different price ranges, performances, and aesthetics. Though not appropriate for most typical structural applications, these products require less maintenance and are often preferred for exterior applications like decking, siding, etc., or when the wood is expected to be in contact with concrete or masonry through which moisture can easily travel. *Treated wood can **corrode metals** over time when in contact, a protective coating on fasteners is required.* Acrylic Impregnated Wood is another modified wood where pores are infused with acrylic resin throughout the wood, making the wood highly dimensionally stable and moisture resistant.

Solid wood can be finished by one of the many stains, seals, and coatings. ***Factory finished** solid wood products are available; or wood can be finished in the workshop or on the site.* Even though it is slower, finishing wood later on can be advantageous in terms of fine-tuning and matching color, but some VOC emissions and dust should be expected, and ventilation time should be accounted for before move-in.

Before the application of any finish coating, the wood substrate should be carefully prepared. The wood might contain cracks, wormholes, knots, and *the various inconsistencies should be treated with **wood filler**. **Sanding** involves applying progressively higher grit sandpaper to smoothen out the wood surface.* Some premium hardwoods such as walnut and mahogany can

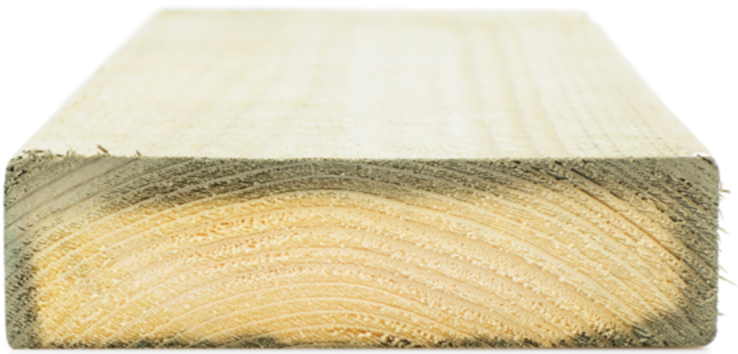

Fig.07/31 *The preservative use in the pressure treatment provides significant protection but harms the structural integrity of the lumber.*

receive finer sandpaper well, while others such as Douglas fir and pine, cannot. Sanding should be applied carefully, always along the grain and after the filler is completely dried. The dust should be completely removed following sanding. *A **wood conditioner** applied shortly before staining helps open up pores and ensure consistent application*.

***Wood stain** is a solution that deeply penetrates the wood and affects color and grain definition.* It can be transparent to enhance the natural visual features or to camouflage the imperfections and inconsistencies on the wood, or anywhere in between. Before applying any coating, water and conditioner can be applied to open up pores. Multiple coats can be applied for better effect. Different types of wood accept stains differently. With its open grain structure oak takes stain well, maple is harder to stain due to its tight grain. On the other hand, for pine, even though it is absorptive, the results would be uneven.

*The designer should consider **compatibility issues**, such as water-based vs. oil-based, between each layer of conditioners, stains, and topcoats, as these can significantly deteriorate performance.*

Vid.07/06 Video on various wood finishes.

Stains only color or tint the wood and they don't provide protection. Therefore, a protective topcoat is often needed. *The most common types of wood finishes are **oil finishes, varnishes, shellac, lacquer, and wax.*** It is possible to flame and char the surface of some types of wood to create a unique look that enhances grain patterns. The surface can be further finished with other coatings after the charcoal dust is completely cleaned.

***Varnishes** are a type of topcoat, often clear, applied as multiple layers of film coating on the wood surface. It isn't absorbed by the wood.* It protects and preserves the wood and makes maintenance and cleaning easier. Stains are absorbed and need to be applied before varnishes. *Varnish can have a tint and different levels of sheen, down to anti-shine matt.* Can be applied with brushes or wiped-on, and some types are available as spray-on. There are different resin-based varnishes with different properties. A water-based acrylic will generate

Fig.07/32 Sanding should be performed across the grain and never against the grain.

Fig.07/33 Stains can alter wood's look to such an extent that identifying species requires careful inspection.

fewer VOCs, on the other hand, alkyds are more water-resistant but generate more VOCs. ***Polyurethane (PU)*** *is another type of varnish that is more durable and applied where intense traffic is expected, such as on floors.* PU varnish is hard and brittle and it can crack if the wood substrate is not dimensionally stable. Polyethylene (PE), is another such alternative.

Natural oils and waxes are a different class of finishing options. ***Oils*** *can penetrate the surface to an extent but not durable as other applications, they can wear or wash off.* ***Wax*** *can be applied as a bare minimum to finish wood or to add sheen and for shedding water.* Other finishes won't adhere to wax, so it needs to be cleaned if an additional layer of topcoat is considered. ***Shellac*** is another similar type of finish that has been in wide usage since the 16th century. It is extracted from natural sources, specifically from the secretions of the Lac bug. It does not feel plasticky and is non-toxic.

Lacquer *is a fast-drying coating, similar to varnishes. It is sprayed on in multiple thin layers that slightly dissolve into each other, creating a thick and smooth coating.* Can be transparent or opaque, there are also high sheen and matt versions available. Lacquer has a desirable elegant look, though it is not durable. Some types are brittle and crackle over time, especially on larger pieces of wood that deform relatively more.

Depending on the species, wood weathers in unique ways based on exposure to elements and most importantly sunlight. Poor construction and finishing, as well as weat, tear, and damage can result in a distressed and rough look, which may be desirable in some cases. *Most finishes cannot block all* ***UV content*** *in sunlight, allowing for the wood beneath to weather.* Most species of wood will darken first and then turn gray. Cherry wood readily weathers and its color tints over time through exposure to air and light. *Sapwood and heartwood can weather at different rates and the color distinction may become pronounced over time.* For wood that is expected to be exposed to sunlight, a layer of UV protective finish will be needed. It is also possible to chemically weather wood and quickly develop a patina.

Fig.07/34 Solid wood and veneer can be sanded and refinished multiple times.

> *The designer should consider that, depending on their thickness, solid wood and veneers can be* ***sanded and refinished*** *multiple times. Some solid wood and veneers are very valuable and refinishing them saves significant cost while minimizing environmental impact.*

VENEERS

Wood veneers *are thinly sliced wood sheets that are applied onto a core panel to be used in furniture, cabinetry, flooring, and paneling.* It has been a widely employed method throughout history to maximize surface coverage of rare woods and also to maintain costs. Ancient Egyptians first used hand sawn wood veneers in furniture making in around 2000 BCE. Veneering gained popularity after Renaissance, and with machine sawing techniques developed during the industrialization period, veneer use

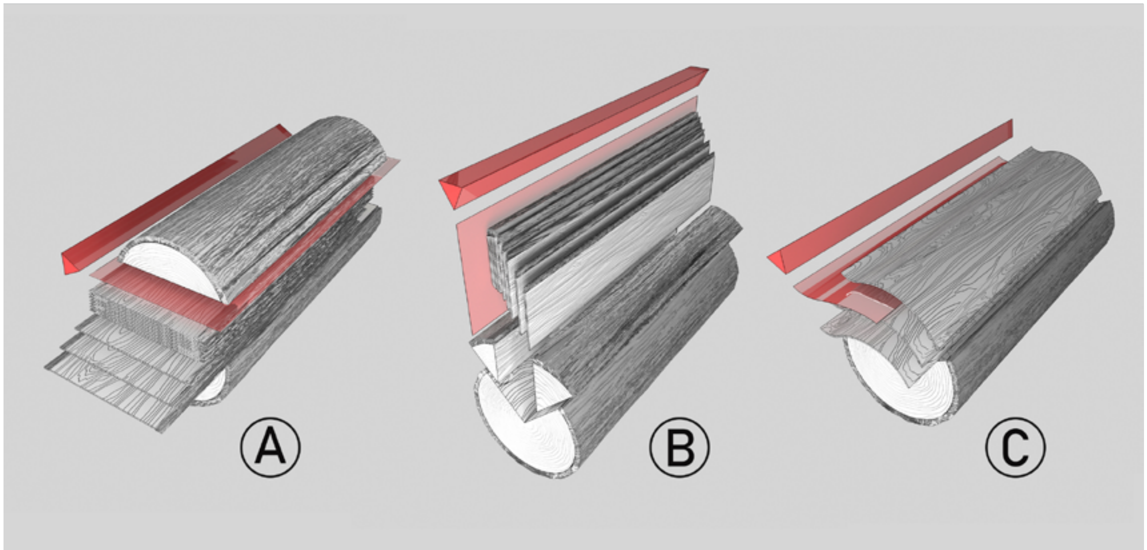

Fig.07/35 Common veneer slicing methods include plain slicing (A), quarter slicing (B), and rotary slicing (C).

became truly widespread. Today, veneer sheets as thin as 0.23 to 0.36 inches can be easily and consistently achieved.

Flitch *is a stack or sequence of veneers that have been sliced from the same log and are kept in order*. Very much like the way the wood is cut, the way the veneer is sliced ultimately affects the texture. Wood can be sliced around the circumference (rotary peeled) or across the width (straight sliced), each approach resulting in a different pattern. ***Rotary peeled*** *is a good option when sapwood or heartwood consistency is sought after.* ***Straight sliced****, on the other hand, emphasizes color and grain.* Plain slicing or crown-cut veneer will give the familiar elliptical pattern, and quarter-cut veneer will feature a uniform and linear grain structure.

Types of wood veneer include raw, backed, and reconstituted veneers. ***Raw veneers*** *feature no backing and are fully exposed, therefore can be fragile and difficult to work with.* Veneers can be of different thicknesses. *For example,* ***shop-sawn veneer*** is around 1/8" thick, appropriate for sanding and penetrating finishes, it can be refinished after a period of use. There are numerous backing options for veneer such as ***paper, polymer, fleece, foil, or wood.*** The backing imbues the veneer with strength and stability, while potentially improving adhesion to the substrate. Lastly, ***reconstituted, engineered, or composite veneers*** *are manufactured from fast-growing wood species, where veneers are dyed, glued, and re-sliced to create the desired effect. They are an economic and versatile option with high visual consistency.*

Fig.07/36 Wenge, an endangered exotic lumber, can be easily imitated with veneer reconstitution.

Vid.07/07 *Video on reconstituted veneer manufacturing.*

Vid.07/08 *Video on wood veneer application.*

Using veneers minimizes the overall impact of wood consumption while enabling designers to utilize the much desired appearance of the wood grain. *Veneers allow for **expensive and rare woods** to have higher surface coverage.* Even though veneers are thin layers and their impact is significantly lower than solid wood, there's still a need for cutting down trees, and high demand for exotic woods can still create environmental repercusions. Another advantage of veneers is that *some species and types of wood that would be **unstable and unworkable as solid wood** can be highly workable when affixed to a stable substrate.* A prominent example of this is burl wood veneer.

*Veneers are typically applied on a **dimensionally stable flat substrate**, such as plywood, particleboard, and medium-density fiberboard.* A large variety of adhesives can be utilized in the process, such as PVA, epoxy, contact cement. The process typically requires clamping, and the edges require trimming and sanding. The process is similar to plastic laminate application. Solid wood parts can be incorporated complex details such as edges, corners, and decorative details. Veneer size is limited and sometimes in order to cover large surfaces, veneers are rotated and aligned in an aesthetically pleasing manner, a set of techniques referred to as veneer matching. ***Book matching*** involves placing two sheets of veneer so that they mirror each other, like an open book. Book matching works well with plain cut veneers creating interesting visuals, though other cut types work as well. ***Diamond matching*** is similar but the leaf is rotated by 45 degrees and mirrored on 2 axes, creating a diamond-like shape with a pronounced center point. ***End matching*** is the same as diamond matching but the veneers are not rotated. ***Slip matching*** involves repeating the pattern, emphasizing the long axis. Slip matching is more appropriate for straight grain veneers, such as quarter sawn oak. In ***reverse slip matching***, every other leaf is flipped on the longer axis, creating a flowy look with plain sawn veneers. ***Random matching*** involves matching, or purposefully unmatching, leaves with random width where seams are highly emphasized. The designer can get very creative and create elaborate patterns, however, this would add to workmanship costs.

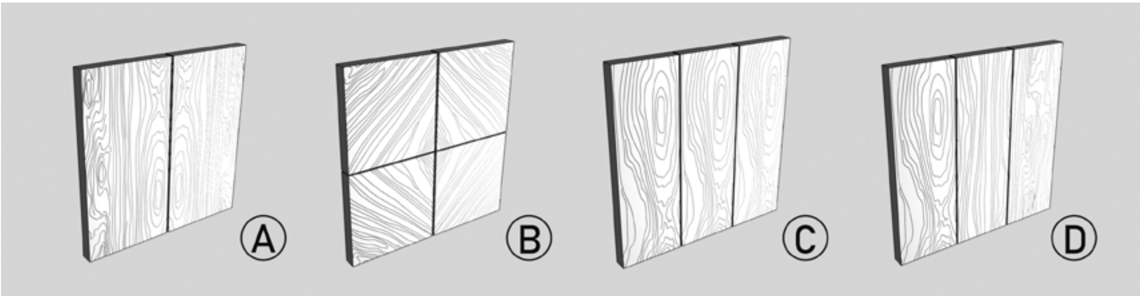

Fig.07/37 *Four veneer pattern matching techniques: book (A), diamond (B), slip (C), and random (D) matching.*

Fig.07/38 Veneer applications can check and peel over time, when exposed to moisture and abrasion.

Solid wood finishing** techniques and processes translate to veneers as well, including staining, sealing, lacquering, varnishing, oiling, waxing, polishing.* Though, thin veneers cannot be sanded down. The substrate can be highly stable, however, veneers can still crack and peel off. *The change in humidity levels or the use of adhesives with high water content might cause the veneer to develop web-like fine cracks, resulting in **checking, a common and important failure in veneer application.

ENGINEERED WOOD

Engineered wood, also known as wood panel products or composite boards, enable efficient and sustainable use of wood waste. The principal idea is bonding wood veneer, chips, and other wood waste with various plastic resin under high heat and pressure. *The strength of the resulting panel is **uniform along the panel**, as knots, checks, shakes, splits, and variations in grain directions and other defects are eliminated.* They are highly stable and do not expand or contract with moisture level changes (except particle board), making them more predictable and consistent. They boast high workability. Very much like solid wood products wood panels can be finished with stains, varnishes, oils, lacquers, veneers, and laminates.

Fig.07/39 Shredded wood waste is held together by formaldehyde resin to manufacture particle boards.

There's no need to acclimatize engineered wood products, but ventilation will be needed due to high VOC emissions from the resin component. For fusing the wood content various types of formaldehyde resin are being used, most common ones being urea-, phenolic-, and melamine-formaldehyde. Urea Formaldehyde (UF) used in the manufacturing process emits harmful VOCs to the environment. It is possible to reduce emissions with a careful laminate application or polyurethane (PU) coating. EPA has set standards for formaldehyde emissions from engineered wood panel products, under the Toxic Substances Control Act (TSCA) Title VI. 0.05ppm is allowed for hardwood plywood and 0.11ppm for medium density fiberboard (MDF). Some boards using UF can stay within these emission limits others can't, largely depending on the manufacturer and origin. Alternatives are being researched continuously, polymeric MDI being a promising low-emission option.

*Since **leftovers and waste** from other wood manufacturing processes are utilized, engi-*

neered woods might seem environmentally friendly, however, processing under heat and pressure results in ***high embodied energy*** *levels, approximately 3 to 4 times more than solid wood.* Combined with high VOC emissions, these products can hardly be called environmentally friendly.

Plywood is manufactured by glueing together an odd number, commonly between 3 to 7, of wood layers/plies (softwood, hardwood, veneers, engineered wood) and applying high pressure. Each subsequent layer is cross-laminated for added strength, meaning grain directions are perpendicular to each layer in sequence. There are different types of plywood appropriate for different uses. Structural or sheathing plywood provides better physical performance and their surface is often unfinished. Hardwood plywood is strong, sturdy, and wear-resistant with a desirable grain structure, used mainly for fabricating furniture and casework, suitable where the surface might be visible. The plywood surface can be sanded and finished like other wood products. Similar to plywood construction, blockboards and lumbercore feature a softwood core made up of thicker glued strips, sandwiched between hardwood veneers. There are also various other plywood products that utilize MDF or particle-board as a core, for price advantage without sacrificing aesthetics. Marine plywood is coated with a water-resistant glue to achieve moisture resistance, appropriate for wet spaces where exposure to high humidity is a concern.

American Plywood Association (APA), or currently known (since 1994) as "APA The engineered wood association", is a non-profit trade organization that sets performance and safety criteria, defines testing procedures, and outlines design standards. APA publishes specific quality grades and ratings for different plywood products and defines their appropriate use. Based on their structural integrity, durability classifications include: exterior, exposure 1, exposure 2, and interior grades which include sheathing, siding,

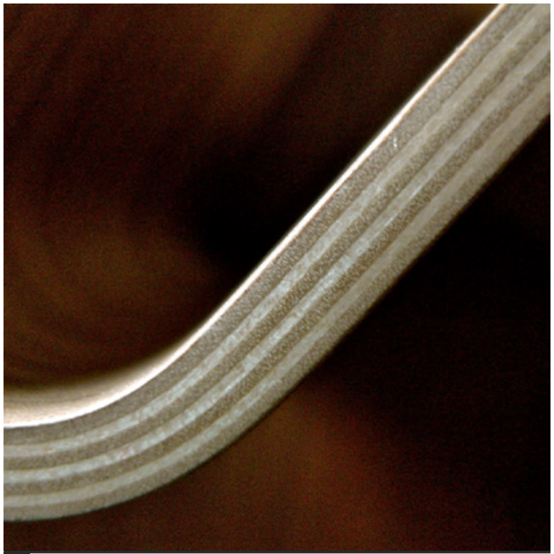

Fig.07/40 It is possible to bend hardwood plywoods such as birch, beech, ash, and oak.

and subfloor underlayment (Sturd-I-Floor). Exterior plywood is manufactured with grade A and B veneer which are free of knot and other defects and have mostly even grain, whereas grade C, C-plugged, and D veneers are used for plywood targeting interior use. All of this can be seen on the APA label on a wood product, along with face grade, thickness, species number, and mill number.

Due to the properties of their adhesive resin, certain types of plywood can be bent using steam or by employing jigs and molds. Birch, beech, ash, and oak veneers can be bent relatively easily. On the other hand, thicker, construction-grade plywoods cannot be bent.

Products such as Wood-Composite Lumber,

Vid.07/09 Video on the manufacturing process of the Eames Lounge Chair.

Fig.07/41 The raw look of the oriented strand board (OSB) became desirable in recent years.

Fig.07/42 The Apple Valley Road Bridge in Lyons, CO utilizes bent GluLam beams as the structural component.

including Glu-Lam, feature layers that are oriented in the same direction, and Cross Laminated Timber (CLT) features layers that are alternated at 90-degree angles; both can span great lengths and support multi-story buildings. Glu-Lam can actually span hundreds of feet, and support greater loads showing similar strength characteristics to pre-cast concrete structural members while being lighter. They can be exposed as they have a unique and desirable look with an already finished surface. There may be some cost savings depending on the fluctuating cost of lumber, though wood-composite lumber products do not perform nearly as well as steel and require more maintenance. It is possible to hybridize the structure and utilize both metal and wood.

Particleboard, also known as chipboard, is manufactured by compressing wood chips, sawdust, and shavings with a synthetic resin, typically urea-formaldehyde (UF), under heat and pressure. They are inexpensive, relatively less durable, susceptible to deformation, especially when moisture is introduced. They are commonly specified in residential and commercial grade casework, as a substrate for plastic laminates and veneers. Plastic laminate is applied to the surface with contact adhesives, and the exposed edges are later sealed with PVC banding, or in some cases MDF or solid wood trims. There are factory laminated board options available for speeding up manufacturing in the workshop.

Oriented strand boards (OSB) are made of randomly oriented long wood shreds bonded under under heat and pressure using a waterproof resin-wax mixture. Even though largely used as a substrate, exposed OSB became a popular sight in some contemporary interior spaces with an industrial look, such as loft designs.

Vid.07/10 Video on particleboard manufacturing process.

Fibreboards are manufactured from residuals of other wood manufacturing processes, mixed with resin and compressed under intense heat and pressure. Medium-density fiberboard (MDF) and high-density fiberboard (HDF) reside in this category. MDF has a very consistent structure and homogeneous performance properties, often at a cheaper price point than plywood. It has a consistent and smooth surface that can be finished with veneers or plastic laminates, as well as lacquers. Since there are no defects or air pockets in the material, it is highly machinable, interesting relief patterns can be attained with CNC routers. MDX is a waterproof variant of MDF. HDF, also known as Masonite™ or hardboard (lesser versions made with linseed oil), used as underlayment for flooring, substrate, or backboards in cabinetry, or door skins. It is thinner and denser than MDF and manufactured for somewhat different purposes. An important technique for processing fiberboards, kerfing refers to a sequence of sawblade cuts making their way through the wood close to the opposite surface, to provide bending capabilities. Kerfing can be an alternative to steam bending.

Fig.07/43 MDF panels can be CNC cut, lacquered, and installed in a sequence to define complex curves.

Vid.07/11 Video on kerfing and wood bending.

Wood Plastic Composite (WPC) is another engineered wood panel product where only around 15% wood flour is used as a filler, and contain around 70% different types of polymer resin matrices, such as polyethylene, polypropylene, ABS, PVC, polystyrene. They have high workability, can be sawn, bent, or CNC routed very much like other wood products. They are water-resistant, popular for exterior uses such as decking, door or window frames, etc.

08

GLASS & CERAMIC

- *Glass*
  - *History and vocabulary*
  - *Light transmission*
  - *Environmental impact and recycling*
  - *Specification and fabrication*
- *Ceramics and porcelain*
  - *Manufacturing process*
  - *Environmental impact*
  - *Ceramic types and properties*
  - *Specification and installation*

Glass is liquefied and fused sand, at approximately 3090ºF, cooled rapidly into a brittle material, referred to as ***non-crystalline or amorphous solid****, meaning it gradually melts instead of at a specific temperature and its internal structure lacks order.* Even though its exact composition widely varies, sand is mostly silicon dioxide (SiO_2), which is also known as quartz. When exposed to high temperatures and the impurities are filtered away quartz becomes transparent to the visible light spectrum as well as an important part of the ultraviolet (UV) and infrared (IR) range. *Glass is strong against* ***compression*** *and weak against* ***tensile forces****.* It is possible to use glass as a load-bearing element. Glass can flex to a very small extent depending on the size of the object or panel. It is completely inert and highly resistant to corrosion, does not react to chemicals or permit microbial and fungal growth.

The volcanic rock known as obsidian is considered a naturally occurring glass, and it was

Fig.08/01 Moldavite is formed by the high temperatures created by a meteoric impact.

used for decorative objects as well as weapons owing to its ability to hold a sharp edge. Another naturally occurring glass, Moldavite, was formed by meteoric impact some 15 million years ago. Glassmaking is an ancient craft with evidence suggesting a history extending back to 2000 BCE Mesopotamia. Romans were pivotal in glass manufacturing. They also experimented with different colors and finishes creating decorative items and mosaics.

Stained glass*, as a historically relevant technique, involves arranging pieces of colored glass into decorative designs. Traditionally lead cames are used to join the pieces.* Even though there is evidence that variations of ***soda-lime glass*** *has been used throughout Europe for millennia, Venetians made great strides in refining the formula and methodology since the 13th century.* It is the most common glass type today and paved the way for many of the relatively modern glass manufacturing techniques.

Plate glass *refers to rolled out sheets of glass, grinded and polished on both sides to achieve the desired finish and clarity*. This was the primary method of producing large flat panes of glass until it was replaced by ***float glass****, a technique that involves floating molten glass on a bed of molten tin to achieve uniform thickness and smooth surface.* This process was developed in the 1950s by Alastair Pilkington and has since become the standard method for producing flat glass.

Glass is transparent to most visible frequencies. ***Color Rendering Index (CRI)*** *indicates how much of the visible spectrum can travel through a piece of glass without being filtered.* A higher CRI would be an accurate representation of colors and a lower CRI would indicate a significant amount of impurity. A CRI index of 100 is true color, a CRI above 90 is considered good, which can be achieved with standard float glass; low-iron glass has a CRI of 99.7. Glass is denser than the atmosphere and it refracts, or changes the direction of, incoming light waves. This feature can be used to focus or spread light.

R-value *indicates the insulation capabilities of a glazing application, its ability to resist heat transfer.* Regular glass is transparent to only the short-wave components (800 nanometers, or 800 nm, to 2,000 nm) of the infrared spectrum.

Link 08/01 Link to the Corning Museum of Glass.

Vid.08/01 Video on float glass manufacturing process.

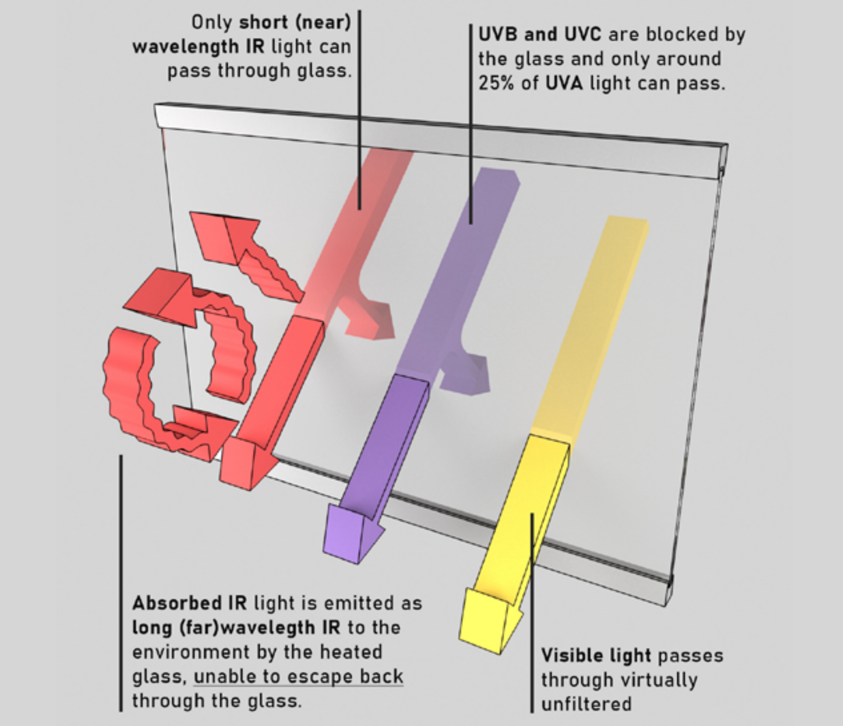

Fig.08/02 *Illustration of the greenhouse effect.*

However, when struck by long-wave components (8,000 nm to 16,000 nm) glass increases in temperature and re-radiates the heat at long-wave infrared light that cannot exit back and is trapped; which ultimately causes overheating. This is known as the greenhouse effect. ***Low emissivity, or low-e,*** *glass coatings can block infrared light as well as minimize radiation.*

Ultraviolet, or UV light *is the wavelength range below the visible spectrum between 100 to 400 nm.* There are three types of UV-radiation: ***UVA,*** *weaker and not absorbed by the ozone layer,* ***UVB****, relatively stronger and partially absorbed, and* ***UVC****, fully absorbed by the ozone layer.* UV light is essential for health in short bursts, 15-minute exposure 2 to 3 times a week is recommended by the Center for Disease Control (CDC). However, both UVA and UVB radiation is also a health risk, and along with cleaning chemicals, a significant cause for material deterioration, weathering, and fading. *Regular glass can block all UVB radiation but only around 25% of UVA radiation. An additional* ***tinted interlayer or UV blocking film*** *is necessary to reduce UV transmittance further.* Even though UVA is weak, it can still cause quite a bit of deterioration. Low-e glass primarily blocks infrared light, but it can also block most of UVA and UVB radiation.

Glass manufacturing process requires intense heat, resulting in ***high embodied energy and carbon footprint***; it is even higher for glass types that require additional processing such as laminated and tempered glass. Furthermore, various harmful chemicals such as sulfur dioxide and nitrogen oxides are produced during manufacturing. *Glass is* ***infinitely recyclable****, but unlike metals, the recycling process requires the same amount of energy as creating virgin material.* The different types of glass should not be mixed together when recycling, it needs to be separated according to chemical additives and impurities. For instance, the float glass of windows and doors cannot be recycled with glass bottles or mirrors. Glass is ***chemically inert and non-toxic***. The impervious surface does not require harsh chemicals for cleaning, though the material can withstand them. Glass ***does not decompose***, and degrades extremely slowly over the course of many thousands of years.

Fig.08/03 *Green and brown glass can only be recycled into new green and brown glass, respectively.*

Vid.08/02 *Video on the intricacies of recycling glass.*

SPECIFYING GLASS

Approximately 90% of glass made today is ***soda-lime glass,*** which is composed of almost 3/4 silica plus soda ash to lower the melting point and limestone to increase stability and chemical resistance. It is inexpensive, stable, predictable, and highly recyclable. This glass can be modified with additives and is suitable for further processing to tailor it for various uses, such as annealing, tempering, laminating, or many others. ***Glazing*** *refers to the glass panel products that cover building openings or facades.* Spandrel glass covers and conceals the structural elements on a full glass façade, in between vision glass that functions as the windows for occupied spaces. A plethora of non-sheet glass products is also available in the market. Glass is extremely versatile in this regard, as it can be molded into tiles and blocks, drawn into tubes, spun into fibers, foamed into insulation, or broken into chunks and used as filler or reinforcement, surface finishes, and decorative components throughout all types of interior spaces.

Annealing *refers to the gradual cooling of glass, that was heated to and hold at a specific annealing temperature.* The aim of this process is to reduce internal stress, increasing the durability, impact resistance, and overall performance of the glass panel or component. This process is inherent to float glass manufacturing, as the material slowly cools while it is floating over the tin pool. Glass can be curved through pressing in between two plates at 1150ºF. ***Tempering*** *glass involves heating the glass to a critical temperature and rapidly cooling it.* This creates internal stress in a specific way so that when met with impact the material crumbles instead of breaking into shards. Annealed glass can be machined, cut, and drilled; however, tempered glass is not workable. The tempering process can be undone by annealing the glass, then it can be worked, and then tempered again. Edges of tempered glass are weaker than the central section of the panel, impact from sides can cause breakage. Low-quality tempered glass with impurities can contain tiny but slowly growing nickel-sulfide accumulations; these can cause spontaneous glass breakage. ***Textured glass*** *is manufactured by rolling the molten glass through patterned rollers.* ***Wired glass*** *features a steel wire mesh embedded within the glass during manufacturing.* IBC requires wired glass for fire-rated openings, as it can

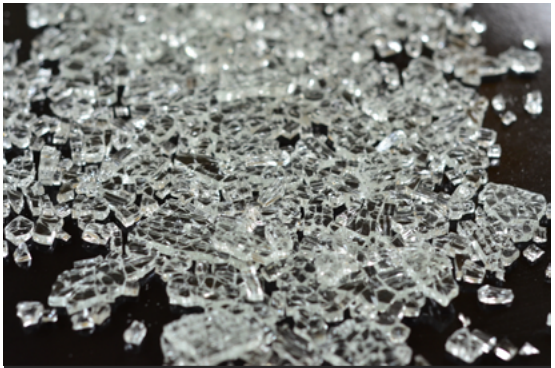

Fig.08/04 *Tempered glass crumbles into small pieces instead of large shards, minimizing risk of injury.*

Fig.08/05 *Glass panels can be bend bi-directionally and tempered to cover curved public walkways.*

Vid.08/03 *Video on spontaneous glass breakage due to nickel sulfide accumulations.*

resist higher temperatures, does not explode like other glass types, and can withstand fire hose stream. However, wired glass has low visibility and associated with many safety concerns. Since 2015, wired glass is required to meet strict impact resistance requirements as it had been a significant cause of injury upon occupant impact. ***Glass-ceramic*** *is a fire-rated, impact-resistant, and clear alternative to wired glass, also permitted by IBC.*

Laminated glass*, also known as safety glass, consists of two or more layers of annealed or tempered glass bonded together with a polymer resin layer.* The resin layer can keep shards together when the glass shatters, reducing the possibility of injuries. IBC requires ***railing glass*** to be tempered laminated glass, to eliminate the

Fig.08/06 *It is possible to use laminated glass as load bearing member in less structurally demanding situations such as supporting stairs.*

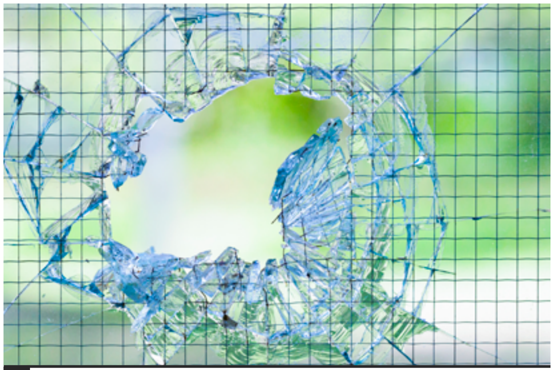

Fig.08/07 *Wire glass can be shattered and penetrated by occupant impact, causing significant injuries.*

possibility of falling or injury by scattering debris. The only exception is the railing to feature additional precautions to prevent falling and there has to be no walkway below. The bonding resin, or the interlayer, can be either poly-vinyl butyral (PVB) or ethylene-vinyl acetate (EVA). This layer can be 11 mils thick and it can be colored. Most types of glass or polymer panels can be laminated to each other, including acrylic and wire-glass. ***Security glass***, as an example for laminated glass, *features multiple layers of glass bonded with polymer interlayers, often incorporating polycarbonate panels for added protection and strength*. The interlayer is resilient, therefore it reduces the transmittance of sound vibrations, contributing to acoustic separation. The typical window has a sound transmission class (STC) rating of 20 to 30, whereas laminated glass can reach over 40.

Double- and triple-pane glass *feature two or three layers of panes, respectively, separated by a vacuum or inert gas-filled space to minimize heat transfer and attain thermal efficiency. 1/2* to 5/8 inch space in between panes is optimal for achieving the highest R-value. Triple pane glass offers an STC rating of 30 to 40. In order to gain better sound attenuation, the distance between glass panes need to be increased which in turn reduces the R-value, therefore the thermal efficiency of the window.

The typical architectural glass contains 0.1% iron-oxide to facilitate the manufacturing process by lowering the temperature requirements. Iron oxide can be in a variety of colors, red, yellow, or blue, depending on its molecular formula (FeO, Fe_2O_3, Fe_3O_4 are all referred to as iron oxide). The iron oxide used in float glass making process creates a green tint while minimizing light transmittance. The thicker the glass panel, the more apparent the negative effects are. ***Low-iron glass*** *is manufactured by lowering the iron-oxide content. It is suitable when high optical clarity, superior color rendering, increased glass thickness, or simply a clear white/colorless look is required, especially at the edges of a glass panel.* For instance, to manufacture thicker security glass without the green tint, or high-end windows to maximize sunlight and clarity of view. ***Anti-reflection coating*** *is a thin polymer film, that minimizes reflections by diffusing and canceling light-rays without impacting clarity or color rendering capability,* often used in optical glass. The coating can also be applied on acrylic and polycarbonate. The product is useful for glass display units, storefront displays, or anywhere reflections are a hindrance. The exposed anti-reflection coating lacks durability and chemical resistance, compared to the glass itself, and specific cleaning procedures outlined by manufacturers should be followed. A ***mirror*** features a thin layer of highly reflective metal such as silver, tin, nickel, chromium, aluminum, or an amalgam of multiple metals, fused on the polished back surface of a glass sheet. ***One-way glass*** is actually a semi-transparent mirror, with a thin sheet of aluminum sputtered on one side; the effect is primarily created by the substantial difference of illumination on both sides. *In* ***privacy glass****, a.k.a. smart glass or electrochromic glass, a small electric current causes a thin electrochromic layer to alter its color and opacity.* This enables the glass to instantaneously shift from a transparent state to a translucent state.

During manufacturing various ***oxides can be introduced*** to the glass mix, as a result the glass selectively absorbs various light frequencies, causing the view behind the glass to appear tinted. For instance, to create a blue tint cobalt oxide is added, while a rich red can be produced by adding gold chloride. These oxides are not the same as paint pigments, they can withstand the high processing temperatures and the resulting color is predictable.

> *It is cheaper and more common to apply a* ***colored polymer resin film*** *to tint glass, though this is only viable for panel applications.*

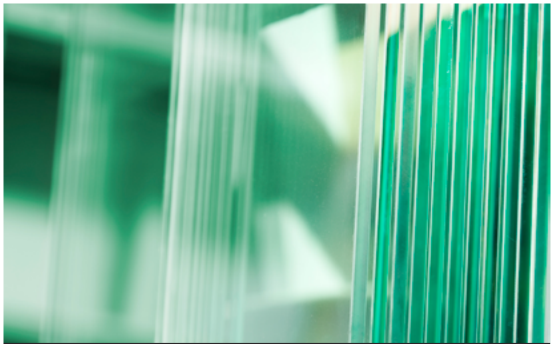

Fig.08/08 Architectural glass features a slight green tint due to iron oxide impurities.

Fig.08/09 Some of the more unique and desirable color tints can be easily achieved with a resin film.

Fig.08/10 Translucent vinyl film is a viable alternative to sandblasting and acid etching.

***Sandblasting** produces a translucent effect by spraying high-velocity abrasive particles against the glass surface.* It can be used to add visual richness, make the glass panel more visible, or ensure privacy to an extent. This process results in many small pores on the glass surface, causing the material to hold onto and emphasize dirt, oil, and fingerprints. Furthermore, the sustained abrasion is detrimental to the structural integrity of the glass panel. Tempered glass might shatter after several passes of sandblasting. The same effect can be achieved via ***Acid etching** which involves applying hydrofluoric acid on the glass surface*. The acid is toxic and highly corrosive to the human body. This process can be applied in layers to achieve multiple levels of translucency, and stencils can be utilized to incorporate interesting graphic elements such as text or logos.

Vid.08/04 Video on sandblasting complex graphics on glass..

Light transmittance of acid etching is lower than sandblasted glass, however, the resulting surface is smoother, shows relatively less dirt and fingerprints. Both types require a protective top-coat for preventing smudges and staining. *A much more convenient and cheaper method of achieving translucency is applying a **translucent vinyl film** on the glass surface.* This provides more control to the designer, however, this layer is not durable and can get damaged over time. Even though relatively more expensive, ***fritted glass*** can create the same frosted look by fusing ceramic frit to glass during the manufacturing process. The resulting panel can be fully tempered and the surface is more durable and scratch-resistant than regular glass. Since the glass is not abraded, its mechanical performance is not diminished. Highly suitable and common for façade applications.

Glass sheet size is dependent upon manufacturing equipment limitations. 84” by 144” inch panels can be supplied by most manufacturers. Oversized custom sheets would cost significantly more than readily available sheets and lead times should be expected.

*Glass is heavy, brittle, and expensive to transport, and lack of **planned and careful handling** can result in breakage.* The designer should make sure that there are no scratches and

Fig.08/11 Inconsistent reflections can create a jarring effect.

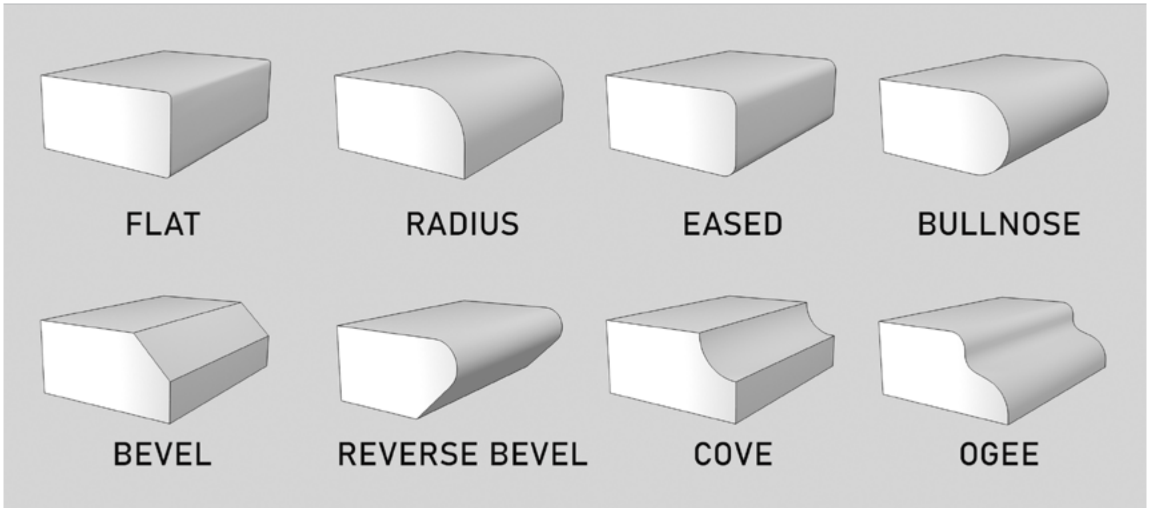

Fig.08/12 The various edge treatment methods used for slab, panel, and sheet products.

defects on glass sheets. Furthermore, glass components need to be checked for alignment to ensure consistent reflections, and smooth operation without friction or obstruction.

It is important to ***specify how the glass will interface*** *with other components.* Being a brittle material, glass is sensitive against dimensional change in adjacent materials, which might induce stress. A dimensionally stable backing or intermediary layer such as MDF or plywood minimizes the possibility of shattering. Even though aluminum profiles are widely available, it is possible to utilize any material with a straight channel, as long as a resilient interface, such as a rubber strip, is provided to prevent cracking; *as the glass will be continuously responding to* ***temperature changes****.* Glazing systems can also be suspended from special clamps – e.g. spiders, mullions, and fins. Glass joints can be sealed with urethane or silicone sealants, weatherstripping, and preformed seals, in order to prevent air and water leaks, minimize heat loss, and ensure acoustic separation. ***Caulk*** *is not appropriate for sealing glass as it hardens*

Fig.08/13 Glass panels can be suspended with spider fittings, enabling a continuous look without mullions.

Fig.08/14 Glass sealers can dry in the long term, losing resiliency and starting to peel off.

over time and inhibits movement. Dry glazing involves using preformed sealers or gaskets and does not require any curing time. Wet glazing refers to using polymer-based sealants or glazing compound that requires curing time.

Glass has several inherent safety problems, primarily related to poor impact resistance and an ability to form sharp edges. For this reason, lamination and tempering are required by code as upon impact, glass can easily shatter or crumble. In addition, raw edges need to be treated with one of the many types of edging methods to facilitate safe handling. Transparency is another safety issue for glass. The application of ***safety squares*** *or other decorative designs on larger glass panes improve visibility and minimize the risk of occupants running into the material.*

Fig.08/15 Safety squares improve visibility of glass panels, useful where occupant impact is a concern.

CERAMICS & PORCELAIN

Ceramics as a category ***comprise a wide array of different materials****, including structural ceramics, refractory ceramics, white-wares, technical, and advanced ceramics as well as ceramic composites.* Ceramics have a long history strecthing back almost 30,000 years, with pottery fragments dating back 10,000 years. In terms of architectural use, glazed bricks were found in the Elamite Temple in Iran, dating back to approximately 1250 BCE. The Islamic architectural tile, precursor to some modern tile designs, started flourishing after the 7th century. Today, depending on their composition and manufacturing method, ceramics can provide high abrasion resistance, non/semi/super-conductivity, high temperature resistance; enabling many uses beyond pottery and tiling.

Ceramics, *in the context of design, primarily refer to white-ware, a category of ceramics comprising formed clay products fired in a kiln at high temperatures to modify chemistry and improve performance.* This category includes products such as porcelain, terracota, and vitreous tiles. *The* ***manufacturing process*** *of common ceramics involves ❶mixing the ceramic body, ❷pressing/forming/molding, ❸drying, ❹bisque firing, ❺glazing, and ❻final firing.* Before first firing and drying, the ceramic product is in the fragile green-ware state, with significant moisture content. Firing can be single-stage or involve two separate stages, referred to as monocottura or bicottura. Drying and firing create considerable dimensional change on the clay body.

Glaze *is an impervious layer or coating, composed mainly of silica, as well as fluxes, pigments, stabilizers, etc.* The glaze is coated on the ceramic body; following the firing process this coating melts and fuses to the ceramic body, forming a non-porous and abrasion-resistant glass-like layer with various physical and visual properties. It can be glossy, matte, textured, it can boast a decorative layer underneath or it can feature colors and textures itself.

> *The main differences between common ceramics and porcelain is use of refined raw materials and **higher firing temperatures** which helps the body to melt and fuse together; they are also called vitrified products.*

3d printing of ceramics is also possible with polymer-derived ceramic (PDC) resin. Ceramics are generally porous and brittle. They cannot withstand deformation and break almost immediately. Ceramic and porcelain tiles are completely fire resistant, do not combust, however, they can crack or shatter at very high temperatures.

*Ceramic tiles have **very high embodied energy** due to multiple high temperature firing sessions.* Proximity to raw materials can reduce environmental impact to an extent by limiting the carbon footprint generated via transportation. It is also more feasible, therefore, it is common to see ceramics manufacturing plants near clay pits. In the past, even the proximity of the heat source, such as wood forests, was an important consideration.

Fig.08/16 Mass-manufactured ceramic products are fired in large kilns.

Fig.08/17 Abstract glazed tiles from Alhambra complex, in Granada, Spain.

*Porcelain tiles and glazed facing of ceramics are **chemically inert, non-toxic, easy to clean,** and can withstand harsh chemicals.* Due to some advantageous visual and physical properties lead is still used in small-scale bespoke ceramic manufacturing. For example, Japanese Raku style glazing. These products are not food safe and there's a possibility of lead exposure, especially dangerous for small children.

Fig.08/18 Gaudi utilized broken ceramic tiles to finish curved surfaces of Park Guell in Barcelona, Spain.

SPECIFYING CERAMICS

There are three major categories of ceramic: earthenware, stoneware, and porcelain. ❶***Earthenware*** is fired at lower temperatures, porous, coarse, and low durability. ❷***Stoneware*** is the common ceramic tile, fired at high temperatures, features an impervious glaze. Lastly, ❸***porcelain*** is fired at even higher temperatures, very high performance, and often used for sanitary components as well as high-performance finishes.

Water-resistance of a tile is influenced by chemical composition, density, and surface quality. *The **vitrification** process involves melting a silicate compound on the fired clay and form glass crystals*, ultimately imbuing the material with impermeability.

Paver is a comprehensive term that refers to stone, clay, concrete, and composite flooring tiles, mainly exterior tiles and rugged interior tiles. ***Quarry tiles** refer to unglazed clay tiles with a matte finish*; can be fired at high temperatures to attain impermeability. Periodic sealing may be needed. ***Terracotta tiles** are natural clay tiles with a characteristic reddish hue*, fired at relatively lower temperatures. They lack durability and readily absorb moisture, rendering them inappropriate for wet spaces due to a significant possibility of mold and mildew growth.

***Ceramic tiles** feature a glaze layer covering the ceramic body.* This layer can abrade over time exposing the tile, which readily absorbs moisture either through exposed areas or more likely through aging grout lines. Most ceramic tiles perform poorly under heavy traffic or high moisture exposure. Ceramic tiles feature unique designs, of numerous sizes and shapes, and interlocking methods. The very small ceramic mosaic tiles feature a mesh backing that groups units together in order to simplify the installation process. It is also possible to order handmade or bespoke tiles from artists, though these will have a higher price tag and often unpredictable performance.

For ***porcelain tiles**, the raw materials that make up the body, the existence of glaze, and firing temperatures are different; resulting in a product that is much denser, dimensionally stable, abrasion-resistant, and truly impermeable compared to ceramic tiles*. These features render porcelain tiles highly effective under heavy traffic loads and extreme moisture exposure, however, the better performance capabilities come with a relatively higher price tag. ***Gauged porcelain***

Fig.08/19 Contrary to what their name suggest, quarry tiles are actually fired clay.

Fig.08/20 The layer of glaze on ceramic tiles is actually thin, can crackle and wear off over time.

tiles are very thin, with a depth of 1/8” to 1/4”; they are relatively lightweight and can be applied with a thin adhesion agent, resulting in a very low profile. The very large gauged tiles of up to 5’ by 10’ minimize the number of grout lines, improving cleanability and ease of maintenance. However, installation requires significant experience and it is relatively costly. ***Color-through****, through-body, or true color, are terms referring to a monolithic body tile with visual and performance properties consistent throughout the entire tile.* This means, there is no glaze to wear off of the surface under heavy use. As the tile abrades under dense traffic, simply more tile is revealed.

When specifying ceramic and porcelain tiles, the designer should consider three separate performance values: water absorption performance, abrasion resistance, and coefficient of friction. ***Water absorption*** is measured via the test ASTM C373, and a rating of non-vitreous (7-20%), semi-vitreous (3-7%), vitreous (3-0.5%), or impervious (less than 0.5%) is assigned based on the rate of absorption in relation to tile volume.

Abrasion resistance indicates the ability of the tile to withstand scuffing and scratching. Higher values indicate better performance under heavier traffic. It is measured with the test method ASTM C1027, also known as visual abrasion resistance. Accordingly, the tile is given a class rating of heavy commercial (V), medium commercial (IV), heavy residential/light commercial (III), residential (II), light residential (I), and not recommended as a flooring material (O). In some tile specifications, ***Mohs hardness scale*** is used. On this scale, porcelain tiles typically perform between 7 to 9 and non-vitreous ceramic tiles are between 5 to 7. For commercial applications, a value of 7 or more is recommended. The ***Porcelain Enamel Institute (PEI)*** has published their own hardness ratings very similar to ASTM C1027, however only glaze wear is considered; the ratings range between Group 5 indicating suitability for heavy traffic, and group 1 indicating suitability limited to residential environments and vertical surfaces.

Fig.08/21 Besides the common rectangular form, ceramic tiles can be manufactured in highly complex shapes with relief effects, enabling creative arrangements.

Tile Council of North America (TCNA)*, the related non-profit international trade organization,* developed a standardized rating system based on the test ASTM C627, that evaluates floor tile installations with a device called ***Robinson Floor Tester***. This relatively simple device applies pressure on the flooring system

Vid.08/05 Video on large-format gauged tile installation.

Vid.08/06 Video on the Robinson floor tester in action.

Fig.08/22 Slip resistance is a significant factor when specifying ceramic and porcelain tiles.

through three wheels that rotate on a circular path. Based on the number of cycles the system goes through, it is assigned a value according to five performance levels: extra heavy suitable for high impact manufacturing plants, heavy suitable for heavy traffic such as retail, commercial kitchens, etc.; moderate suitable for restaurants and hospitals; light is suitable for offices and reception areas, and residential spaces. ***Coefficient of friction (COF)*** *is tested according to ASTM C1028, indicates slip resistance of a flooring finish.* A static COF of 0.6 or less when wet is required for interior finishes and 0.8 or less is required for exteriors. A newer method, dynamic COF is replacing the static version and wet slip resistance of smaller than 0.42 is being required. In these tests 0 means no friction, and 1 means maximum friction, therefore the highest level of safety.

Sorting category*, or calibration code, is used to ensure that tiles are both dimensionally and visually consistent.* The test ASTM C609 determines a tile's aesthetic class at 5 increments, from V0 with maximum color and texture consistency between tiles to V4 with substantial color and texture variance.

TCNA publishes a handbook for ceramic, glass, and stone tile installation setting standardized guidelines from substrate preparation to mortar selection. Substrate preparation is very important in tile setting. *The* ***substrate should be*** *sloped to drain water, and the surface should be smoothened out to ensure consistent tile setting. In addition, the substrate needs to be dimensionally stable, completely cured and dry, and should not react to or absorb moisture.* If moisture migration to or from concrete is expected, for instance, for wet spaces or below grade applications, a ***vapor barrier*** underneath the mortar layer is required. For vertical applications, drywall substrates require water-resistant adhesives and grouts such as epoxy. *Better substrate alternatives are water-resistant "green boards", backer boards, cement boards, or plywood*. However, these might delaminate in time with excessive moisture exposure.

When planning how tiles will be laid, the designer should first think which section would be more visible and which section should be concealed, subsequently focusing on minimizing slivers while trying to align grout lines with spatial features, such as columns, stairs, built-in furniture, windows, etc. *The best method of planning involves placing a* ***"key tile"*** *at the center of the room, loose laying tiles to calculate distances, and sliding the key tile in accordance with the room's features.* If the flooring design involves complex patterns, it is better to correctly draw and specify the tile types, cuts, and locations

Vid.08/07 Video on subfloor preparation for tile application.

Vid.08/08 Video on tile layout planning.

Fig.08/23 The three steps for tile installation: troweling, laying, and compressing.

before the construction process. Tiles can be equally and consistently spaced by using plastic spacers. Alternatively, there are self-spacing tiles available on the market as well.

Thick-setting *involves laying tiles on a thick mortar bed over the substrate*. Also referred to as mud installation, this method is great for compensating for unevenness or flaws on the substrate as well as for more flexibility while sloping. It is possible to mechanically separate the mortar bed from the substrate with a membrane, allowing to compensate for the dimensional movement difference between the substrate and the application. The thickness of the mortar bed is around 1” to 2” depending on the specific method. *Thick-setting for wall surfaces must involve a* ***furred metal mesh or ribbed metal lathe*** *to allow for holding onto enough mortar.* Wall tiles are usually 1/4” to 5/8” thick and feature a raised pattern on their backside for better adhesion and stability. Tile applications on walls with cementitious adhesives are not recommended for exteriors, as moisture can seep behind a tile and when frozen, forces the tile to come loose. A much more common tile setting method is ***thin-setting****, also referred to as dry-set mortar, which involves adhering tiles to the substrate with a 3/32” fine cement or polymer resin layer.* This technique is relatively quick and less expensive, on the other hand, the dimensional movement on the substrate can crack grout lines or loosen tiles. Non-cementitious adhesives, such as epoxy or polymer/latex modified mortars can provide better adhesion, chemical resistance, impermeability, though these can be expensive and somewhat difficult to apply.

Vid.08/09 Video on correct adhesive troweling method.

An ***expansion joint*** is a divider strip with a resilient component that can accommodate dimensional movement. These are recommended by TCNA for every tile installation in a gap at the perimeter of the room which can be hidden underneath a baseboard, or for larger rooms, situated at every 12’ to 16’. Without expansion joints cracking and tenting can occur. Especially for large format tiles, in spaces with direct sunlight and moisture variations, expansion joints are highly recommended.

The term ***grout*** *refers to cementitious or polymer-based mortars used to fill the seams, or grout lines, between tiles in order to compensate for building movement and thermal expansion, accommodate size variations between tiles and minimize liquid seepage to the substrate.*

Cementitious grout mortars harden quickly but they can develop cracks over time. So, a polymer-based filler, such as acrylic latex grout, is a better choice if a lot of building movement or substrate deflection is anticipated. Typical grout space for a ceramic tile is 1/8”, usually

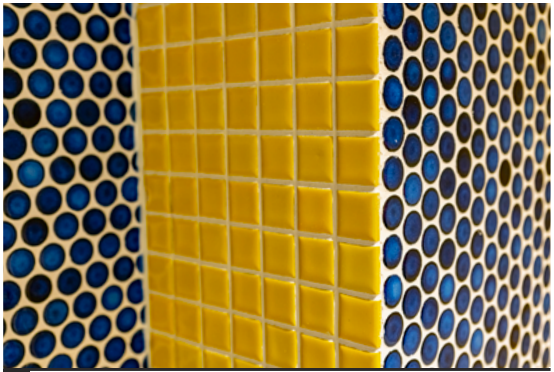

Fig.08/24 Mosaics feature a much higher grouted area compared to other tile types.

Fig.08/25 Without the use of grout release, colored grout applications can easily stain white tiles.

this is smaller for porcelain tiles as tile sizes are more consistent. During manufacturing, porcelain tiles shrink in a more predictable manner, consequently minimizing dimensional variability between tiles which can help minimize grout width. However, spacing smaller than 1/16" cannot be properly filled with grout, therefore unfeasible. Large format tiles, which are tiles with one side longer than 15", require at least 1/16" grout space; but manufacturers recommend up to 3/16" grout space to accommodate movement and tile size inconsistencies, which can be more severe for larger tiles.

Besides their functional contributions, grouts are a visual element that can either enhance or deteriorate the aesthetic impact of the tile. ***Grout fillers*** *are available in different colors to introduce contrast and visual interest.* ***Grout release*** is a type of removable surface coating, administered before grout application to protect tiles from staining.

Vid.08/10 Video on grout release and grout application.

Grout lines can facilitate ***bacterial and fungal growth****, therefore minimizing the overall proportion of grout lines results in a more hygenic and healthy design solution.* Large-format porcelain tiles are better for minimizing grout lines, whereas ceramic mosaic tiles feature the maximum proportion of grout lines. *A* ***grout sealer*** *can be applied on cured grout to minimize moisture penetration under the tiles.* With the exception of polymer-based fillers, grouts expire relatively quickly and require periodical cleaning, re-grouting, and resealing.

09

TEXTILE

- *Textile vocabulary*
- *Environmental impact of textiles*
- *Fiber types and yarn construction*
- *Natural and synthetic fibers*
- *Textile manufacturing and performance*
- *Leather*
- *Carpet construction and types*
- *Carpet installation*
- *Upholstering and soft goods*

Textile refers to either woven or non-woven, flexible sheet products. ***Woven*** *products are networks of fibers constructed via techniques like weaving, knitting, braiding, crocheting, or netting.* ***Non-woven*** *products are either hides from animals, compressed or matted fibers, or they are calendered, heat-bonded, or dip-coated polymer sheets.* Research indicates that humans started to utilize textiles as clothing between 50,000 to 180,000 years ago. Felt was believed to be the first actual textile besides sticthed animal hides. Some early woven textile examples were used to enshroud the dead, found at a prehistoric site in Anatolia. One type of textile gave its name to the Silk Road, and dominated international trade and cultural exchange for centuries. With the industrial revolution, fabric production became mechanized. Consequently textiles became more varied and accessible.

There are three fundamental definitions pertaining to textiles: Fiber, fabric, and textile. ***Fiber*** *is a linear construct with varying cross-sections*

Fig.09/01 A colorized cotton mill interior from the 1850s.

Fig.09/02 The Textile Fiber Identification Act requires all manufacturers to provide a detailed label.

and lengths, essentially a basic building block for textiles. ***Fabric*** *is a flexible planar material made through weaving, knitting, or matting fibers.* As previously mentioned, ***Textile*** *is a more general term that includes woven fabrics as well as some non-wovens.* Textiles can be used for upholstery, window treatments, and finishing interior surfaces. *Identification of textiles is controlled through the* ***Textile Fiber Products Identification Act***, which requires the manufacturer to provide a label containing the manufacturer's name, the country where the fabric is manufactured or processed, generic names and weight percentages of all fibers used, and lastly, the Registered Identification Number (RN). ***Association for Contract Textiles (ACT)*** *is a non-profit organization that represents companies and individuals involved in contract textiles manufacturing, design, and trade as it relates to commercial interiors.* The organization's website contains a list of industry-leading textile manufacturers; it has published several voluntary performance and flammability guidelines; the organization also promotes the NSF/ANSI 336, or the Facts Sustainability Certification program.

Water consumption *is necessary for all steps of the textile manufacturing process.* It is estimated that each piece of fabric requires the consumption of around 200 times of water in its weight. When the consumption for plant cultivation is added, it is estimated that around 2000 gallons of water is required to manufacture a single pair of jeans. Furthermore, the chemical footprint of this process is also concerning. Especially in developing countries, an absence of government regulations leads to contaminated discharge being dumped directly into waterways. ***Closed-loop*** *dyeing systems, where water is filtered and reused, are proposed to overcome resulting detrimental environmental effects.* It should also be noted that, recycling fabrics is a very complicated task and not always feasible.

Link 09/01 Link to the Association for Contract Textiles website.

Blending *involves spinning diverse fibers into yarns. It improves performance and cost but complicates reprocessing. For example, it is extremely hard to separate wool fiber from polyester fiber after they are spun together into a yarn.*

Textiles are commonly manufactured by following a series of discrete steps. The very first step is fiber production followed by spinning fibers into long continuous yarns, suitable for use during the rest of the fabric weaving process. Following the weaving of the fabric, pre-treatment processes such as washing, scouring, bleaching, or mercerizing can be applied; some of these can also be applied during previous steps. The fiber can be drawn from pigmented pellets, can be dyed in yarn form, or after the weaving process. Then a final finish layer such as glazing or fire-resistive coating can be applied.

Fibers are basic building blocks for most textiles, typically categorized as either natural or synthetic. ***Fiber cross-section*** *is pivotal in determining the performance, appearance, and feel of the overall fabric.*

Denier *(den, or d), is a fixed-length unit of measurement to indicate the weight and bulk of a fiber.* It is the number of grams (0.035oz) per 5.6mi (9km) of fiber. Silk is around 1 den and is commonly referred to as a basis for the denier unit. Microfibers are 1 denier (or 1 den) or less. A strand of human hair is 20 den. A 40 den fiber is very lightweight, whereas a 500 den fiber will feel heavy and bulky, and over 1000 den is very heavy and bulky. Carpet fibers can vary between 700 den up to 2400 den and are associated with carpet softness and wear resistance. There are various other units to refer to the mass and bulk of a fiber, per determined length, such as “tex”, which is a similar measurement system that is based on the metric system, values are 9 times smaller than denier, despite serving the exact same function. *The thickness can be referred to as* ***yards-per-pound****, in the fixed weight system, the lower the number, the thicker the fiber will be.* Over 1500 yds/lb is a fine fiber whereas lower than 500 yds/lb is a bulky fiber.

The bulky fibers mentioned here are actually yarns that feature many fibers twisted or fused together, or unified by some other technique. There are two types of yarns: filament or spun. ***Filament yarn*** *requires very long fibers to be grouped or melted together to create a smooth continuous yarn with a consistent thickness.* This method is suitable for synthetic fibers as well as silk. ***Spun yarn*** *involves twisting together shorter fibers, or staples, creating a fuzzy look and softer feel.* More suitable for natural staple fibers. *The twisted yarn can be twisted again*

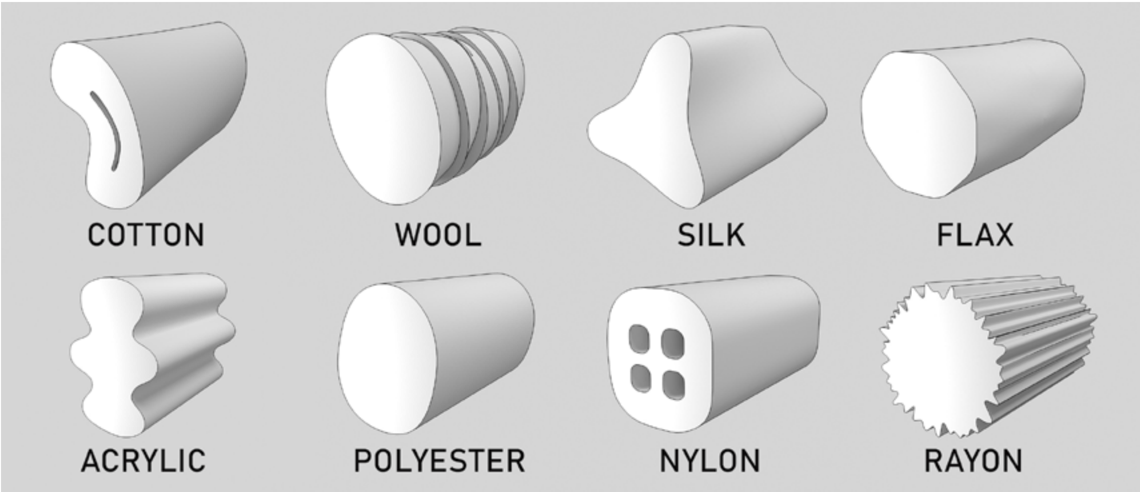

Fig.09/03 Common natural and synthetic fiber cross sections.

with another yarn for added strength, each one referred to as a ***ply****.* Two-ply yarns are more durable than single-ply yarns. The resulting yarn's denier value will be the total of the denier values of all fibers used in the process. For instance, if two 10 den fibers are twisted together, they would make a 20 den single-ply yarn.

The designer should treat these numbers as a way to compare various fibers and yarns, making sure to ***compare the same type of values*** *between products.*

> *Yarn weight and bulk is only one facet of* ***wear resistance****; spinning method, weaving method, density, and overall build quality, all factor in to wear resistance of a fabric.*

Based on their length, fibers are referred to as staples or filaments. ***Staples*** *are short fibers, up to 30" in length, whereas* ***filaments*** *are continuous.* All natural fibers are staples, except silk, which is categorized as a filament. Synthetic fibers can be manufactured as continuous filaments with indefinite length. *Longer fiber lengths indicate durability and smooth surface quality.* Fibers can be *naturally* ***crimped*** *or they can be artificially crimped before yarn spinning, showing irregularities along the length* that improve various performance parameters such as resiliency, stretch, bulk, absorption, and insulation, while negatively impacting appearance parameters such as smoothness and luster.

NATURAL FIBERS

The fibers extracted from plant, animal, and mineral sources are referred to as natural fibers. In order to enhance their properties, they are often combined with synthetic fibers.

Cellulosic fibers *originate from the cellulose found in plants such as cotton, bamboo, and hemp. They undergo extensive processing and are regenerated in fiber form.* ***Retting*** *is*

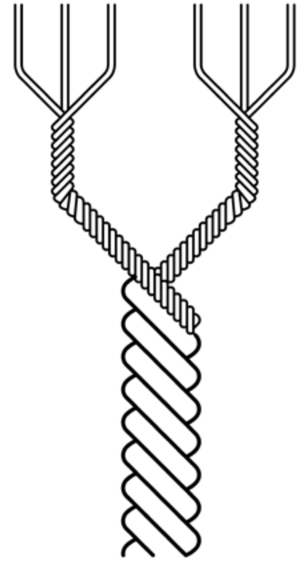

Fig.09/04 A 120 den yarn structure comprising 2 plies with three 20 den fibers.

a process that involves soaking plant stalks in stagnant, chemical-laced water, and decaying the pectin to separate fibers. This category of fibers features high absorbency and low resiliency, biodegradable, and flammable.

COTTON ● Cotton is made from the fuzzy bolls that surround the seeds of the cotton plant. The fiber is soft to the touch, absorbent, and hypoallergenic, commonly used in the apparel industry. It has relatively high durability but is susceptible to UV damage. Even though cotton is a popular and convenient fiber, it has a significant negative impact on the environment. *It requires an*

Vid.09/01 Video on the steps of manufacturing fabric in a modern mill.

Fig.09/05 *Cotton fiber is derived from the fuzzy bolls of the cotton plant, which are pure cellulose.*

Fig.09/06 *Jute is a cheap and durable fiber, yet the yarns are often very coarse in texture.*

immense amount of water *to cultivate and the* ***agrochemicals*** *needed in the process degrade soil and underground water resources.*

BAMBOO ● Bamboo fibers are extracted through mechanical or chemical processes, typically utilizing natural enzymes or mild chemicals like sodium hydroxide. It is comparatively softer than cotton, absorbent, breathable, UV resistant, and flexible. Bamboo fiber manufacturing is environmentally friendly in the sense that it does not require irrigation systems or agrochemicals, however, the increasing demand has been causing some deforestation in China and India.

HEMP & FLAX ● Hemp is a durable, resilient, and sustainable substitute to cotton. It is anti-bacterial, and compatible with many other fibers. Used for making linen, flax fibers are relatively less elastic and coarser than cotton, but more absorbent, breathable, and stronger due to longer filaments. Linen does not lint, pill, fray, and crease easily; becomes softer as it is used.

JUTE ● Jute is a coarse and brittle fiber, used in packaging and apparel. In interiors it is used for area rugs, as well as carpet backings. It is very popular in South-East Asia, yet not so much in the Western world. Being a plant-based natural fiber, it is rapidly renewable, biodegradable, antistatic, and hypoallergenic. Finer jute can be woven in combination with cotton.

Animal fibers *are protein-based natural fibers derived from hairs, fur, as well as secretions of various animals.* They are ***hygroscopic****, meaning they absorb and retain humidity from the surrounding atmosphere*. These fibers require antimicrobial treatment as they are very susceptible to insect attack as well as mold and mildew growth, especially when they are used for carpeting or carpet pads. Animal fibers lose some strength when wet and do not react well to alkaline cleaning chemicals.

SILK ● Silk is a luxurious and somewhat expensive fiber that is generally obtained from mulberry silkworm cocoon, a species cultivated specifically for silk production. Silk is a strong and flexible fiber, exhibits moderate resistance to abrasion and wrinkles, boasts a high sheen and dyes very well. Silk quickly deteriorates, yellows, and fades under UV exposure. It is somewhat fire-resistant, hard to ignite, and burns slowly.

WOOL ● Wool is sourced from sheep as well as other animals such as goat, alpaca, camel, llama, and rabbits. Wool is a common fiber used in interior textiles such as upholstery fabric, drapery, carpeting, and wallcoverings. Wool is lightweight, resilient, flexible, and an efficient insulator. Wool resists combustion and can self-extinguish. Wool

Fig.09/07 The cocoon of the mulberry silkworm is boiled to extract silk fiber, killing the creature in the process.

Fig.09/08 Sheep farming causes considerable amounts of greenhouse gas (methane) release.

carpets are seen as a benchmark for quality; good at hiding soil and provide high appearance retention. Wool, however, can build up a static charge and needs antistatic treatment. *Wool staple length and quality depend on **how the sheep are farmed**.* Relaxed conditions such as open pastures allow for longer, straighter, higher quality staples; while rocky and rough conditions create a shorter, scalier, and lower quality fiber. ***Worsted*** is a type of wool yarn that is stronger, finer, and smoother as it is constructed with longer staples; as opposed to ***woolen***, constructed with shorter scalier staples, which has the characteristic fuzzy texture that traps air, rendering it insulative and warm.

Even though wool is often referred to as a rapidly renewable resource, ***large-scale sheep farming** generates methane, an impactful greenhouse gas, can cause deforestation, soil erosion, and water pollution.* Recycling wool is also possible, however, the recycling process results in increasingly shorter fibers and consequently lower quality textiles.

Vid.09/02 Video on the differences between worsted and woolen fibers.

There are many different types of wool harvested from animals other than sheep. ***Mohair*** fibers harvested from angora goats is one example. Even though expensive, they are also smooth, absorbent, and show relatively high abrasion resistance. ***Cashmere*** fibers are ultrafine, super soft, and luxurious; harvested from cashmere goats bred for their high-quality fleece.

MINERAL FIBERS ● Mineral-based fibers are classified as natural fibers. Glass fibers are formed when glass is melted and extruded into fine strands, they are highly fire-resistant. They are also very brittle and subject to abrasion. Even though the research is not conclusive, there's a possibility that *persisting glass fiber exposure may be **carcinogenic***. Asbestos is also a natural fiber that can be woven. Even though it was a fascinating and useful material in the past, today the risks are well understood.

SYNTHETIC FIBERS

*Although they were originally developed to replace natural fibers at a lower price point, **synthetic fibers** evolved to feature many robust and desirable properties not found in any natu-*

Fig.09/09 *PVC fibers are being drawn and spun into spools.*

ral fiber. Synthetic fibers can be manufactured from plant-based sources such as wood pulp or totally synthetic sources such as polyvinyl chloride (PVC). Synthetic fibers can be processed to mimic the look and feel of natural fibers, for example, acrylic fiber can be processed to feel like wool, cotton, as well as silk. Synthetic fibers can be heat set enabling them to hold pleats and resist wrinkling. Crimping is also achieved via heat-setting. They are mold, mildew, and insect resistant; most resist ignition, some self-extinguish, but most melt. *One big disadvantage of synthetic fibers is their tendency to* ***retain static electricity*** *that can cause light electric shock.* Especially for carpeting anti-static treatment is a necessity. Pilling is another issue for most synthetic fibers partly due to their strength in holding on to abraded lint and partly because of static electricity built up. *Anti-static, flame-resistant, stain-repellant, etc.* ***additives can be used to augment the performance*** *of synthetic fibers.* Synthetic fibers are often blended with natural fibers to provide desirable properties and to control costs. For instance, wool is blended with nylon to make an otherwise delicate wool fabric more elastic and machine washable. Or, a high-end woven carpet can feature wool blended with nylon for high traffic use without sacrificing luxurious feel.

RAYON ● ***Rayon*** *is the first synthesized fiber*, essentially regenerated cellulose (viscose) from refined wood pulp, therefore it is not completely synthetic. The manufacturing process is harmful to the environment and the workers due to high carbon disulfide and sulfuric acid usage.

NYLON ● ***Nylon*** *is a thermoplastic polymer, developed by DuPont® in the 1930s as a synthetic replacement for silk*. A type of polyamide (PA) itself, Nylon has many variations. For example, Nylon 6 exhibits good performance and high recyclability, whereas Nylon 6,6 exhibits higher performance but is difficult to recycle. Nylon fibers in general have good elasticity, elongation, and recovery. *They have low moisture absorption and high abrasion resistance, rendering them very suitable for* ***carpet manufacturing***. Nylon has low UV resistance.

ACRYLIC ● ***Acrylic*** *fibers can be engineered to mimic the look and feel of natural fibers such as silk, wool, and cotton*. Acrylic is UV resistant, retains color well, and does not react to harsh cleaning chemicals, therefore appropriate for heavy traffic loads. It can provide significant bulk due to its lightweight and compatible with other fibers.

OLEFIN ● ***Olefin****, a polymer family that usually reference polypropylene and polyethylene*. This fiber is relatively cheap, lightweight, and resilient with good colorfastness. Melts easier than other synthetic fibers. Relatively low static electricity generation, commonly used in carpet manufacturing. It cannot perform as well as Nylon.

Vid.09/03 *Video from 1949 on the comparison of nylon and rayon.*

POLYESTER ● Polyester is a very popular synthetic fiber commonly utilized in the apparel industry. Strong with great abrasion resistance, dimensionally stable, retains its shape well, and very suitable for crimping. It also retains color and vibrancy well. Polyester has relatively good UV resistance, easier to maintain than many other fibers, and as a result, often blended with other fibers such as cotton, wool, or rayon to increase fade resistance, wrinkle resistance, and washability. A blend of polyester coated with Polyvinyl Chloride (PVC) can offer extra durability and resilience, at a slightly higher price point.

ARAMIDS ● *Aramids are a category synthetic fibers known for their strength and fire resistance.* Kevlar and Nomex are brand names for aramid (aromatic polyamide) type fibers famous for their impact and fire resistance. Woven aramids and other fabrics can be laminated for added performance. ***Carbon fibers** are synthesized under intense heat from various polymers such as polyacrylonitrile (PAN) or Acrylic (PMMA).* Carbon fibers are woven just like normal textiles and then they are set in resin. The resulting product is a very high strength, lightweight material with high chemical and fire resistance, especially when formed into carbon-carbon composites.

MICROFIBERS ● Microfibers are fibers with very fine cross-sections drawn from common plastic resins such as acrylic, polyester, nylon, etc. These fibers retain the properties of the original resin, but they are softer, flexible, can be woven densely. These are popular as cleaning cloths since the tiny extensions on the surface can reach the smallest crevices and hold onto dirt efficiently.

METALS ● *Metals can be expanded, drawn, spun, or cut to fibrous shape and form **metal fibers**.* Similar to other synthetic fibers the fiber profile can be modified to increase strength, durability, flexibility, or appearance. It is also possible to coat metal fibers with a transparent polymer film to minimize eroding and tarnishing. These fibers can be spun with other fibers during yarn manufacturing or can be directly woven into the fabric. Gold fiber has been used to decorate fabrics throughout history. Silver fibers can be woven in to imbue a fabric with anti-microbial and conductive properties. Copper further provides structural support and creasability. Aluminum is a multipurpose and cost-effective alternative to other metal fibers. It is also possible to weave a fabric only with metal fibers. ***Metal meshes** with thicker fibers and wide spacing are very suitable for spatial applications.*

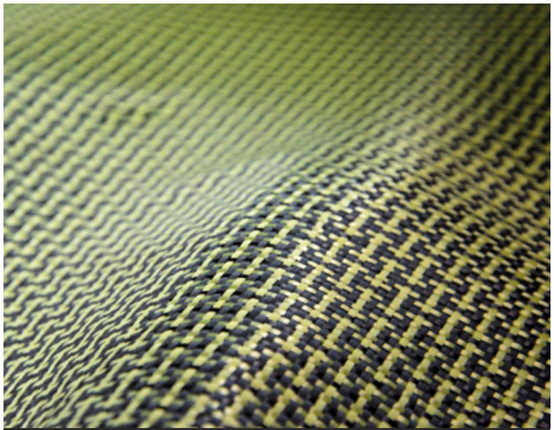

Fig.09/10 Aramids, a fire resistant fiber, can be woven with carbon fiber for increased effectiveness.

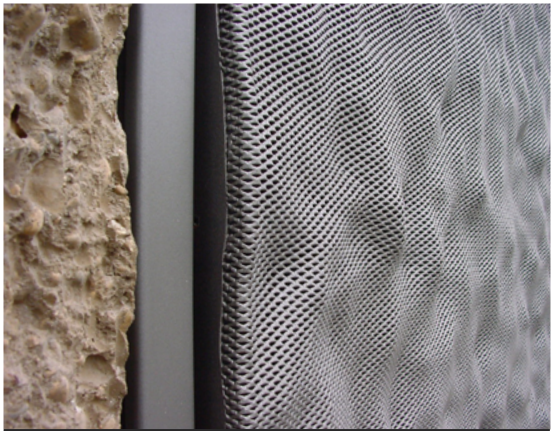

Fig.09/11 A non-woven metal sheet product, expanded metal mesh is able to hold form.

TEXTILE SPECIFICATION

Woven fabrics are manufactured on a loom by ***interlacing two or more threads*** *at a perpendicular angle.* These threads, or floats, are referred to as warp (goes up) and weft (goes left). Woven fabric width is determined by the manufacturer based on the capabilities of the looms used; most common widths are between 36" and 60". ***Textile hand*** *refers to the physical feel of the fabric, defining characteristics such as smoothness, drape, elasticity, etc.*

The density and type of weave affect fabric texture, durability, and stability. The denser the weave and the more interlacing points there are, the more durable the fabric will be. The simpler and balanced the weave, the more durable it is. The longer a thread is exposed, or floating, the more it is susceptible to wear, snagging, and seam slippage. The direction of the abrasion or friction determines how the fabric will wear. For instance, floats of a weave that are perpendicular to the seating direction experience significantly more snagging.

Plain weave has a basic over-under pattern, very strong and durable, featuring a subtle texture particularly suitable for printing applications. Basket weave is a variation of the plain weave with an over-over-under-under pattern and slightly less strength due to reduced interlacement of threads. ***Twill weave*** is characterized by a diagonal construction rendering it more durable to unidirectional wear. The widely recognizable texture of denim is cotton twill weave. Herringbone weave is a variation that alters the direction of twill lines, creating a distinctive zig-zag pattern. ***Satin weave*** features extended floats for enhanced luster, however, it is prone to abrasion and snagging. Most other weave types are variations of these basic weaves.

Computer-driven looms that are highly capable in articulating yarns allow for highly complex and visually interesting weaves. *The* ***jacquard loom*** *was the precursor of the modern computerized looms, it utilized punch cards to automate the complex weaving process.* Today, the term Jacquard is also used to refer to all automated power looms that can create complex weaves such as brocade, damask, brocatelle, messier, pique, and tapestry. Moreover, it is not uncommon that all of these different complex weaves are referred to as simply Jacquard weaves.

In weaving, two straight threads run perpendicular to each other, whereas *in* ***knitting****, a single thread meanders, both creating and going through consecutive connected loops.* As a result, the knitted fabric gains high elasticity, bulk, and provides great insulation, especially

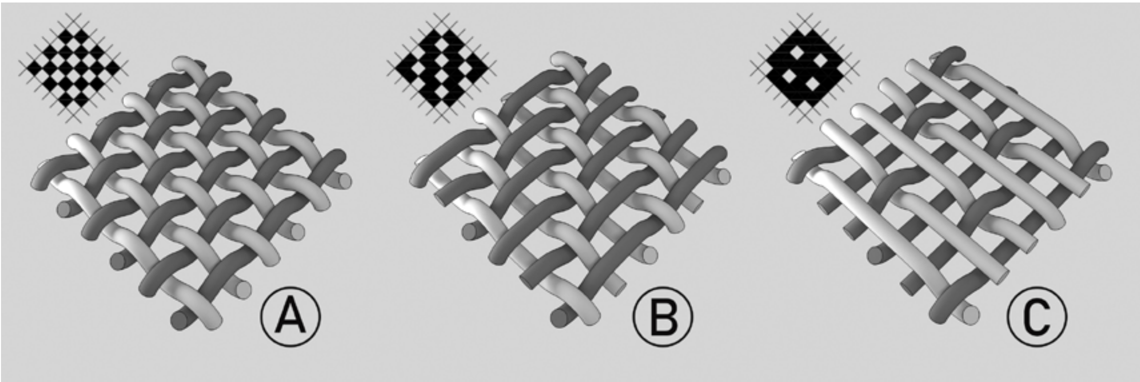

Fig.09/12 Common weave types include plain weave (A), twill weave (B), and satin weave (C).

Fig.09/13 An original Jacquard loom with punch cards, that detail the pattern, fed from the left.

desirable for winter apparel. Knitted fabrics are harder to work with and sew, they are prone to snagging and pilling.

Felting *refers to compressing or matting randomly arranged fibers, often in a solution.* Felting is fairly straightforward and has a history stretching 8000 years back to Asian nomadic tribes. Felted fabrics are usually compressed or needled wool or wool blends, categorized as non-woven. Felt is a great insulator, can be very firm and strong, or soft and easily workable depending on the manufacturing process. The acoustical advantages made felt slats, tiles, and panels a popular way to introduce color and texture to an interior space while controlling the acoustics of the interior environment.

Fibers, yarns, or whole fabrics can be dyed or printed on. *Dyeing is a* ***water-intensive*** *process.* Over 20% of the discharged water from dyeing processes contains pollutants. ***Mercerizing*** *involves treating fibers in a caustic solution (sodium hydroxide) and stretching them.* This process enhances the luster, absorbency, and dye affinity while reducing shrinkage.

There are multiple dying methods, each with different purposes, features, and price points. ***Solution dyeing*** *refers to coloring the melted synthetic resin before it is drawn into fiber*; different than other methods where color is applied to the fiber, yarn, or woven good. Since the color is inherent to the material, this technique provides higher colorfastness, lightfastness, and stain resistance as the pigments are part of the composition of the fiber. Custom coloring is relatively hard with long lead times. ***Stock and Skein dyeing*** *involves submerging stocks of fibers or yarn skeins – which are loosely coiled yarns – into boiling dye vats, allowing the pigments to penetrate the material.* This is a fairly old,

Vid.09/04 Video on the comparison of weaving and knitting.

Fig.09/14 Traditional skein dying involves submerging the yarns in boiling dye vats.

labor-intensive, and expensive method, though colorfastness is fairly high. The fiber or yarn also gains a softer fuller feel. The dyeing process is fairly quick, measured in hours, and custom colors can be done fairly quickly. ***Greige goods*** *are undyed, colorless (gray) textile products that are waiting to be further processed.* ***Piece dyeing*** *involves dyeing woven or knitted fabric or carpet in large batches.* Very useful for large solid color fabrics. Relatively cheap and large amounts of material can be dyed very quickly, however, visual evenness and color retaining ability are relatively low. Crafted pieces can also be piece dyed. ***Printing*** *is a way to attain complex patterns without the cost of a complex weaving process.* There are two major printing methods: screen printing and digital printing. Screen printing involves creating several large screens to transfer transparent colors in overlapping layers, when combined forming an image or a pattern. This option is cheaper when large production volumes are involved. On the other hand, in digital printing, the printing area and output volume are limited, though the result can be higher quality with techniques such as dye-sublimation. It is priced per product, hence expensive regardless of volume. For both printing methods, the durability and color retention properties would be fairly low as the color is not inherent to the fiber but it is merely a topcoat.

Colorway *is a term used to refer to textile color schemes,* often containing two or more colors. Alternative colorways may be present for each pattern. This term applies beyond textiles, to many other designed products. Color trends in the textile industry rapidly change. Consequently, the designer should be mindful of the fact that many patterns or colors can go out of fashion and become hard to procure.

Vid.09/05 Video on traditional dyeing with natural pigments.

Fig.09/15 Textile patterns often feature various colorway alternatives.

Textile finishing is the final process that the product will go through, in order to improve the performance and appearance of the fabric, such as shrinkage and wrinkle control, UV protection, moisture resistance, impermeability, fade resistance, stain resistance, insect, mold, and bacterial control, etc. ***Flame retardant finishes*** *can help reduce or prevent combustion. However, direct skin exposure, especially of younger children, to these finishes should be minimized due to potential health risks*. Such treatments can also be corrosive, therefore any metal component in contact should be carefully selected. ***Glazing*** *is a process that introduces sheen and smoothness to a fabric surface.* The fabric is first impregnated with the desired wax or resin, then, a calendaring process – which is compressing fabric in between two heated rollers – is used to apply polish via friction. This process increases the durability of the fabric, very useful in upholstery applications. One example of this process

Fig.09/16 Nanocoating imbue fabrics with desirable qualities, yet they tend to wear off with use.

is the fabric type known as “chintz”, which is fundamentally shiny glazed cotton, featuring floral patterns. ***Nanocoatings*** *can be applied to enhance fabric properties such as cleanability, abrasion-resistance, and hydrophobicity.* Nano-coatings, as well as other finish coatings wear off over time.

Fabric weight *is the measurement of the weight for a unit area, typically expressed in ounces per square yard; it is a good indicator of the workability and durability of a textile.* Lightweight fabrics have a weight of less than 4 ounces (per square yard) and are appropriate for upholstery, draperies, linings, etc. Medium-weight fabrics have a weight of 4 to 10 ounces and are appropriate for upholstery, draperies, decorative elements, etc. Heavyweight fabrics are over 10 ounces and are appropriate for upholstery, draperies, etc. Similar to fiber weight, fabric weight does not immediately determine quality.

When specifying fabric for various uses, the designer needs to consider a multitude of variables in order to judge the suitability, cost, and life expectancy of the product. Each one of the prominent variables is elaborated on below.

Abrasion Resistance *signifies the capacity of the fabric surface to resist mechanical wear via friction with another surface*, a good indicator for the useful life of the fabric. There are two important abrasion tests that designers frequently encounter when specifying fabric: Wyzenbeek and Martindale abrasion tests. *The* ***Wyzenbeek method*** *features a sandpaper abrader being rubbed against the fabric test sample and the number of double rub cycles before yarn breakage indicates abrasion resistance of the fabric.* On the other hand, *the* ***Martindale method*** *involves a wool abrader moving in a figure 8 pattern, instead of sandpaper moving back and forth, and the outcome is measured in cycles.* Consequently, more cycles of the Martindale test can match the performance in the Wyzenbeek test. For example, textiles with 10K double rubs in Wyzenbeek test and 15K cycles for Martindale test performance are appropriate for residential use, and 30K double rubs in Wyzenbeek test and 40K cycles for Martindale test performance are appropriate for commercial use. When going through fabric test results it is not uncommon to see products with 100K to 250K published results. Another important abrasion test is the ***Taber test.*** *This method is commonly used for leather but for other textile and non-textile products as well, including but not limited to vinyl sheets, powder-coated metal, or hardwood.* This test features a revolving sample under two revolving abraders with change-able weights. So, Taber test results can vary based on different weights and abrader types and when comparing products this needs to be considered.

Vid.09/06 Video showcasing the Wyzenbeek abrasion test.

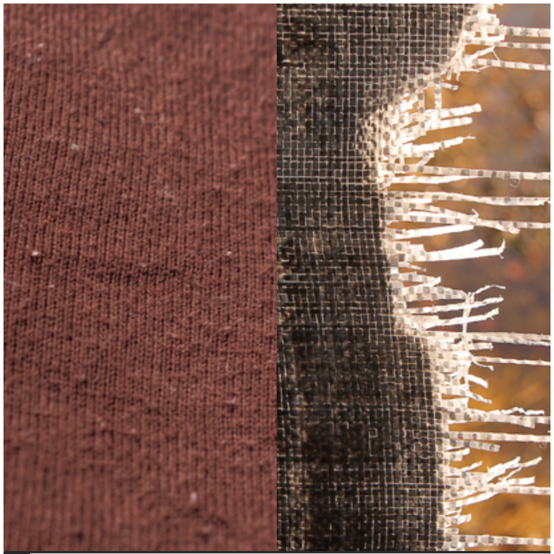

Fig.09/18 Examples of common textile wear: pilling on the left and fraying on the right.

Pilling** is caused by short filaments breaking away from the yarn* due to abrasion and forming small chunks of lint on the fabric surface. Staple length and yarn construction directly determine the intensity of pilling. Wool, cotton, and polyester fabrics pill more; and linen, silk, and nylon pill the least. Every fabric eventually pills, therefore pilling is not considered a defect and does not correlate with fabric quality. The designer should anticipate the amount of abrasion the textile will receive and specify a fabric with tighter yarns and longer staple lengths to minimize pilling. ***Fraying** refers to the threads at the edges of a woven fabric coming loose.* This affects seam allowance and might hasten seam slippage under heavy traffic load. Heavier fabrics with tighter weaves fray less than lighter fabrics with looser weaves. ***Selvage is a densely woven edge of the fabric to prevent fraying in textile while stored, it is not intended to be used as part of textile construction. Nonwoven and knitted fabrics won't fray. ***Seam Slippage** refers to a section of seam pulling apart and opening up due to fabric construction giving in, yarns opening up, and stitches losing grip.* When constructing a seam, the number of stitches per inch can be increased especially in areas expected to receive higher pressure, such as seat cushions and armrests. A fabric with a denser weave construction can also be used, the fabric can be reinforced at the seam, hemming or overlocking can be applied. ***Overlocking**, also known as a serged seam, is a seam constructed with multiple threads, the edges are cut off and automatically finished so fraying is minimized.*

***Colorfastness** refers to the ability of a textile to hold onto pigments and resist color loss.* Some textiles can lose color and fade significantly based on abrasion, UV exposure, water and moisture exposure, heat exposure, and reaction to cleaning products and other chemicals. The dyeing method, type of dye, dye penetration, hue and shade, all determine the strength of colorfastness. ***Crocking** is the smearing of textile dye*

CONTENT	83% Wool, 15% Post-Cons. Recycled Polyester, 2% Acrylic	**ABRASION RESISTANCE**	Martindale Test - 65,000 Wyzenbeek Test - 50,000
WIDTH / WEIGHT	57 in. / 14.7 oz.	**FLAME RESISTANCE**	NFPA 260 - Class 1 CAL 117 / 2013 Section I - Pass
COLORWAYS	Ash, Fire Opal, Green Tea	**COLORFASTNESS TO CROCKING**	AATCC Method 8 Wet: Class 3 / Dry: Class 4
PATTERN REPEAT	H: 2.3, V: 2.4	**COLORFASTNESS TO LIGHT**	AATCC Method 16 (40 Hours) Class 4
AVERAGE BOLT LENGTH	55 yd.	**CLEAN AIR CERTIFICATE**	Gold
CUTTING DIRECTION	Non-Railroaded	**PILLING RESISTANCE**	ASTM D3511 - Class 4
CLEANING	Only use mild, pure water-free dry cleaning solvents.	**SEAM SLIPPAGE**	ASTM D434 / D3597 Warp: 53 lbs, Fill: 71 lbs
SEWING	Ball-tipped needle and polyester thread are recommended.	**BREAKING STRENGTH**	ASTM 5034 Warp: 282 lbs, Fill: 295 lbs

Fig.09/17 Sample textile information card.

to another surface and causing staining through contact. There is a wet and a dry crocking test available for measuring crocking resistance with grades assigned based on the fabric's performance. Grade 5 signifies no transfer and Grade 1 is high degree of color transfer. For upholstery and drapery Grade 3 and up is required. Sometimes crocking resistance information is provided as colorfastness, or colorfastness to crocking. The test methods are developed by the American Association of Textile Chemists and Colorists (AATCC). ***Lightfastness** is the resistance of the textile against fading under UV exposure.* Similar to crocking resistance test, AATCC developed another test for lightfastness which exposes the fabric sample to a carbon-arc or xenon-arc lamp for 40 hours of accelerated fading units (AFU) and compares fading. 1 hour of AFU approximates to 1.3 hours of direct sunlight exposure. Similar to crocking resistance, Grade 5 signifies no fading, grade 4 is slight fading, and grade 1 signifies little fading resistance.

*All textiles soil and stain during use, and based on the extent of active usage, **periodical cleaning** is necessary.* Not all fiber types and fabric constructions are compatible with every cleaning product and method in the market. The cleaning procedures for healthcare or restaurant environments are different from an executive office or a residential environment. The cleaning protocols and practices to be employed need to be checked with the manufacturer's cleaning recommendations for the product. ***Commercial grade** textiles can withstand the harsher types of cleaners, whereas **residential grade** textiles are relatively more delicate.*

> *Yarn weight and bulk are only one facet of wear resistance; spinning method, weaving method, density, and overall build quality, all factor in to **wear resistance** of a fabric.*

LEATHER

Leather is a non-woven sheet product, classified as textile, manufactured from hides of animals such as cattle, sheep, goats, pigs, reptiles, and even birds. Leather is speculated to be the first utilized textile in history, possibly worn as clothing while also being used for shelter construction and insulation. Leather boasts strength, puncture and tear resistance, insulation, breathability, elasticity, and moldability. It also exhibits resistance to chemicals, abrasion, fire, fungi, and mildew. Leather is very versatile; it can be dyed, painted, embossed, carved, or stamped. The majority of hides obtained for leather production are by-products of the meat industry, implying that it is a rapidly renewable and sustainable material at first glance. However, *leather tanning processes require **substantial amounts of water** and chemicals to produce workable and durable leather, resulting in nega-*

Fig.09/19 *The historic leather tanning pools in Fez, Morocco are the oldest in the world.*

tive environmental impact. Leather is a recyclable material; even though the resulting product, known as bonded leather, is of inferior quality. Besides the environmental impact, public sensitivities are a concern as well; various groups of people are known to be against leather use due to religious or humanitarian reasons.

Left untreated, leather is extremely perishable, quickly deteriorates, and decomposes therefore it is immediately cured. After being transported to the processing facility, hairs are chemically removed with the liming process. At this stage, the excess flesh is also removed and the hide is split into desired layers. This process is followed by tanning, dyeing, and finishing. *The raw hide itself is thick and is commonly **split into multiple layers** with distinct properties. **Rawhide** refers to the de-haired and cured but untanned leather.* Typically rigid, becomes workable when wet. It acquires a natural patina with use. ***Full-grain** is the outermost layer of a hide*. The entire grain is unaltered, featuring natural scars and blemishes. It is highly desirable and expensive due to resilience and visual character. ***Top grain** is positioned slighly below full grain, second in terms of quality.* Its surface is corrected via sanding and buffing to create a consistent and smooth result and embossed with an artificial grain pattern, lacking natural variations. ***Split grain** is the lower and thinner layer of leather with loose collagen fibers*. This layer can also be embossed with artificial grain or buffed to create suede. ***Genuine** leather produced from this layer is actually of lower quality and desirability*. ***Bonded leather** is the lowest grade leather: featuring shredded leather scraps reconstituted with bonding agents pressed into sheets.* It is highly susceptible to cracking, peeling, and flaking. *A fabric backing can be covered with a polyurethane (PU) or vinyl (PVC) layer then embossed with leather grain texture to manufacture **artificial leather**.* Vinyl's natural sheen creates a plasticky look therefore forming a fake and cheap impression. Polyurethane, with its more diffuse visual quality, higher breathability, strength, and durability, is considered a good alternative to natural leather, though it is considerably more expensive than vinyl. The polyester and polyurethane blend ***Alcantara** can mimic suede with enhanced qualities, providing durability and stain resistance*.

Vid.09/07 Video on the types of leather.

***Tanning** is a chemical process that inhibits decomposition of the hide by binding chemicals to collagen fibers, permanently altering the protein structure.* There are two fundamental ways of tanning: one is chromium tanning and the other is vegetable tanning, named based on the chemicals used in the process. *Almost 90% of all leather receives **chromium, or mineral, tanning** treatment.* The resulting leather attains high flexibility, it is more workable, and can be dyed in a large variety of colors. The trivalent

Fig.09/20 Artificial leather is highly susceptible to cracking and peeling.

Vid.09/08 Video on the steps of the tanning process.

chromium (III) used in the process is not as toxic as chromium (VI), but it is still considered environmentally problematic. ***Vegetable tanning** is a lengthier and more expensive tanning process, during which the tannins in tree bark, especially from oak, are utilized.* The resulting leather becomes relatively stiffer after drying, however, it is comparatively more durable. The color choice is limited to shades of brown. It features a unique smell and develops a dark patina over time if the natural grain is exposed.

***Leather is graded** based on the quality of the hide and presence of damage and defects, such as holes, cuts, wrinkles, scores, and gouges as well as visible grain defects.* The various areas of the hide such as the neck, belly, and bend – which is the central area – yield different quality hide. A high-quality grade A/No1 hide contains

Fig.09/21 Leather defects determine the quality grade of the material.

Fig.09/22 The required leather pieces are outlined in a way to keep desired patterns and leave out defects, while using the hide as efficiently as possible.

almost no defects, grade B/No2 hide contains individual defects no larger than 1” and less than 1sqft of warts, and for grade C/No3 hide criteria is more than 50% of the surface area should be usable. The lowest grade is called utility grade. The following will affect the cost of the leather: ❶species of the source animal; ❷origin and health of the animal; ❸quality of the rawhide; ❹method of manufacturing; ❺tannery practices (regulations and quality standards); ❻dyeing and finishing process.

Leather can have a large variety of finishes. It can be dyed, waxed, oil-treated, embossed, perforated, brushed, sanded, buffed, or distressed. ***Aniline dye**, comparable to wood stains, is a penetrating translucent dye that imbues the leather with brightness while enhancing the natural grain pattern, color variations, and imperfections*. Highly desirable and expensive, yet aniline leather requires careful maintenance and regular conditioning. In ***Semi-aniline dyeing**, the leather features a protective topcoat while featuring a slightly more uniform*

Fig.09/23 Chromium tanned and artificially dyed leather can feature any color.

look. ***Artificial dyeing*** *is the application of a protective solution with opaque pigments as a topcoat on buffed and sanded leather.* The natural texture and color is removed and the material is embossed with an artificial grain pattern. A large range of colors can be attained with absolute control over texture consistency, and the resulting product is more durable.

Leather has various interior finish applications besides upholstery. ***Leather tiles*** *are often manufactured from unsplit full hides, commercially available for vertical surfaces as well as for flooring applications.* It provides a robust and refined appearance, might be associated with luxury and prestige. However, these tiles are susceptible to staining, deteriorate under UV exposure, and not suitable for medium to high traffic loads, moreover, they require yearly conditioning and maintenance. In any case, *it is important to use a* ***leather conditioner*** *to sustain the material's health and suppleness.* Leather requires gentle cleaning practices, such as being wiped with a damp cloth.

Vid.09/09 Video on leather conditioning.

CARPET

Carpet is a versatile and relatively low-cost woven floor covering. ***Carpet*** *has a litany of variations based on yarn properties, weave, and composition. It caters to a large variety of spatial design scenarios.* Carpet weaving is an ancient art, origins tracing back to the Neolithic period. Started out as a handmade and fairly expensive product, carpet gradually became affordable and varied since the introduction of the first woven carpet mills in the 18th century. A major milestone was the introduction of the mechanized tufting machine in the early 20th century, which streamlined manufacturing and significantly reduced costs. *As of 2022, carpets accounted for a* ***33.7% market share*** *in the US floor covering industry.*

Carpets feature the same types of fibers that are used in many other fabrics, such as wool, nylon, acrylic, olefin, etc. Although, the yarn construction is thicker and it features techniques such as bulking and crimping to increase wear resistance. When choosing the appropriate fiber, the designer should focus on abrasion, flame, and fade resistance values as well as the price point. *Due to its versatility and performance characteristics nylon seems to be the most popular fiber for carpet manufacturing today with almost 30% of the market share.* ***Bulked Continuous Filament (BCF)****, is single continuous nylon, or other synthetic, fiber that is given bulk through a zig-zag or randomized crimping process.* Since there's no yarn spinning involving shorter staple fibers, the resulting yarn is more durable, wear-resistant, and won't shed and lint like many natural fibers, such as wool which is only available as staple fibers.

Aside from the properties of fibers being used, carpet construction is important in determining the purpose and quality of the product. High-quality carpets typically feature densely packed yarns. ***Woven carpets*** *offer more durability and stability for an additional cost, preferred for high*

Fig.09/24 Carpet is one of the most popular flooring materials throughout the US.

Fig.09/25 Woven carpets are commonly specified for high-end high traffic spaces, such as casino atriums.

traffic loads and demanding locations, where the aesthetic value is also important, such as casino lobbies and corridors. There are two important types of carpet weaving: Axminster and Wilton. ***Axminster** weave can feature up to 10 colors and intricate patterns often specified for hospitality and healthcare environments where visual versatility and a sense of luxury are as important as durability and strength. **Wilton** weave features a continuously running yarn, therefore, there are fewer colors, smaller pattern size, and pattern complexity is limited.* Due to its more complex interlaced construction, it has relatively higher durability, dimensional stability, and body. Both weaves are suitable for bespoke designs. As opposed to woven carpet construction, *in **tufted carpets**, yarns are inserted through the backing and then secured into place.* Tufted carpets are significantly cheaper, simpler, and faster to manufacture than any woven alternative. Tufted carpet construction is one important reason why carpeting became so prevalent in the US. *In **fusion-bonded carpets**, yarns are set at specific lengths and densities, then affixed to a polymer backing using a liquid adhesive, ensuring they are firmly anchored.* This is an even cheaper construction as there's no need for stitching.

> *Tufted carpets allow for relatively limited visual variety and they are said to have lower durability, though this is also largely determined by the **manufacturing quality** of the specified product.*

The way piles of yarn are finished is another important property for carpets. ***Cut piles** are manufactured by shaving the ends of the yarn loops.* Exposed ends render this pile type dense, plush, and pleasant yet less durable. Cut pile is highly susceptible to showing footprints and crushing. Oppositely, ***loop piles** are manufactured by leaving the loops of yarn untouched.* They are suitable for high-traffic as the yarn ends are not exposed. It is possible to combine cut and loop piles on the same carpet to create

Vid.09/10 Video on the differences of nylon and wool carpet fibers.

Vid.09/11 Video on the differences of tufted and woven carpets.

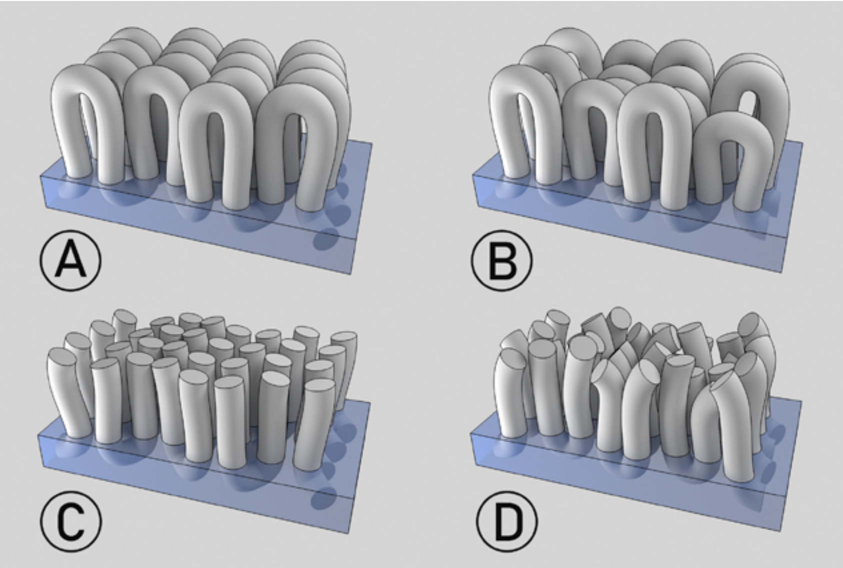

Fig.09/26 *Common tufted pile types include level loop (A), multi-level loop (B), cut loop (C), and twist pile (D).*

visual interest. *In a* ***twist pile****, each yarn is tightly twisted. When cut, the twist opens giving body to the yarn, provides durability, hides footprints and vacuum tracks. The fuzzy appearance of twist pile is useful in hiding stains.* The designer should consider that the *complexity of visual patterns help conceal soiling and track marks*.

There are various important structural properties that apply to all carpet constructions, determining their performance under use. ***Stitch rate****, or stitches per inch, denotes the number of fibers per inch.* This value ranges from 5 to 12 per inch, or 25 to 144 stitches per square inch. A higher number indicates higher durability. ***Gauge*** *refers to the distance between each stitch,* 8 stitches per inch would equal to 1/8 gauge. *For woven carpets a different unit,* ***pitch*** *is used, which is the number of ends or stitches per inch multiplied by 27*, as the standard carpet width is accepted as 27". So 8 stitches per inch would be equal to 216 pitch. ***Pile density*** *refers to the density of fibers on a carpet surface, based on the number and size of tufts per unit area.* Expressed in ounces per cubic yard. For example, commercial carpets range from 4200 to 8000.

Low-density carpets *cannot resist crushing, quickly reveal seams, and fail to retain appearance, therefore not appropriate to receive heavy traffic.*

Even though *longer* ***pile height*** *is more comfortable and pleasant underneath the feet, shorter pile height is more durable, cleanable as it can resist staining, matting, and crushing*, which is especially important for nylon fibers. Short pile height is more appropriate for commercial applications where appearance retention under heavy traffic is key. The designer should also consider that longer pile height means retaining more dust, dirt, and mites. Without frequent and correct cleaning, this might affect indoor air quality negatively. It is possible to have varying pile heights for creating texture. ***Shag carpet*** *piles that are substantially deeper*, creating a fluffy appearance. Despite being comfortable with a softer feel, it tends to trap dust, debris, and mites, while being challenging to clean. ***Face weight*** *refers to the total weight of carpet yarn per square yard.* This value ranges between 20 to 100 ounces, however, a higher number does not always correlate with durability. Face weight is helpful for comparing carpets with the same

Fig.09/27 *Pile height can be manipulated for texture effect.*

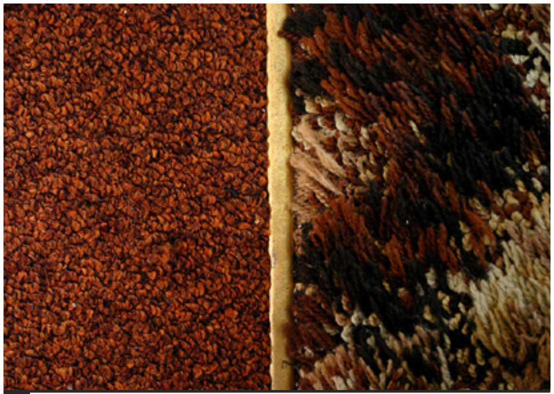

Fig.09/28 The pile depth of shag carpet provides comfort, however, it is also difficult to clean.

Fig.09/29 Carpet pads improve both physical and acoustical performance of the carpet.

construction. Only then it can accurately indicate higher strength, otherwise, it can be misleading. Total weight value includes face weight as well as the weight of the backing.

***Carpet backing** is the foundational sheet layer underside of the carpet, providing dimensional stability and durability.* There can be two layers of backing: one securing the yarn loops in place and the other one supplying support, strength, weight, and in some cases, padding. Depending on the quality of the construction, the secondary backing can delaminate over time, creating ripples and wrinkling on the surface.

***Carpet pad** is an underlayment typically placed during carpet installation; while increasing comfort it adds resilience, insulation, acoustical absorption, and extends the lifespan of the carpet.* The carpet pad also enables the carpet to be installed on any even substrate, softening any irregularities. As a result, the visual integrity of the upper layer does not suffer. There are many padding alternatives on the market such as polyurethane (PU) foam which can be thicker and squishier, or rubber which can be thinner and denser. There are also synthetic fiber pads that feature a felt-like appearance and consistency, or re-bonded foam scrap which is manufactured from all recycled content, therefore, more environmentally friendly. A thicker and softer carpet pad is useful for achieving comfort while sacrificing durability and appearance retention. On the other hand, a firmer thinner carpet pad achieves more durability under high traffic load though comfort and sound absorption/insulation are sacrificed.

Color can be applied on carpets in a multitude of ways, similar to other textiles. Fibers or yarns may be dyed before fabrication or the coloring might happen after the weaving process. ***Predyed** carpet refers to a dyeing the fibers before they are tufted or woven into the final carpet.* This way, color is infused to the fiber; achieving higher colorfastness. ***Postdyed** carpet refers to a dyeing process after the carpet is fabricated.* It is possible to piece dye or print on a carpet. Postdyed carpet will have low colorfastness, and as it wears away it will develop an undesirable faded look.

Carpet size is a crucial concern for the designer. The most common size is the ***broadloom carpet,** typically at 12' wide, though there are wider or narrower alternatives available depending on the manufacturer.* ***Carpet tiles** are modular square pieces with dimensions of 18" by 18" or 24" by 24".* These are more convenient to install and remove, they can also be arranged

Fig.09/30 Carpet tiles are especially useful when access to the substrate is required.

Fig.09/31 Persian rug being hand-crafted.

in custom patterns. Carpet tiles are suitable for replacement, especially for high traffic sections that can crush and wear under heavy weight. It is also convenient for accessing the substrate. How carpet tiles are laid out is important. It is useful to create a diagram to balance the look and minimize thin pieces and slivers. Upon entering a room the occupant sees the center and the opposite edge of the flooring. Therefore, *it is imperative to align the most visible pieces to the center and the opposing walls to achieve a balanced, pleasant look*.

Essentially, ***rugs** are pieces of carpeting that are unfixed, floating on the substrate or finished flooring.* They can be of any size, though they are typically smaller than the room that they occupy. Rugs can be hand- or machine-made to specific or custom dimensions or they can be cut from broadloom carpets. Rugs feature a finished border to minimize fraying due to exposed edge fibers. Rugs serve various functions aside from providing warmth and comfort, such as defining an area, delineating paths, directing attention, and visually relating spatial components; or they can protect the substrate and provide slip resistance.

*The **Carpet and Rug Institute (CRI)** is an independent non-profit organization that sets standards and develops tests for carpet installation, cleaning, maintenance, removal, and end-of-life procedures.* ***CRI Green Label Plus*** program is important in identifying carpets, paddings, and adhesives with low VOC emissions. The National Sanitation Foundation (NSF) also develops standards for carpeting. For instance, the NSF/ANSI 140 Sustainable Carpet Assessment Standard takes a broader, life-cycle assessment based approach awarding public health and environmental considerations, bio/based recycled content, reclamation, end-of-life management, as well as overall manufacturing and innovation.

*Carpet is a complex material featuring multiple components enmeshed together and it is **very hard to recycle***. Face material has to be identified and separated from the backing. The resulting yarns are often too short and hard to process due to the coloring, additives, and f theinish applied during manufacturing. On the other hand, the unrecycled carpet directly contributes to landfills. In order to counter this, the State of California has established the “Carpet Stewardship Program” to incentivize and increase the recycling ratio of carpet, establish drop-off sites and collection procedures, as well as develop educational programs. Carpet America Recovery Effort (CARE), is a nationwide non-profit program that serves a similar purpose.

Vid.09/12 Video on the intricacies of recycling carpet.

CARPET INSTALLATION

There are two common types of carpet installation: stretch-in installation and glue-down installation. *In **stretch-in installation**, tack strips are secured to the subfloor along the perimeter of the application area, and following the seaming process, the carpet is tightly stretched across with knee kickers or power stretchers.* This method is not suitable for larger areas as the installation process would be very difficult and the carpet can loosen, buckle, and ripple. Also, under heavy circulation load, the seams would quickly peak. Nonetheless, for smaller residential spaces, this is a fairly straightforward, quick, and convenient application where no adhesive is involved, therefore VOC emissions will be very limited. This is especially useful if moisture and heat release is expected from the substrate. A carpet pad or cushion can be placed underneath the carpet, significantly increasing comfort. The lack of adhesives also allows for relatively easy removal and replacement of worn carpet and padding.

The other major method is the ***glue-down installation** which typically involves gluing the*

Fig.09/32 The long tool is the power stretcher, a crucial tool for stretch-in installation process.

carpet to the substrate. This method is suitable for commercial and public interiors as there are no installation area restrictions, the flooring has higher dimensional stability and reduced movement under high traffic loads, including rolling loads, preventing the carpet from buckling or rippling. It is especially suited for stairs and ramps. The direct glue-down installation does not typically feature a carpet pad or other cush-

Vid.09/13 Video on stretch-in carpet installation.

Fig.09/33 Glue-down application involves a thin layer of adhesive on a smooth substrate.

ioning, offering limited comfort and insulation. This means there's no cushion cost, however, there are other labor requirements. For instance, the substrate needs to be perfectly flat, as without any padding in between, the imperfections would telegraph through very easily. Furthermore, irregularities can cause undesirable wear patterns. *The **double glue-down installation** features a pad that is adhered to the floor, and the carpet is adhered to the pad.* This is a stable, durable, insulative, and comfortable installation, however, it is time-consuming and relatively expensive. One big downside of glue-down installation is stripping the worn carpet, which is more difficult compared to the stretch-in method. When constant flooring replacement is expected, carpet tiles might be a better option compared to a broadloom carpet. *Glue-down installation also enables the designer to utilize custom **CNC cut inlays and graphic inserts** which are not possible with a stretch-in installation.* Aside from the substantial expertise requirement, this technique is time consuming and expensive. Another

Vid.09/14 Video on glue-down carpet installation.

important concern with glue-down carpet installation is the VOC emissions during and following the application. The designer should be careful when specifying the adhesive, paying attention to specifying low VOC alternatives.

> *Curing time for carpet adhesives is another important concern. Adhesives can have **varying curing times** and accordingly, the application area should be closed to traffic until the adhesive is fully cured.*

*There are **self-stick, or peel and stick** alternatives in the market sold in carpet tile format.* These are suitable for small-scale and quick DIY projects, and temporary corrections. They are very cheap to install, however, the seams between tiles easily open up, and since there's no padding, wear can be very inconsistent. *It is also possible to loosely lay a cut-to-fit carpet in an area, without stretching or gluing. This method is referred to as **free lay**.* This is a very simple installation method, enabling the easy removal of the carpet. It is very well suited in situations where constant aeration or cleaning is needed. However, the carpet will constantly shift and move, and in some cases it might slip if the backing is not rigid enough or there's not enough friction between the backing and the substrate, causing significant safety issues.

With the exception of carpet tile installation, both the stretch-in and the glue-down methods require ***seaming**, either by hot-melt taping or sewing.* A seam diagram shows the exact location of seams and nap directions. ***Nap** is the prominent direction of fiber ends on the carpet.* Even though preparing a seam diagram can be somewhat time-consuming and expensive, it is useful for assessing the aesthetics and expected wear of the carpet application and possibly minimize wastage. ***Nap direction** often runs the length of the carpet.* When the nap direction is not aligned well between seams, the seam can

Fig.09/34 A grooming roller can be used to improve the performance and look of the seam.

Fig.09/35 Trim strips conceal the seam between two different flooring materials.

become visible. But more importantly, if the nap direction opposes the prevailing traffic direction, the wear will be more intense in addition to the detriment to walking comfort. Even when the nap direction is aligned properly, seams can still become visible after a period of use, therefore, aligning the seams in a way to minimize visual exposure and receive less traffic is important for retaining the look in the long term.

Trim strips *are used to cover the transition between two different flooring applications to prevent edge deterioration and to ensure a clean finish.* Any exposed carpet edge is more susceptible to wear, and in the case of a carpet, trim strips minimize fraying of the exposed edges. ***Carpet shims*** *are used to raise the carpet application, for smoothly transitioning to a thicker or higher floor finish,* especially when it is not practical to adjust the substrate height.

Due to a large number of gaps and crevices between each pile and tuft, combined with the electrostatic build-up, carpets not only attract dirt but also hold onto it. This creates a constant need for cleaning. Moreover, besides being a detriment to indoor air quality, dirt and grit abrade the fibers creating a faded look, especially for synthetic fibers. Aside from regular vacuuming, periodic deep cleaning can be done to attain a relatively clean carpet.

The designer should consider that the deeper the carpet pile, the ***more dirt or spills will be pushed into the pile*** *and cleaning will become increasingly harder.*

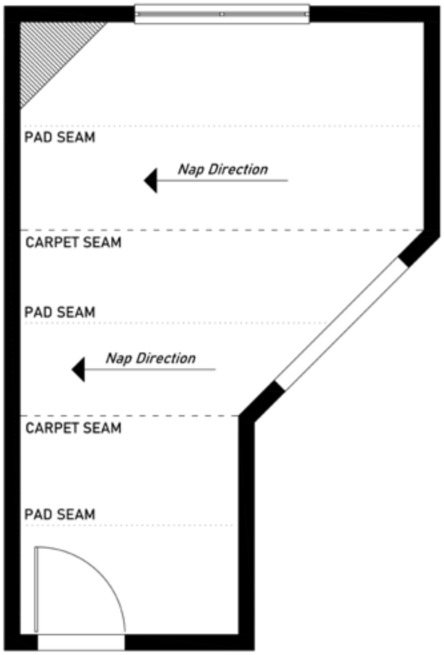

Fig.09/36 Sample carpet and pad seaming diagram with nap direction.

UPHOLSTERY

***Upholstery** refers to a common method of textile-based fabrication that is based on framing, padding, and sewing to create and retain form*. Upholstered furniture typically feature a frame, webbing or spring suspension, cushioning, and fabric. Custom upholstered furniture should feature a wood frame construction, preferably kiln-dried to minimize dimensional movement. Plywood and MDF can also be utilized. The construction typically features dowels, glue, screws, brackets, and staples in combination. Edges of the framework should be rounded to avoid upholstery wear. The frame can be reinforced by utilizing corner blocks or brackets.

The designer should pay close attention to the weight and density of the foam being specified. ***Polyurethane (PU) upholstery foam** is the most common cushioning material.* The durability and support is dependent on the foam's density. The indentation load deflection (ILD) is a test outlined by the Polyurethane Foam Manufacturer's Association, measuring the firmness of PU foams. An ILD value of 8 is very soft, whereas 50 would

Vid.09/15 Video on timber furniture frame construction.

be very firm. *A typical application would feature multiple layers of foam at different densities to achive desired firmness.These can be CNC cut to support different parts of the body as it shifts on the seat, sofa, or bed.* For instance, a semi-firm thin outer layer, softer middle layer, and a firmer inner layer can achieve a great sense of comfort and support while minimizing fabric wear. The foam may be surrounded by polyester fiber batting, such as Dacron, to prevent slippage and retain appearance. Back cushions can be filled with polyester fiberfill, down, or shredded polyurethane foam. The general feel of an upholstery is determined by the padding and fabric together. Consequently, a softer foam underneath a firm and heavy fabric won't feel as comfortable. ***Suspension systems** can also contribute to the overall comfort when used in conjunction with foam.* They flex in reaction to

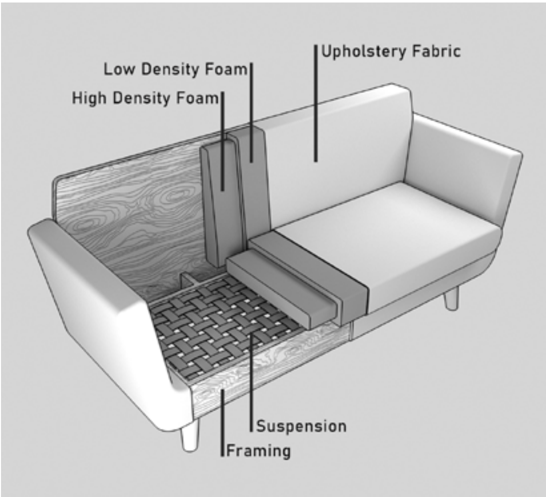

Fig.09/37 The individual constituents of a typical furniture piece.

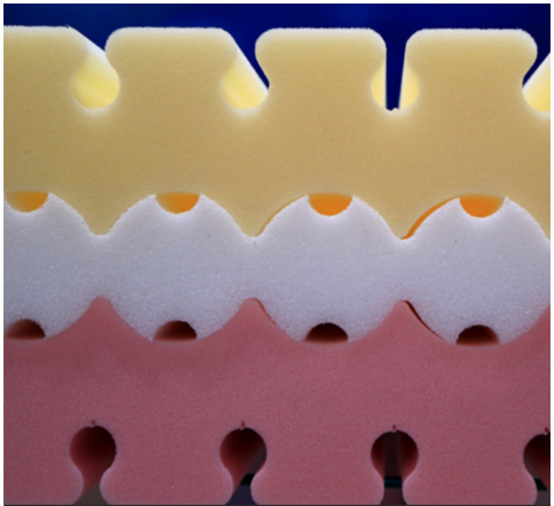

Fig.09/38 Many layers of different density foam should be used to provide proper support.

body weight and movement, increase support and comfort. A typical suspension system would feature springs, coils, straps, webbing, and meshes, often in combination.

Upholstery, as it relates to unfixed mass-manufactured furniture, is not part of the construction contract but rather part of the ***furniture, fixture & equipment (FF&E)*** *contract.* Therefore, custom upholstery acquisition and coordination is often the responsibility of the FF&E contractor, which can be a furniture dealer or the designer themself. This is one of the reasons why big furniture manufacturers such as Knoll and Herman Miller also sell proprietary upholstery fabric.

Fabric ***pattern matching*** *is an important consideration as it relates to upholstering.* Proper alignment is crucial for a clean, professional and pleasing look. Complex patterns can be difficult to match and result in a lot of wastage to achieve a satisfactory alignment. The process requires substantial skill on the craftsperson's part, however today, digitalized visualization, matching, cutting, contouring, and stitching systems help with the process and minimize wastage.

There are two ways to apply patterns on a piece of furniture. *In the more traditional* ***regular (run-right) application*** *the patterns run on the vertical axis, perpendicular to the floor.*

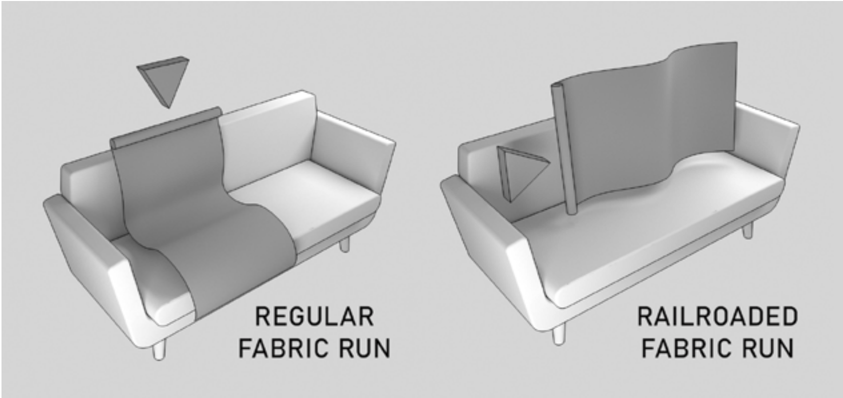

Fig.09/40 Common pattern alignment methods for upholstery.

At around every 44" to 54", a seam is needed due to limitations in fabric width, depending on how much is left after seam allowance. *In* ***railroaded application****, patterns run on the horizontal axis, parallel to the floor.* This application is appropriate for pieces with longer widths as fabric rolls can run up to 100 yards, and can be somewhat more efficient in terms of minimizing seaming and wastage. The designer should carefully consider the orientation. Some fabric patterns are designed in a way that works only in one direction or it may clash with the visual features of the furniture to be upholstered. The stitching method for seams is another import-

Fig.09/39 The seams, buttoning, and nailhead trims utilized on the chesterfield sofa form a unique visual character.

Fig.09/41 Re-upholstery is both budget and environment friendly.

ant aspect of upholstery work. *There are many different **types of stitches** each with different functionality, strength, stability, and aesthetic quality* such as plain seams, topstitched seams, double-stitched seams, French (inverted) seams, lapped seams, piping, cording, and welting.

***Re-upholstery** is a sustainable way to approach upholstered furniture.* The same furniture frame, suspension, and padding can be retrofitted repeatedly. Designers can find and buy old furniture for re-upholstering online, at auctions, in antique shops, or flea markets. Re-upholstered furniture can introduce a vintage feel and charm to a project and add interest by contrasting the more modern elements.

Vid.09/16 Video on re-upholstering a wooden armchair.

SOFTGOODS

*The term **softgoods** refer to textile products that lack the support of a rigid framework.* This section focuses on the products featured in interior spaces, such as window treatments, upholstery, bedding, and accessories. Apparel products are also considered soft goods.

Window treatments are design components that work in conjunction with a façade opening in order to control daylight and ventilation, modify the appearance, adjust the level of privacy, and alter the view. *The designer should focus on the following when specifying window treatments: ①sunlight and glare control, ②solar heat gain, ③view and privacy, ④child and pet safety, ⑤user-friendly operation, ⑥aesthetic contribution, ⑦acoustical contribution, ⑧increased property value. **Shading coefficient** indicates how effectively a window treatment can reduce solar heat gain, typically expressed on a scale from 0 to 1,* though these values are often between 0.1 to 0.8 for common products. The adjustability of the window treatment is fairly important as it can save part of the energy spent for cooling in the summer but also for heating in the winter.

There are various types of window treatments in the market, and depending on their functional-

Fig.09/42 Shutters are hard window treatments and they can block sunlight relatively well.

Fig.09/43 Different types of shades provide different functionality.

ity, combined applications are not uncommon. ***Shutters** are hard window treatments covering the entire frame of the window*, and by use of adjustable louvers allow sunlight, adjust airflow, and alter the view. ***Blinds** feature slightly thinner and narrower slats.* Sunlight, view, and airflow can be altered by adjusting the spacing and rotation of said slats. However, side leaks can be a problem since, unlike shutters, the entire opening is not covered. Blinds can be cheaper compared to shutters, also dependent on type and quality. Cleaning is a problem for both window treatments as the slats collect and retain dust. It is possible to integrate blinds in between panes of double glazed windows, preventing dust accumulation.

***Shades** feature a continuous fabric mounted on a rolling mechanism.* The fabric can be rolled down to cover the window, though there are bottom-up versions as well. Shades are very useful in terms of filtering or partially allowing sunlight and controlling glare. Some versions of roller shades allow for varying the opacity by aligning two layers of horizontally striped fabric. Side leaks are a problem for shades as well.

***Draperies** are panels of loose fabric suspended from a track or traversing rod.* Sunlight, view, and privacy are manually adjusted by pulling the drapery to the sides of the window. Draperies often feature pleating in order to increase volume, level of insulation, and add visual interest.

Vid.09/17 Video on drapery headers.

***Fullness** refers to the relationship between the actual width of the fabric and the desired application width to be covered.* Fuller draperies have more volume, are visually more imposing, provide better insulation and sound absorption. *Depending on the pleat type and desired fullness, the required drapery width can be **multiple times longer** than the actual application width.* For instance, a simple box pleat would require a fabric 3 times the size of the application width, a ripple fold with shallow pleating would require at least 1.5 times. The measurement should also

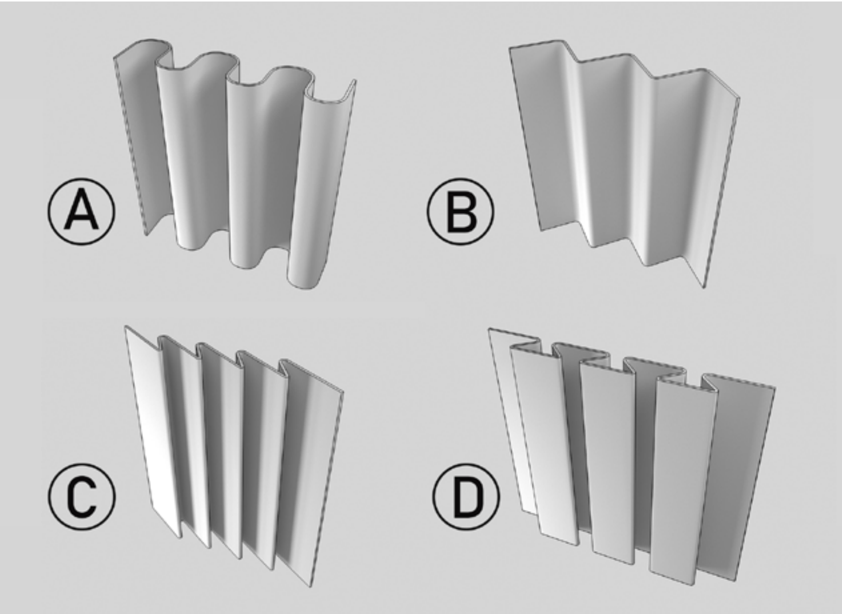

Fig.09/44 Common pleating types include rolling pleat (A), accordion pleat (B), knife pleat (C), and box pleat (D).

allow for seams and side hems. Fullness can be expressed in percentages. 120% fullness means that 120% longer fabric is used for a certain length. For example, to cover a 10’ opening with 50% fullness 15’, plus sewing and hewing allowances, need to be considered. *A **“pleat to”** dimension indicates that the designer wants a certain length of fabric to be pleated to a certain width.* In the case of a 48” fabric, pleat to 24” means 100% pleat fullness. The designer should consider that not all fabric patterns work with all pleating types.

*Draperies can feature **lining** in order to enhance their various properties*, such as increasing UV resistance, adding bulk and weight, increasing acoustic control, etc. For instance, a blackout lining can be a necessity in a conference room where a projector is utilized. ***Hems** are the folded and stitched edges of drapery to maintain appearance while adding visual interest,* can feature tapes or weights.

***Acoustic draperies** can be used as an alternative to or in conjunction with acoustic wall panel applications.* The thickness of the fabric, pleating fullness, and distance to the wall behind impact how effective the drapery will perform in terms of sound absorption. It should be noted that acoustic draperies are fairly ineffective at lower frequencies.

Vid.09/18 Video on the different types of hems.

Curtains** are similar to draperies, however, their construction is simpler and they don’t feature mechanical hardware as they are not intended to be operated.* A common example is café curtains covering only the lower half of a window. ***Valance is an ornamental piece of drapery covering the curtain rod or track at the top of a window. As a type of valance, ***swag***, is a piece of fabric that is draped or hung in a cascading fashion across the top of a window. ***Cornice*** is a horizontal box-like rigid structure also covering

Fig.09/45 The many components of a drapery form a very specific look and ambience.

> *When considering custom-made window treatments, it is important to clarify that the workroom is* ***expected to take or retake*** *all necessary measurements.*

the top. ***Jabot*** is a fabric draped or swagged on each side of a window.

Even though contemporary textile manufacturers are quite competent in terms of quality control, it is imperative that *all ordered fabrics* ***should be inspected*** *under bright light for defects, before starting the fabrication process.* Even if the fabric gets replaced without charge due to a defect, the lost time and effort for fabricating defective pieces can harm the overall project schedule considerably.