10

METAL

- *Core terminology for metals*
- *Metal alloys*
- *Corrosion, weathering, and patina*
- *Processing metals*
- *Finishing metals*
- *Ferrous metals*
- *Non-ferrous metals*

Metals are elementary substances that display high malleability, ductility, conductivity properties. They are opaque and exhibit a unique luster when the material is freshly exposed. The combination of these properties rendered metals valuable throughout history, they were extensively used for crafting tools as well as ornaments. Two highly useful properties of metals are ductility and malleability. ***Ductility*** *refers to a material's ability to withstand and deform under tensile stress without failure – meaning the lack of unexpected and unwanted yielding, buckling, deflecting, or fracturing.* This property enables metals to be drawn or extruded into useful shapes and profiles. ***Malleability*** *is a similar property, however, this time the material can withstand compressive stress and deform without failure.* This property enables metals to be pressed into thin sheets; most other materials can't perform as well as metals in sheet form. *A material's strength in relation to its density, known as specific strength or* ***strength-***

Fig.10/01 The malleability of metals enables the creation of hand-made textures such as hammered bronze.

Fig.10/02 304 series stainless steel alloy panels were used for the Gateway Arch construction.

to-weight, is another important property that renders some metals, such as aluminum, magnesium, and titanium highly useful, enabling components with the same exact strength to be manufactured at a much lower weight. *All metals are **highly recyclable**. Recycling is highly feasible unlike many other materials as the recycled content is equal or highly comparable to the virgin material.*

> *High recycling potential also means that scraps carry **considerable value**; an important consideration when planning a demolition phase.*

***Alloying** is the melting and mixing of different metals as well as metalloids such as silicone or non-metal carbon, in very specific ratios to create a metallic admixture* with very specific properties based on the interaction between base metals and the newly formed crystalline structures. For example, brass (copper+zinc) and bronze (copper+tin). The resulting alloy inherits some desirable properties as well as some weaknesses, such as lower or higher melting point, corrosion resistance, luster, color, conductivity, formability, fatigue limit, price point. Metals are primarily used in alloy form and very rarely in pure form. Based on the formulation of elements and their percentages, there are hundreds of aluminum alloys for many different purposes, and tens of steel alloys, steel being an iron alloy itself. There's a "best" alloy for every specific design scenario.

Every metal and alloy feature a unique color. Metals can be polished to have a very smooth and reflective surface, they can also be texturized

Vid.10/01 Video on the intricacies of various metal alloys.

Fig.10/03 Galvanic corrosion can even happen between stainless steel (nut&bolt) and mild steel (beam).

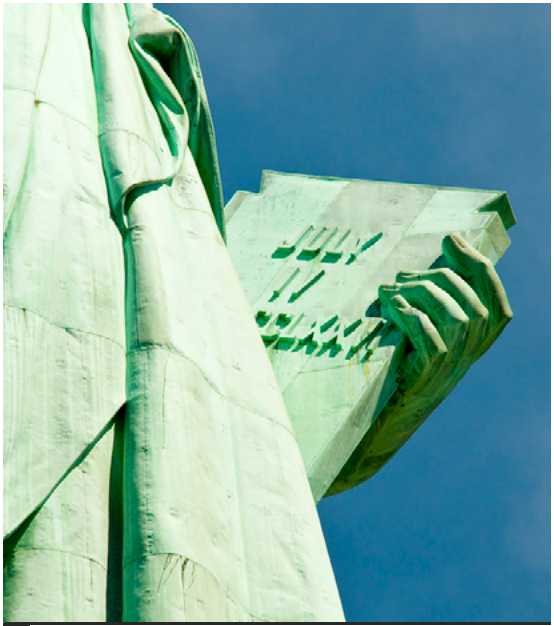

Fig.10/04 The unique light green patina of the Statue of Liberty showcases the impact of site conditions.

owing to their high malleability. When exposed to elements metals tend to corrode. ***Corrosion** is a natural process, during which the metal is attempting to return to a more stable natural state.* There are many types of corrosion, such as ***pitting** where metal corrodes from a localized point that eats into the metal fairly rapidly,* stainless steel is very susceptible to this type of corrosion. Uniform corrosion is another type, referring to an even corrosion on a large area on the metal's surface. Impurities in a metal's microstructure can cause a phenomenon called inter-granular corrosion. ***Galvanic corrosion** manifests when an electrical current, known as galvanic current, flows through liquids, vapor, humidity, or any conductive substance between two dissimilar metals; dissimilar in terms of the relative difference in nobility and electrochemical potential.* The process erodes the metal with the lower galvanic number, such as aluminum and zinc. For example, as soon as a current runs through aluminum and steel, aluminum will corrode, unless an insulative coating is applied.

Vid.10/02 Video on the construction of the Statue of Liberty.

*Metals that are highly reactive, such as copper, zinc, or iron, will start developing an oxide layer, commonly referred to as **patina**, shortly after being exposed to the atmosphere.* Patina can be very desirable as it protects the metal underneath while providing a unique visual quality. For instance, the greenish film developed over its copper cladding gives the Statue of Liberty its unique color. Patina develops over time, as the metal goes through oxidation stages with different visual characteristics until an equilibrium is reached. Copper's patina can develop over 10 years, whereas aluminum or zinc develop patina within a year. Gold never develops a patina. It is also possible to expedite the patina development process via the use of various chemical coatings. The resulting products are referred to as ***pre-weathered****, very useful for achieving the desired look quickly, and very helpful for matching color and texture during repairs while minimizing visual inconsistencies.* However, the designer should also consider that the atmospheric conditions, such as the salt present in the environment or unique weather conditions affect the natural development of the patina and the result will be more authentic.

Metals typically require ***milder cleaning methods*** *in order to minimize damage to patinas and coatings.* There are purpose cleaning solutions available on the market but oftentimes dusting with a clean cloth, vacuuming, and mild cleaning chemicals are appropriate and sufficient.

> *Most metals show* ***anti-microbial*** *properties; some more intense than others, like copper and silver. This is achieved by metal ions disrupting the vital processes of microorganisms and preventing reproduction.*

PROCESSING METALS

Metalworking processes can be broadly categorized into forming, cutting, and joining. Multiple processes may be involved in the fabrication of a single metal component. Metals can withstand plastic deformation before breaking, thanks to their malleable and ductile nature. This enables cold forming techniques such as bending, rolling, extrusion, punching, stamping, drawing, spinning, etc. to be utilized. ***Extruding*** *involves forcing metal through a shaped aperture to achieve a lengthy component with the desired profile.* Large roller presses can shape metal into a profile or flat plane. Metal fibers can be drawn with a similar technique. ***Casting*** *involves pouring molten metal into sand, wax, plaster, ceramic, or die cast molds.* Metals that are highly fluid in molten state, and with low viscosity and die shrinkage are the most appropriate for casting, especially if complex geometries and thin wall sections are required. Some highly suitable metals are zinc, copper, cast iron.

Forging *is heating and reheating cold metal and shaping it with presses, hammers, and other tools. The metal piece that is being worked on is called a* ***workpiece****.* While the metal is being worked it becomes harder as the molecules are dislocated, this process is called strain hardening. ***Annealing*** *is a heat treatment method to attain a more workable wokpiece, by relieving stress and increasing ductility.* The metal is heated to its recrystallization temperature and slowly cooled in a furnace. ***Normalizing*** *is another heat treatment similar to annealing, however, the cooling process happens in room temperature.* This is a cheaper process but it might create slight impurities and defects. ***Quenching*** *involves rapidly cooling a workpiece in water, oil, or stream of air to increase hardness.* ***Tempering*** *is performed by heating the quenched workpiece to a certain temperature below the critical point and cooling by exposing*

Fig.10/05 Compressing and shaping metals increases their strength and hardness while decreasing their malleability and workability.

Vid.10/03 *Video on heat treatment of metals.*

Vid.10/04 *Video on latheing a cube within a cube.*

it to still air. This process reduces excess hardness and restores some ductility, rendering the workpiece stronger.

***Milling** is a subtractive forming process. It involves shaving off material using rotary cutters to achieve the desired shape.* Milling can be done with manual or digitally controlled (CNC) tooling machines. There are a variety of CNC or computerized numerical control machines available, the most important feature being the number of axes and reach available to control the cutting tool. This feature determines the types of metal that can be tooled and the size and complexity of forms that can be achieve. ***Latheing** is similar to milling with one crucial difference, during latheing the actual workpiece is rotating rather than the cutting tool itself.*

Fig.10/06 *The impressive reach of a 5-axis CNC milling machine enables intricate 3d details to be fabricated.*

Additive manufacturing is also possible with metals. *Various metals such as titanium and aluminum can be **3d printed** with techniques such as selective laser sintering and laser metal deposition*, even though the resulting metal component would not perform as well as a milled counterpart in demanding situations.

***Gauge**, or gage (ga), is a measurement indicating the thickness of a sheet metal.* Thicker sheets are referred to as heavy gauge and the opposite as light gauge. The larger the number the thinner the sheet is; 10ga is 84% thicker than 16ga. One problematic aspect of gauge is, for different types of metals a specific gauge can refer to a different sheet thickness. For example, 12 ga steel is 0.105 inches thick, whereas 12 ga aluminum sheet is 0.0808 inches thick. The thickness can also vary between suppliers. Sheets thicker than 0.25 inches (6mm) are referred to as plate. A foil is sheet metal with a thickness of less than 1/128 of an inch.

There are various ways to join two pieces of metal and form strong bonds. Welding, soldering, and brazing are based on the principle that it is possible to melt pieces of metal to form a connection by applying focused intense heat to multiple points on their shared edge, essentially fusing them. The main difference between each of these three processes is the working temperature and if the base material or filler material is melted or not. It is also possible to weld plastics and wood, though the process, tools, and temperatures are vastly different. ***Welding** involves melting the base metal at incredibly high temperatures* (10,000 to

Fig.10/07 Welding is suitable for demanding applications, such as lug joints.

Fig.10/08 Riveting is a time consuming process, harder to conduct on-site, therefore a mixture of rivets and bolds is not an uncommon sight in construction.

50,000ºF). Welded joints are stronger than the other two methods and can join thick sections, appropriate for high-stress load-bearing applications. There are different types such as arc-welding, electron or laser beam-welding, and friction-welding. Some types of welding require a filler material and others don't. Welded sections require heat treatment to relieve residual stress built-up during the welding process. ***Soldering** is done at lower temperatures (below 800ºF), a metal alloy is melted between workpieces.* This filler metal flows into the joint, cooling and binding workpieces. The process bears similarities to welding, with the exception that the base metal stays intact, the mechanical properties of the base metal are protected. Soldering is not appropriate for load-bearing applications, commonly used in jewelry and electronics. Welding requires the welded parts to be similar, however, there's no such limitation for soldering. ***Brazing** is very similar to soldering but performed at slightly higher temperatures (above 800ºF), not so high that the base material is melted.* The joints produced are stronger than soldering, but they still won't be suitable for demanding applications. It is important to consider the types and properties of metals, specifically the alloys to be used as workpieces, the type of load expected, the connection strength required, worksite, budget, and schedule limitations.

It is also possible to join metals with mechanical fasteners. ***Bolting** involves joining, or essentially clamping, two plates of metal with large bolt fasteners; bolts can be pre-tensioned to increase strength.* Bolts are considered temporary; this means removing them won't destroy the fastener. Loosening can happen but it is not common. ***Riveting** involves a rivet, a heated steel rod with a cap, going through two metal plates to be permanently secured by forcing it into a die on the other side.* Riveting usually involves more fasteners on the surface and the process is time-consuming, however, higher joint strength is achieved. Mechanical fasteners are useful for assembling prefabricated elements

Vid.10/05 Video on hydraulic hot riveting.

on-site, as opposed to welding on site which can be inconvenient and expensive. A strong bond is attained not only through the shank of the fastener but also through the friction between large, overlapped surfaces. Increasing the number of fasteners helps spread the load.

Adhesive bonding is also an option for metals. *Epoxy and acrylic* ***structural adhesives*** *work best between metal to metal bonding, as well as for bonding other materials to metals.* Adhesives are useful for hard-to-access points, for quick on-site corrections, and when mechanical fasteners or weld lines need to be hidden. They are not as strong or reliable to replace welding or mechanical fasteners in demanding applications.

FINISHING METALS

There are three overarching metal finishing types: mechanical, chemical, and coating, as outlined in the ***Metal Finishes Manual*** published by the National Association of Architectural Metal Manufacturers (NAAMM). The strength, durability, and price point that can be attained with each finish type is different, primarily based on the metal or alloy to be finished as well as the task the finish is specified for.

Common ***mechanical finishes*** *include grinding, honing, lapping, polishing, and buffing. These usually involve creating a gradually smoother and bright, reflective specular, satin, or fine to coarse matte finish by applying increasingly finer abrasives.* ***Brushing*** involves abrading the surface in a single direction to create a distinctive linear pattern. ***Particle blasting*** is abrading the surface by means of blowing coarse particles to the metal surface to create more diffuse reflections. Some more malleable sheets of metal can be hammered to create a more textured look, great for hiding surface defects. This technique is commonly used for copper hoods.

> ***Abrading the surface*** *can create slight distortions on the material and it can be detrimental to the metal's ability to resist corrosion and aging.*

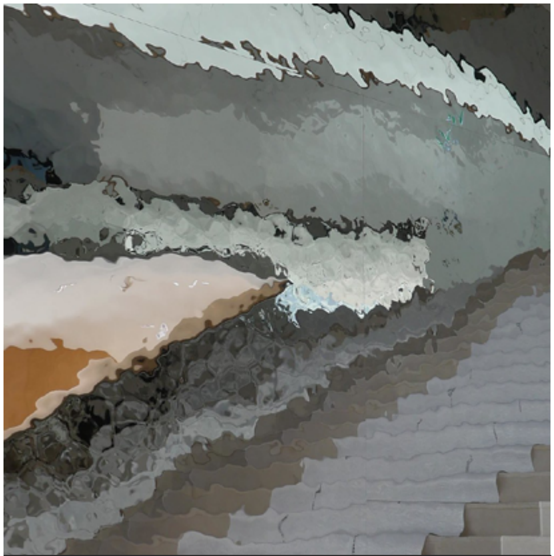

Fig.10/09 Slight wavy texture on polished stainless steel surface can create unique reflections.

Fig.10/10 Brushed stainless steel is a very common finish for home appliances.

Chemical finishes *include acid etching, hot and cold patina solutions, chemical weathering, and controlled corrosion via oxidizing agents.* Some of these methods are used for surface cleaning, preparation, or as intermediary steps for other finishing methods. For instance, a chemical conversion coating or chem-film can act as a protective intermediary surface, or it can be a standalone finish. ***Electropolishing***, or anodic polishing, is a great tool for finishing oversized or complex and delicate pieces by dissolving the metal surface in a very controlled way. Chemical finishes can create noticeable visual defects on exposed welded joints, and they may not be a good choice without careful detail design.

Coating *processes involve depositing material over the surface of the metal either through brushing, spraying, hot dipping, or various chemical, magnetized, electrical, methods.* PU coating, vinyl foils, powder coating, lacquers, waxes, enamels, galvanizing, electroplating, or clear sealants are all considered in this category. The extra layer of material creates an important barrier against weathering and corrosion while improving the ability to clean and maintain the surface. PU film application or lacquering can be used on metal surfaces to lock and retain the desired appearance, stop weathering, and provide a bright sheen. Anti-ice, fire resistance, or hydrophobic qualities can be achieved by various coatings. ***Anodizing*** is an electrochemical coating process that involves forming a durable anodic oxide layer on the metal surface. This finish can be transparent, translucent, or opaque, and it can be given a unique color and tint. Aluminum is highly suitable for anodizing; a finish popularized by Apple® products. Ferrous metals are difficult to anodize and the results are not as durable. ***Enameling*** is fusing the metal surface with glass frit. A large selection of lively and lasting colors as well as a smooth and resistant surface can be achieved. On the other hand, enameling is often prone to cracking and chipping. ***Electroplating*** involves running an electric current through a metal to coat it with a thin but consistent layer of another metal, through a process called electro-deposition. The commonly known chrome plating technique is one example. This process creates a durable, bright, and mirror-like finish but byproducts of the process, including hexavalent chromium residue are known to be persistent environmental polluters and pose great health risks.

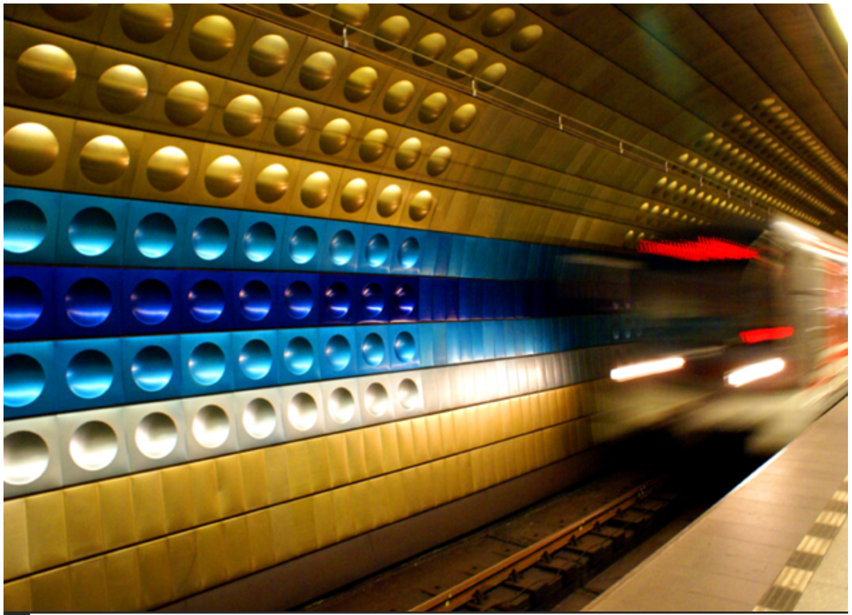

Fig.10/11 Anodized aluminum cladding can feature a wide range of colors.

Vid.10/06 Video on powder coating metal components.

Vid.10/07 Video on anodized aluminum finish.

FERROUS METALS

Ferrum is Latin for iron (Fe) and ferrous refers to metal alloys that contain iron. There are many classifications of metals, however, *based on the significance of iron for the construction industry, the* ***ferrous vs. non-ferrous*** *classification is the most useful for spatial design.* Iron is among the most abundant elements; 35% of earth's total mass and 85% of the earth's core is iron. During ancient times meteoric iron was discovered occasionally; a rare and valued iron type that was stronger due to its nickel content. As the earliest example of metal working dating back to 3200 BCE, Egyptians used meteoric iron to craft cylindrical beads. The archaeological artifacts suggest that a number of civilizations learned smelting and refining iron ore between 1600 and 600 BCE, making various tools, weapons, and ornaments. Over the centuries blast furnaces were developed for large-scale iron manufacturing but only during the mid-18th century iron manufacturing reached an industrial scale and found widespread use in building construction.

The addition of carbon increases the strength and hardness of iron but reduces ductility and ability to be welded. ***Wrought iron*** *has a low carbon content of less than 0.1% and it is ductile, can be wrought to shape. On the other hand,* ***cast iron*** *has a high carbon content of more than 2%, more suitable for molding.* ***Crude iron***, also known as pig iron, is an intermediate product that is used in the production of other ferrous products such as steel or wrought iron. It has a very high carbon content, up to 4.7%, very brittle and not very useful. Starting around the 18th century ***cast iron*** could be produced in large quantities and in a consistent, reliable, and convenient manner that it was commonly used as a structural component. The high fluidity of molten cast iron, relatively low casting temperature, high-quality surface finish, and reusable casts render it a suitable material for fabricating detailed ornamentation. Doors, corner blocks, columns, and other building components can be manufactured this way, however, the resulting product is substantially heavy. The crystal palace was an important example of a cast iron structure, which was destroyed in a fire in 1936, 85 years after its opening. ***Wrought iron*** on the other hand is relatively soft, strong, and malleable thanks to its low carbon content. However, its load-bearing capabilities are somewhat limited. Eiffel Tower is the tallest wrought iron, specifically of puddled iron subtype, structure. Iron in general is unstable when exposed to the atmosphere or most acids, it would corrode readily and rapidly. This is the reason why the Eiffel Tower is painted every 7 years.

Fig.10/12 Meteoric iron was one of the first types of metal to be processed.

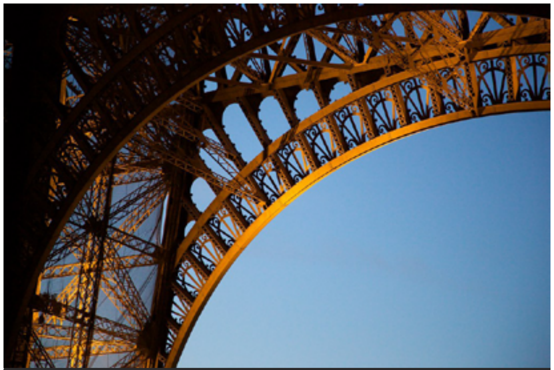

Fig.10/13 The Eiffel Tower is the tallest wrought iron structure, at almost a 1000ft.

Fig.10/14 The original Bessemer converter design was a huge improvement over blast furnaces.

Steel *is another iron alloy with a carbon content between 0.1% to 2%, basically between wrought and cast iron.* The invention of the Bessemer process, or conversion, in 1855 enabled steel to be manufactured from low-grade ores in industrial quantities. Following the great Chicago fire in 1871, there was a rising demand for rapid construction and steel was extensively employed. Rand McNally Building in Chicago, built in 1889, was the first steel-frame skyscraper.

There are 3 common grades of steel: carbon steel, stainless steel, and tool steel. Each category contains several sub-categories, such as mild (low-carbon) or high carbon steel or, 200, 300, or 400 series stainless steel alloys; each one with different properties ranging from high castability, ductility, corrosion resistance, etc. ***Stainless Steel*** *contains at least 10.5% chromium, which in turn develops a corrosion-resistant selft-healing chromium-oxide film when exposed to oxygen.* Stainless steel is highly suitable for industrial equipment where corrosion resistance, anti-microbial properties, and cleanability are required in addition to strength and durability which can already be attained by carbon steel. Professional kitchens often feature stainless steel countertops, one of the few National Sanitation Foundation (NSF) approved materials for commercial food preparation. Stainless steel is almost completely corrosion resistant. Salt flakes, cleaning agents, or rigorous cleaning practices with abrasive tools can cause the protective film to be damaged, which might in turn cause stainless steel to corrode inward, a phenomenon known as pitting; it starts as very small black or brown dots on the surface. It is possible to improve resistance against pitting by adding nitrogen to the alloy mixture.

Steel manufacturing causes one important sustainability concern, *the process of removing the impurities in iron to make steel requires very high temperatures, which results in* ***very high embodied*** *energy and a significant carbon footprint.* However, steel is also very recyclable, utilizing around a quarter of the energy required to manufacture virgin material. Furthermore, steel is magnetic and it is relatively easy to separate from mixed waste. Another sustainability issue for steel is the dangerous gases and particles produced during manufacturing and later processing and finishing procedures.

Steel is among of the most commonly utilized metals in the building sector, including interiors, owing to its high strength, durability, and reasonable price point. Steel beams are fundamental components of steel frame construction. *Common types of structural steel such as wide flange, I-beams, and structural channels, are manufactured via* ***hot working*** *techniques such as rolling, extrusion, forging.* Steel is easier and

Vid.10/08 Video explanation of how pitting occurs.

Fig.10/15 Trusses enable longer spans to be covered efficiently.

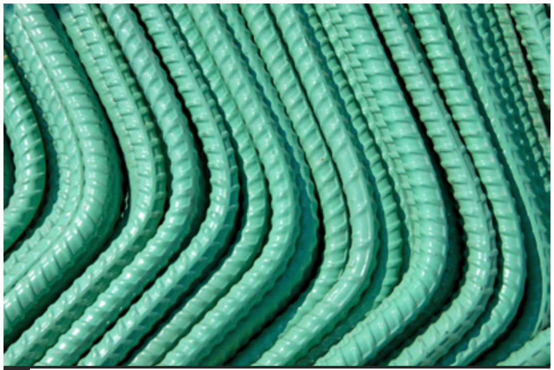

Fig.10/16 The epoxy coated, ribbed rebars are appropriate for demanding applications.

cheaper to form when hot, and it gains strength and durability as it is being worked. However, there can be internal stresses, weak spots, dimensional tolerance problems due to inconsistent cooling. Trusses are another structural component comprised of interconnected triangular units engineered to efficiently distribute vertical and horizontal forces throughout their framework. ***Cold rolled*** *steel, features a better finish and minimal dimensional tolerance problems, appropriate for more accurate jobs.* Even though it is more expensive, the process puts a lot of stress on the material, improving mechanical strength properties. Steel can be extruded into various profiles and then can be welded. Steel sheets can also be pressed or stamped, and reshaped with the help of a die, e.g. stainless steel sinks, appliance panels, pans, pots.

Rebars*, short for reinforcement bars, are manufactured from mild steel and used in the construction of reinforced concrete*. Rebars are laid to form a lattice within a mold referred to as formwork, within which concrete mixture is poured. Reinforced concrete is a highly effective composite material due to the fact that mild steel has a very similar coefficient of thermal expansion to concrete. Moreover, the specific pH of the concrete wrapping steel rebar keeps them from corroding However, embedded steel reinforcement can corrode within the concrete in time, causing failure. Rebars can be epoxy coated, galvanized, or simply manufactured from stainless steel to prevent this phenomenon. The surface of mild steel bars is smooth, but high-strength tensioned rebars can feature ribs, threads, and other details to increase bonding.

Steel has high finish retention and there are a multitude of specialized finishes available for various purposes, including specific interior applications. Besides being used as framing members, polished or brushed steel is commonly used as column covers or wraps. Patterns of holes, slots, or decorative shapes can be punched or stamped out of sheets of metal, producing perforated panels. In addition to the finishing procedures utilized in other metals, galvanizing is a very significant and common finish for Steel. In simple terms, ***galvanizing*** *refers to coating steel with a zinc film. Zinc provides what is known as sacrificial protection, which means that zinc will preferentially corrode even though the metal underneath is exposed to an extent.* Galvanizing can also act as a foundation for paint, it is also possible to apply a protective topcoat of corrosion inhibitor. Galvanized steel sheets are also a commonly used material for manufacturing cold-formed building components such as studs, braces, girts, and railings. Corrugated metal decking is one such material; it is profiled to increase resistance

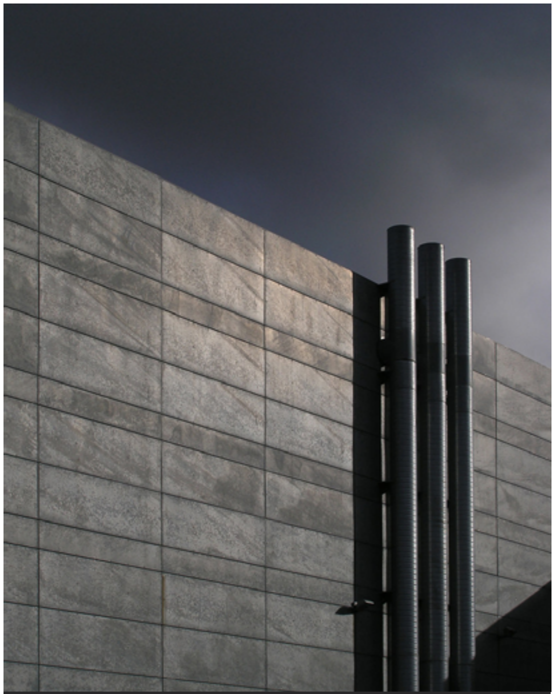

Fig.10/17 Galvanized steel features a highly characteristic flaky gray appearance.

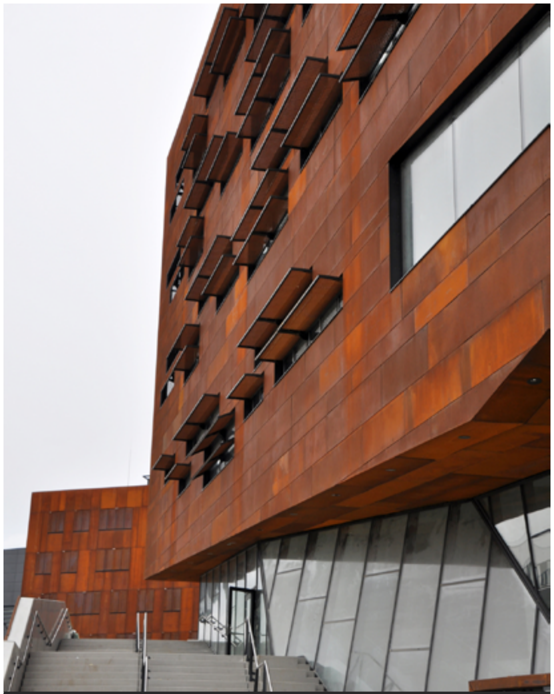

Fig.10/18 Weathering steel panels introduce unique earthly colors and natural texture variations.

against compression loads, placed over joists in order to support a concrete fill or a plywood substrate. Corrugated sheets are also used for supporting roofing materials and insulation.

Weathering steel*, commonly known by the trademark COR-TEN, is a metal panel or sheet product that is basically a weathered steel alloy that has a distressed, rusted look.* It is very durable and requires minimal need for maintenance. Nevertheless, this finish may not exhibit stability in damp and caustic environmental conditions, such as near coastlines. The material can be coated with polyurethane (PU) film to protect the finish from further corrosion.

Vid.10/09 Video on the hot dip galvanizing process.

Even though the melting temperature of steel is 2600 to 2800ºF, the material loses its stiffness and strength way before melting. Prolonged exposure to temperatures above 1000ºF can render steel plastic, weak, and highly prone to deformation and failure. Therefore, ***fireproofing*** *structural steel is required especially for high-risk construction, such as high-rises and institutional buildings.* It is possible to apply intumescent paint or spray on vermiculite for fireproofing, however, these finishes are relatively delicate and might need additional protection from abrasion, impact, and weathering.

Vid.10/10 Video on steel fireproofing.

NON-FERROUS METALS

***Non-ferrous** metals refer to metals other than iron, or iron alloys.* These metals can feature some unique desirable properties such as higher malleability, lower melting temperature, high castability, non-magnetism, corrosion and tarnish resistance, or simply unique color and sheen. Non-ferrous metals have been used for design applications throughout history, mainly as decorative components. The first known use of copper to make pendants dates back to around 9000 BCE in the Middle East. Around 3300 BCE, Sumerians were the first to alloy copper with tin, which they used to make bronze religious statues.

ALUMINUM ● Approximately 8% of the earth's crust contains aluminum, making it the third most abundant element on earth, and the most abundant on earth's crust. Aluminum is always found bonded to other elements, commonly in bauxite form and the extraction and refinement process requires significant energy. *Even though aluminum has very high embodied energy, it is also **extremely recyclable**.* The recycling process requires only 5% of the energy needed to produce virgin material and there is virtually no difference between virgin and recycled material. However, there are several other issues with aluminum manufacturing with regard to environmental impact. The ore bauxite is extracted through open pit mining, which inevitably causes land and ecosystem destruction. The electrolysis-based aluminum refinement process is highly energy-intensive and uses a lot of water. The chemicals used in the process create a mixed residue called red-mud that is not water-soluble and potentially toxic.

***Aluminum** boasts superior strength-to-weight, is highly pliable and machineable, in addition to being chemically inert with no toxicity.* Furthermore, it is resistant to corrosion owing to the rapidly forming oxide film when exposed, the only exception being alkaline conditions (contact with mortar, cement, etc.) where corrosion rate rapidly increases. Aluminum is often used in alloy form. The base metal aluminum can be combined with copper, nickel, magnesium, iron, titanium, silicon, tin, and zinc to form alloys.

Aluminum has a wide range of uses in the construction industry; it is used for structural members, paneling, cladding, roofing, window

Fig.10/19 Red mud is a toxic byproduct of virgin aluminum refinement process, source of serious environmental concerns.

and door frames, railings, hardware, and even flooring. *Sheet aluminum can be **folded** to attain structural strength and stability without adding weight, a principle often used in framing members.* Aluminum louvers and window blind slats are other popular uses. Aluminum can be foamed, which actually involves creating a cellular structure with numerous gas-filled bubbles. Aluminum can also be woven and used as wall finish. Aluminum composite panels (ACPs) are lightweight but sturdy construction materials, a low-density core such as foamed metal or honeycomb panel can be sandwiched between two sheets of aluminum to achieve extremely high strength-to-weight ratio, a versatile method commonly utilized in the aerospace industry. Aluminum is totally impervious to light and moisture, chemically inert, and non-toxic with a modest price point, making it highly suitable for food packaging.

COPPER ● ***Copper** is a pliable and ductile metal with high castability.* Pure copper displays excellent conductivity and corrosion resistance. Copper has been and is still being used for electrical wiring, and it has been used for plumbing and fittings in the past. Copper does not corrode in

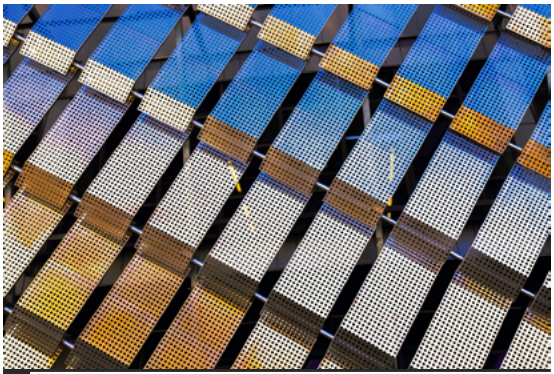

Fig.10/21 Perforation decreases the weight of a panel, allow passage of light, and improve aesthetics.

alkaline conditions therefore prolonged contact with concrete and masonry is possible. When exposed to the atmosphere and elements, copper can develop a patina that gradually transforms from a brown to a light green color, typically over the course of several decades. Copper has two very common alloys: bronze containing primarily tin, and brass containing primarily zinc. Bronze has a lower melting point thanks to added tin. *When molten, **bronze** is highly fluid making it a great choice for intricate casting,* one reason for the countless number of bronze statues. Unlike

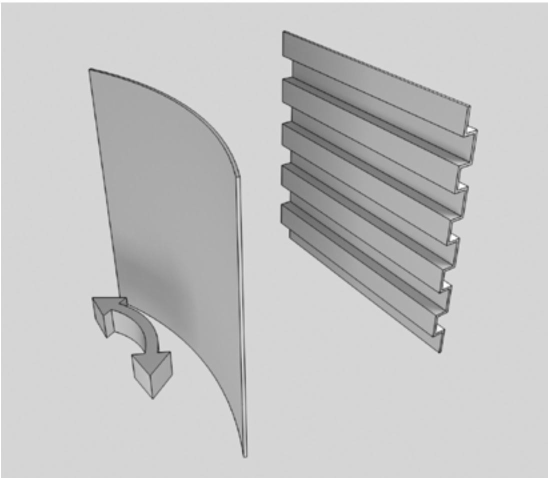

Fig.10/20 Folding, corrugating, and ribbing increases strength of the sheet metal by creating resistance.

Fig.10/22 Constant visitor contact prevented the development of patina, revelaing the true color of bronze.

Fig.10/23 *Copper is suitable for contact surfaces where hygiene is a major concern.*

Fig.10/24 *Gilding has been a feasible way to use gold in interior spaces.*

the pinkish color of bronze, ***brass*** *has a color and luster resembling gold.* The strength and workability of brass can be modified by adjusting the ratio of aluminum and zinc, respectively. Copper mining leads to extremely ***hazardous waste products*** containing arsenic, lead, antimony, and mercury. However, copper itself displays antimicrobial properties and commonly used in medical instruments and healthcare interiors. Bronze has uses in other interiors too, mainly utilized for decorative purposes on components such as lighting elements, furniture details, railings and balusters. Copper tiles are also available on the market.

GOLD & SILVER ● ***Gold and silver*** *have been associated with wealth and nobility throughout history, they were used for coinage, and high-value items such as crowns, decorative hilts, etc.* This is mainly due to the relative scarcity of these materials, ease of smelting, resistance to corrosion and tarnishing, as well as a unique color. All exposed metals lose their appearance to varying extents, however, gold is an exception in that it stays intact without corroding or tarnishing. Both gold and silver are highly malleable and moldable, very popular in jewelry applications. *Due to their high costs,* ***coating and gilding*** *are popular ways to cover decorative elements in interior space.* The mining processes are detrimental to the environment, for both silver and gold. Furthermore, the use of chemicals such as cyanide and mercury during the process can be extremely polluting. Both metals are highly recyclable and owing to their high value, almost all gold and silver is recycled.

CHROMIUM & NICKEL ● ***Chromium*** *is a durable and lustrous metal commonly used in alloys and plating other metals due to high polishability and abrasion resistance.* When exposed to oxygen, chromium rapidly develops a protective coat. There are three states of chromium: divalent, the unstable state; trivalent, the less toxic state; and hexavalent, the highly toxic state known to be a carcinogen. Chromium is an important component in stainless steel alloy, and commonly used for chrome plating, also used as a chemical component in the leather tanning process. Besides steel, other metals such as aluminum,

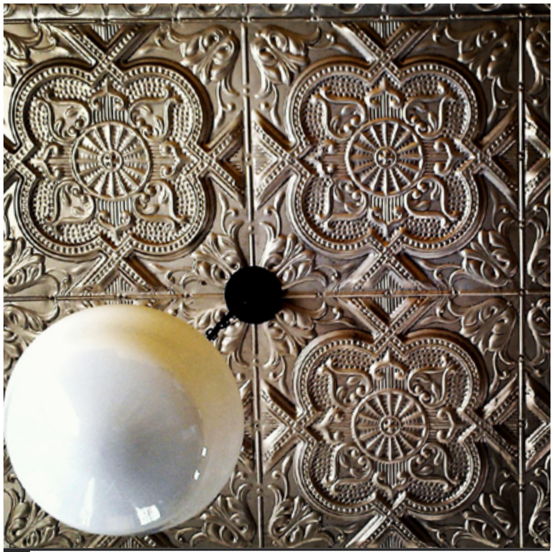

Fig.10/25 Embossed tin ceiling tiles can retain intricate detail and introduce a unique sheen.

Fig.10/26 Zinc panels are commonly utilized in contemporary architectural facades.

copper, zinc, magnesium, and titanium can all be chrome plated. ***Nickel** is a bright gray metal, pliable and ductile. It receives polish and maintains clarity well.* Nickel and chrome can be plated on the metal in succession to produce a shiny, durable, and corrosion resistant finish.

TIN ● ***Tin** is a buffable silvery metal with subtle bluish tint, commonly used to form alloys or for protective plating.* Tin is also used in decorative elements such as ceiling, wainscoting, cabinetry panels, etc.

TITANIUM ● ***Titanium** is stronger than steel at almost half the mass, able to provide superior strength-to-weight.* Titanium is very hard to refine and very unstable after refinement. As a result, its embodied energy is high and workability is low. Titanium tiles are available for facades and interior spaces in a wide range of colors. These are often manufactured from recycled content and are lower grade. The famous Frank Gehry building Bilbao Guggenheim Museum features titanium cladding throughout its exterior.

ZINC ● ***Zinc** is bright bluish-silver when freshly cast; through weathering it gains a dull dark gray, and later black tint.* Even though a strong, ductile, and durable metal itself with great castability. In the construction industry, much of zinc is used for galvanizing or plating. Galvanizing involves coating iron or steel with zinc layer to prevent oxidation and minimize wear. The coating is distinguishable by the matt gray spangled or flaky texture. There are different methods of application such as hot-dip galvanizing and electro-galvanizing. Depending on the environment, zinc corrodes 1/10th or 1/40th of the speed of steel, however, if the barrier is damaged an under-film corrosion can spread rapidly. Zinc also protects steel by sacrificing itself through cathodic protection, this ensures that when steel is exposed it is still protected to an extent. Zinc can quickly develop a matte gray patina to protect itself, even as a layer on top of steel. Normally it takes 6 to 12 months for the patina to develop but pre-weathered zinc panels are available in the market.

11

PLASTIC

- *Polymers and plastics*
- *Synthesis and key additives*
- *Environmental impact of plastics*
- *Resin identification code and recycling*
- *Common thermoplastics and thermosets*
- *Plastic manufacturing methods*
- *Composites*
- *Polymer products specific to interiors*

The term ***polymer*** *refers to chained large molecules composed of repeating the same monomer subunits.* Polymer and plastic are used somewhat interchangeably, however, plastics are a sub-family of materials polymerized from basic petrochemicals such as ethylene, propylene, butylene, etc. Polymers are the overarching category and not all polymers are plastic. For instance, silicone is classified as a polymer, but it is not a plastic. Polymerizing is an energy intensive process where the basic building blocks called monomers are chained to form complex plastics. For example, several thousand ethylene molecules can be chained together via a chemical reaction to form polyethylene, or tens of thousands of ethylene molecules can be chained to form high-density polyethylene (HDPE). *Plastics are sometimes referred to by popular* ***trademarks,*** such Plexiglas for acrylic, Teflon for polytetrafluoroethylene, Cellophane for cellulose-acetate, Fiberglas for glass fiber reinforced polymer (GFRP), and Nylon for polyamide.

Fig.11/01 Patented in 1859, celluloid became synonymous with film stock.

Fig.11/02 Acrylic is commonly referred to as Plexiglas, Lucite, Acrylite, or Perspex.

***Resin** refers to a viscous blend of polymers and additives that can be spread, sprayed, molded, or foamed and transformed into its final form through cooling or curing.* Resin is not a type of plastic, but rather an intermediary state that the plastics can be in. Epoxy resin is well known and sometimes referred to as just "resin" but most plastics can be in resin state, such as polyester resin, acrylic resin, vinyl chloride resin, melamine resin, polyolefin resin, etc.

The rapid development of a large variety of synthetic products since the mid-19th century changed manufacturing possibilities, and consequently, how products and interior spaces were designed. ***Celluloid** was the first synthesized thermoplastic, patented in 1859.* It was transparent, moldable upon heating, and retained form when cold; offered great versatility, surpassing all-natural alternatives. ***Rayon** was regenerated cellulose developed to imitate silk fiber, patented in 1894. The invention of **Bakelite** in 1907 marked the debut of fully synthetic materials.* By 1970, plastics had become integral to a wide variety of industries. Today there's a plastic component present in almost every product and interior space.

Vid.11/01 Video on polymers and the synthesis of plastics.

Polymers are highly versatile. There's a litany of polymers available with vastly different properties, it is also possible to further modify them with the inclusion of pigments, plasticizers, fillers, stabilizers, and other types of additives; enhancing their mechanical performance, impact resistance, moldability, fire-resistance, surface finish, etc.

***Pigments** are added to determine the color of the plastic.* The inherent transparency and surface quality of the resin determine the saturation and vibrancy of the resulting color. Various additives can be used to further enhance color properties, for example, clarifiers can be used to enhance transparency. As opposed to paints and coatings, added pigments are much more durable as they are diffused throughout the plastic body.

***Plasticizers** are added to increase the flexibility and strength of the material.* For instance, PVC is inherently a brittle plastic, however, with the addition of plasticizers it acquires flexibility, which helps vinyl to be much more durable, and in some cases more workable. The basic properties attained with plasticizers can be lost over time as the additive can evaporate or leach as it migrates towards the material surface. This behavior also causes serious health issues.

Fillers/Extenders *are added to give the material bulk and strength.* They are useful for decreasing raw resin consumption, therefore, lowering costs. However, they are also useful in increasing moldability, stability, and strength. In some cases mineral fillers can imbue the plastic with fire resistance. Glass fibers are one such additive. In fiber-reinforced plastic applications it can give polypropylene (PP) bulk as well as help the material to keep itself together and sustain heavier loads and impacts.

Stabilizers *are used for increasing the useful life of plastics by slowing down degradation, ensuring colorfastness, increasing UV resistance, inhibiting oxidation, etc.* They are also useful in minimizing manufacturing defects and in some cases contribute to recyclability along with compatibilizers. For example, without stabilizers (specifically HALS) common polyolefin impurities can cause excessive UV light absorption and degradation.

Additives have both positive and negative implications for the recycling process; *they* ***contribute*** *by protecting the original resin, restoring diminished qualities, eliminating inconsistencies, making sure that recycling stays feasible; on the other hand, they* ***complicate*** *the waste separation process which in turn can deteriorate the recycled product quality.* The variety of additives present in contemporary products is one reason why PVC recycling is limited.

Fig.11/03 A heap of PVC waste including rigid and flexible components, waiting for separation.

Plastics can be ***alloyed*** *like metals, by mixing multiple resins with desirable properties.* For instance, the impact strength, flame resistance, and mold shrinkage of acrylonitrile butadiene styrene (ABS) can be improved by mixing it with PVC. Even though alloying plastics improve performance and visual/tactile qualities, the resulting mixture is even harder to recycle.

Over the decades the environmental impact of plastics became well documented and better understood. Plastics are a byproduct of the oil industry, accounting for 9% of the total oil consumption. This slowly depletes oil and natural gas resources, which are finite. Initial polymerization, as well as further processing of plastics, require intense heat, resulting in high embodied energy. Most importantly, the natural degradation of plastics is very slow, causing continuous debris build-up in varying sizes, from large containers, fishing nets, broken-off chunks, or even microscopic particles. ***Microplastics*** *are tiny pieces of plastic, specifically less than 5mm (3/16") in length, that were broken down through oxidation, UV exposure, and mechanical forces.* Although less common today, a number of cosmetic products like some face scrubs and toothpastes contain already broken down microplastics which are flushed directly down the sink and easily mixed into waterways. According to the US National Oceanic and Atmospheric Administration (NOAA), microplastics are the most common type of marine debris today. Many research indicates seafood as a common means for ingestion of such particles by humans, which can cause gastrointestinal obstruction. Fat and water-soluble plastic components have the potential to impact immune and endocrine systems, though there's need for additional scientific evidence for a certain conclusion. However, the health detriments of plastics stretch further. As previously explored, synthetic materials tend to emit VOCs and leach chemicals, a process that can be sped up with the increased presence of heat and humidity. *Plastic particles and fumes are notorious **asthma triggers**.* Formaldehyde has a bad reputation for the high level of VOC emissions, aside from being a known irritant and carcinogen with developmental toxicity effects. Bisphenol A and phthalates are additives that can cause hormone-related developmental problems. When combusted, PVC can release highly toxic and deadly chemicals such as CO, hydrogen chloride, chlorine, and benzene.

*On a yearly basis, of all the manufactured plastics, only **9 percent is recycled** and around 19 percent is incinerated.* The rest of the plastic content ends up in landfills or is left to break down in the environment. Some plastics are so cheap to manufacture that the recycling process needs to be extremely efficient to be feasible. One example is virgin PVC. Made up of salt and oil, it is very cheap to manufacture, and PVC waste is very hard to separate for recycling due to the number of mixed-in additives and other plastics. Without any incentives, this causes a constant PVC waste build-up. Virgin plastic cost is linked to the price of oil and it fluctuates. When oil prices fall recycling becomes less cost-effective and less likely. It is always best to check the commitment of a company to utilizing recycled content. When recycling is not financially justified, *it is also possible to **incinerate plastic waste** and recover energy.* This method is widely incorporated throughout the European Union countries, however, burning plastics produces a significant amount of CO_2 and some toxic gases and it may be doing as much harm as it is creating benefit.

Vid.11/02 *Video on waste management in Las Vegas.*

Fig.11/04 *Plastics in nature break down into increasingly smaller pieces known as microplastics, bioaccuulative and difficult to clean.*

The visual and performance characteristics of recycled resin can be different from virgin resin due to cross-contamination, with regard to existing pigments, plasticizers, and extenders, as well as other resins, being present, and the extent of degradation sustained by the recycled content. In 1980s, *the Society of the Plastics Industry, SPI, created the **resin identification coding (RIC)** system, to facilitate the recycling process by assigning numbers to various resins.* RIC simplifies the waste separation process, however, the consumers often think that any plastic carrying the mark is infinitely recyclable, which is not true. This can create a carefree attitude, highly detrimental to the environment. Another challenge is the resin code #7, which is named "other". Many common and very recy-

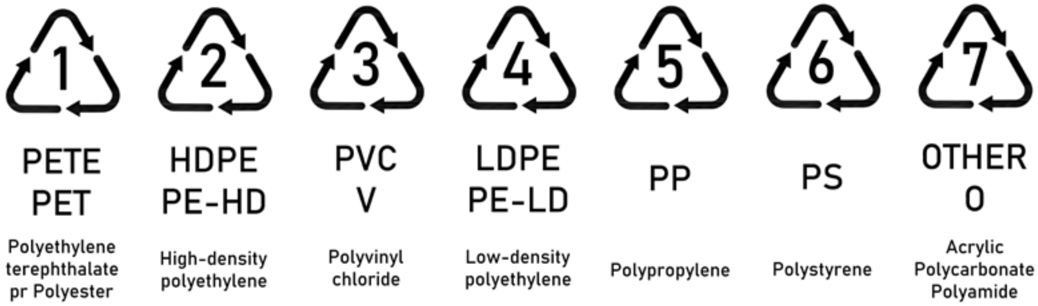

Fig.11/05 The plastic types included in the resin identification coding (RIC) system simplify waste separation, to an extent.

clable plastics such as nylon, acrylic, and polycarbonate fall under this category and they are often impossible to separate based on the identification code, unless they are clearly marked with resin name. For other plastics, resin code does not help much. For instance, resin code #3 for PVC does not get close to covering the number of variations in the available resin.

PLASTIC TYPES

Plastics can be grouped under two overarching categories: thermoplastics and thermosets. ***Thermoplastics*** *become soft and viscous as they are heated, and when left to cool they harden back.* This process can be repeated infinite times enabling the plastic to be processed and reprocessed. This category includes some widely known plastics such as nylon, acrylic, polycarbonate, polypropylene, and PVC. The general characteristics of thermosets include high impact resistance, high moldability, and most importantly recyclability. On the other hand, ***thermosets*** *are permanently hardened, through a one-way chemical reaction that generates cross-linked chains throughout the material, and cannot be softened with heat.* Some known examples are rubber, silicone, polyurethane, and formaldehyde resins. Thermosets cannot be recycled, though they can be shredded and used as a filler in other plastic products or they can be incinerated. ***Elastomer*** *refers to a category of plastics that can stretch and deform when a load is applied and return to its original form when the load is removed*; they can be thermoset or thermoplastic. Most elastomers are thermosets such as polyurethane foam or rubber tires, there are some thermoplastic elastomer examples that can be repeatedly heat processed and recycled. Thermoplastic polyurethane is one example with a wide range of uses. ***Bioplastics*** *are resins that are derived from renewable biomass such as maize, sugar cane, potato starch.* The more popular and feasible examples include Cellulose Acetate, Starch

Fig.11/06 Thermoplastic Polyurethane (TPU) drapery, TPU is the thermoplastic version of the widely employed thermoset plastic polyurethane (PU).

Plastic, and Polylactic Acid (PLA). Characterized as highly biodegradable, these methods reduce the environmental impact associated with drilling, mining, and refining processes. Even though the end-of-life impact for bioplastics is lower, extensive farming is incentivized which might ultimately result in deforestation, agrochemical use, extensive irrigation and drained aquifers, genetically modified products, and diverting food resources to industrial procedures.

THERMOPLASTICS

ACRYLIC (PMMA) ● *Polymethyl methacrylate (PMMA), the plastic widely recognized as **acrylic**, is a thermoplastic with great optic clarity, it is lightweight, strong, chemical-, weather-, and UV- resistant.* Acrylic is often referred to with common trademarks such as Plexiglas, Lexon, and Lucite. As a transparent plastic with almost 92% light transmission, and the ability to maintain optical quality despite the increased thickness, it is superior to all other plastics as well as glass, except for surface durability. Available in a vast range of colors and transparency/translucency levels; fluorescent versions are also available for enhanced edge glow. It is possible to process acrylic panels with woodworking tools; CNC machining is another possibility. Adhesives need to be carefully picked when joining acrylic panels; silicone-, epoxy-, and acrylic-based adhesives are the most appropriate as they don't damage the material. Acrylic's hardness allows for polishing and coating, but it is also highly prone to scratches. It can be buffed and polished repeatedly; the surface can also be treated for scratch resistance. Acrylic should not be cleaned with ammonia and other glass cleaning chemicals, as they cause yellowing; only the manufacturer's recommended cleaning products should be used. Polycarbonate (PC) has higher impact strength but slightly lower optic clarity. Glass has better surface reflections, harder to scratch, and looks more high-end. Acrylic is brittle and when it breaks large blunt splinters are formed. *Acrylic can be **laminated with film** to introduce tint or translucency, or layered effects.* Companies such as Lumicor® suspend different materials and objects such as leaves, straws, textiles in acrylic resin to create cast panels with various visual effects. Miss Blanche Chair by Shiro Kurumata features this aesthetic. It is also possible to suspend LED, products manufactured by Sensitile are one example. It is also possible to edge-light laser-etched acrylic pieces for interesting effects. Good melt flow, low shrinkage, and good dimensional stability render acrylic highly processible and appropriate for molded complex 3d forms where glass fails due to high post-mold shrinkage.

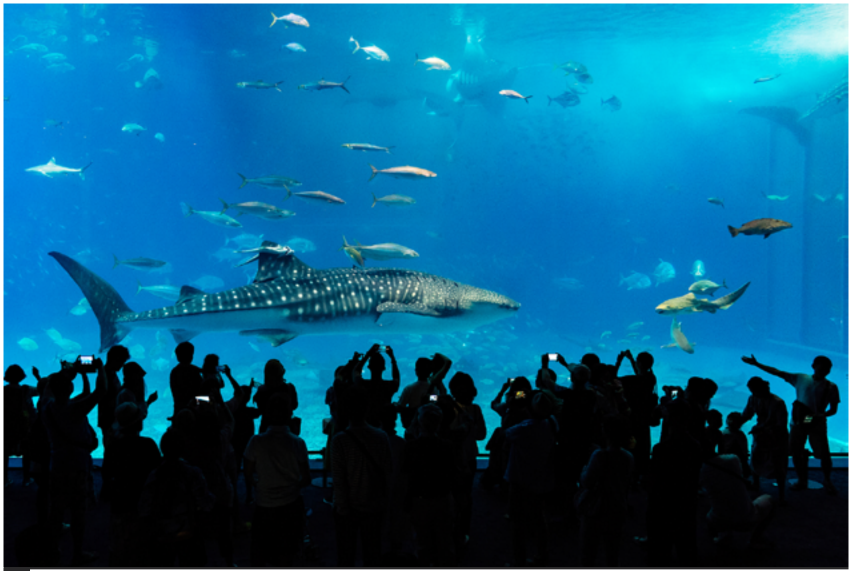

Fig.11/07 Acrylic retains optical quality despite increased thickness. It is commonly used in giant aquarium displays holding thousands of tonnes of water.

POLYCARBONATE (PC) ● ***Polycarbonate (PC)** is categorized as an engineering thermoplastic owing to its high strength, optic clarity, and predictability.* It is six times lighter for the same volume compared to mineral glass, which helps reduce weight in transportation applications. It can also be used to create safety goggles, break-resistant

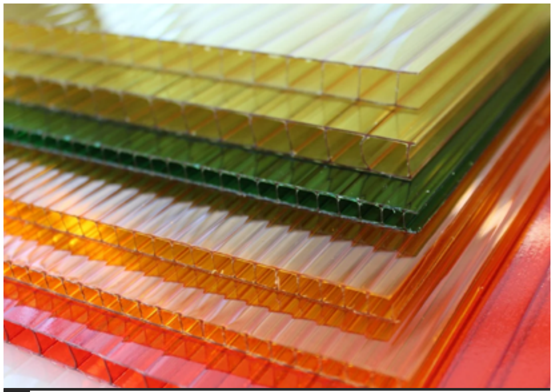

Fig.11/08 Twinwall polycarbonate (PC) panels are durable and lightweight, commonly used in skylights.

Fig.11/09 Thanks to their flexibility, PEX pipes can be run like electrical conduits, without elbow joints.

glass, and skylight covers. It can be laminated with other types of glass to create security glass. With glass fillers, PC can achieve even higher tensile strength. Acrylic has similar optic clarity and high light transmission properties, however, performs poorly in terms of impact strength and dimensional stability, PC is 1/3 more expensive than Acrylic. The biggest problem with PC manufacturing is that *it is manufactured by polymerizing* ***Bisphenol A (BPA)*** *with carbonyl chloride, which is often not completely polymerized and can leach into liquids.* The surface of PC is not durable which contributes to BPA contamination through further abrasion. Recycling is somewhat difficult due to the fact that both acrylic (PMMA) and polycarbonate (PC) are assigned to the resin identification code #7, making it very hard to separate them from waste streams.

POLYOLEFIN ● ***Polyolefin*** *is a family of commodity polymers, including polyethylene (PE) and polypropylene (PP), and they are very common and versatile plastics with a wide range of uses as sheet materials, fibers, and furniture.* A wide range of bright colors and good quality finishes can be achieved from glossy to matte. These are hydrophobic polymers that can prevent staining in carpets, however, they retain and build electrostatic energy. They are viable alternatives to the very commonly used nylon fibers, more recyclable but display lesser performance. This polymer family is almost totally inert, meaning they have minimal toxicity and are widely used in food packaging. ***Polypropylene (PP)*** *is a very low-density all-purpose plastic with balanced thermal, physical, and chemical performance.* Widely used in packaging. ***Polyethylene (PE)*** *is a thermoplastic but can be transformed into a thermoset via chemically building cross-link bonds.* ***Cross-link PE****, also known as PEX or XLPE, is commonly used for contemporary plumbing applications.* The material is low-cost, impact and cracking resistant, hydrophobic, non-toxic, flexible, and feature very high on-site workability. There are highly convenient cutting tools and connectors available and thanks to the material's flexibility, plumbing can be run behind wall panels in a way similar to electrical conduits, which in turn minimizes demolition. PE has been slowly replacing PVC for some resilient flooring applications. ***High-density polyeth-***

Vid.11/03 Video on polycarbonate vs. acrylic.

ylene (HDPE) *has high tensile strength, though not as high as acrylic and nowhere near polycarbonate.* HDPE sheets can be used in construction as a machinable and thermoformable panel product; it is also used as plumbing material. Tyvek is an HDPE film manufactured by DuPont, used for weather protection during construction (housewrap), insulation aid, as well as industrial packaging.

Polyolefin polymers can be a very suitable matrices for glass fiber (GF) composites, commonly used in furniture manufacturing. Verner Panton's S chair is one example of GF reinforced PE, and a modern version is available that is manufactured from PP. There's also a more expensive polyurethane (PU) version available. GF reinforcing negatively impacts finish quality, especially in darker colors.

The polyolefin family is highly recyclable with associated resin codes such as #2 for HDPE, #4 for LDPE, #5 for PP. When used as singular plastic, for instance in packaging, they are even more recyclable, but recycling ratios are still lower than most metals.

POLYVINYL CHLORIDE (PVC) ● Thanks to a wide range of modifications that can be attained with additives, ***Polyvinyl Chloride (PVC)*** *is a highly versatile and popular thermoplastic.* It is extremely cheap to manufacture, vastly cheaper than comparable wood and metal-based alternatives. In industrial products PVC can attain desirable tactile and visual qualities, its transparency and glossiness levels can be tailored, and big range of vibrant colors can be attained. PVC is a good thermal and electrical insulator. With the correct additives, PVC can have a very long useful life, measured in decades. Over time white PVC can yellow with UV exposure, which can be prevented through the use of additives. On the other hand, this can also be a useful property. For instance on smoke detectors yellowing indicates aging and a need for replacement. PVC products are low maintenance, highly reliable, predictable,

Fig.11/10 Without stabilizers, PVC yellows over time. A useful quality to indicate component age.

and workable, especially on site. PVC can be expanded into foam for insulation or sheet products can be used as wood panel replacement for casework, signage, partitions, etc. 70% of manufactured PVC is used by the construction industry as building infrastructure and fittings, making up 75% of combined plastic use in constructions.

Vinyl flooring *is a very durable product with high staining, scuffing, denting, and tearing resistance.* It is relatively low cost and the most popular among all resilient flooring materials. There are many product variations with names such as SVT – Solid Vinyl Tile; VCT – Vinyl Composition Tile; VET – Vinyl Enhanced Tile; LVT – Luxury Vinyl Tile. Usually when there is a "V" in product name it suggests the product is some PVC variant. Vinyl flooring is available as planks of 4" to 12" wide and 36" to 48" wide, exact dimensions vary by manufacturer; it is also available as continuous sheets of 6' to 12' wide, similar to broadloom carpet. Vinyl flooring has a very thin profile and when discarded, its landfill contribution is limited. *It is possible to* ***weld vinyl*** *at seams and use* ***flash coving*** *at wall bases to create a continuous flooring installation for excellent impermeability and cleanability.* This is a very popular application detail in healthcare facilities where hygiene is a significant concern and floors need to be constantly cleaned. *There*

Fig.11/11 *Vinyl flooring application in an operation room corridor, the welded seams and flash coving at the perimeter are compatible with the strict hygiene require-*

Fig.11/12 *Vinyl flooring is available in a large selection of colors.*

*are two seaming methods, one involving **fusing two sheets** of vinyl together via a solvent, and the other involving **melting a vinyl rod** into the seams*, a time-consuming and expensive operation though the result is a better seal. Unlike sheet vinyl flooring, vinyl tiles cannot be seamed.

***Vinyl composite tile (VCT)** features mineral-based aggregate filler within a vinyl matrix.* It has a simple constitution, a single consistent material throughout the depth of the product. It can be fairly brittle, and has low abrasion and tear resistance. The color and pattern options are limited. Its lower upfront cost may be enticing at first, however, the maintenance requirements and the constant buffing and polishing costs add up in the long term. Another vinyl product, on the other hand, *the **luxury vinyl tile (LVT)** is a slightly more expensive product with features such as a decorative printed layer and a durable wear layer.* The decorative layer can mimic natural products such as leather, cork, or solid wood. Custom patterns can also be ordered. A transparent or translucent wear layer is featured above the decorative layer determining the abrasion resistance capabilities of the product. A PVC layer between the decorative layer and a backing layer below provide increased resiliency. The make-up of the tile depends on the manufacturer and it can be highly complex with many more layers. *Vinyl flooring is graded in accordance with the standard ASTM F1303, based on the **expected traffic load**, Grade 1 is*

Vid.11/04 *Video on heat welding vinyl flooring seams.*

suitable for high traffic load commercial environments to Grade 3 for light traffic load residential environments.

Vinyl is also used in textiles and apparel. A common example is faux leather. PVC coated fabric can be embossed and finished to mimic the look of leather, though the shiny specular quality cannot exactly match real leather, creating a plasticky impression. Furthermore, it has a hot and sticky feeling as it is not breathable; tends to quickly crack and delaminate. Polyurethane (PU) is a better option for imitation leather though it is several times more expensive.

Compared to other plastics PVC has low embodied energy. Nevertheless, the overall negative environmental impact is substantial. PVC manufacturing produces large amounts of chlorine, which is a highly toxic and persistent chemical. Some of the additives such as phthalates as well as unpolymerized chemical intermediaries can be released to the surrounding environment over time, creating significant health risks for the occupants, especially developing children. *From 1954 until 1980 asbestos was used as a binder in* ***Vinyl Asbestos Tiles (VAT)****. These tiles are still present in many old constructions and require vigilance and specialized services to safely remove them.* Another big health issue with PVC is its burning characteristics. It is

Vid.11/05 Video on the vinyl waste separation and recycling process.

self-extinguishing when exposed to a small fire, however, when combusted PVC emits carbon monoxide, hydrogen chloride, and benzene which are serious irritants with high toxicity. Even though PVC is recyclable with its separate resin identification code, #3, due to a large range of modified versions in the market, separating is very hard, and recycling is not justified as virgin material is very cheap. PVC is praised for its durability; however, it does not biodegrade or break down which makes it somewhat of an environmental menace.

While not classified as a polymer, linoleum is the predecessor of the modern vinyl flooring and there are many overlapping features. ***Linoleum*** *is manufactured by oxidizing linseed oil, or flax oil, and developing a composite mixture with wood and cork flour as well as various natural resins and pigments.* The material is porous due to wood and cork filler content, requires yearly sealing. It is insulative and feels warm. It is non-toxic and fire-resistive, anti-static, repels dust and dirt. Seams can be joined by melted

Fig.11/13 Luxury vinyl tile (LVT) can imitate any material thanks to a printable layer.

Fig.11/14 Linoleum is capable of complimenting any contemporary environment.

linoleum rod or latex adhesives, which improves the hygiene factor. UV light exposure causes yellowing. Linoleum has relatively low abrasion resistance. It can show scuff marks, however, it can also self-heal very small dents over time. It can be buffed and refinished. Linoleum is a natural product and it is completely biodegradable. It can also be composted, yet this makes it susceptible to mold and mildew growth. Linoleum is susceptible to staining and yellowing when in extended contact with alkaline liquids and cleaning products.

POLYSTYRENE (PS) ● ***Polystyrene (PS)*** *is a fairly cheap plastic with low melting point rendering it highly suitable for low-value, disposable items.* It can be utilized either as foam or in rigid form. Commonly used for disposable tableware and protective, insulative, and disposable packaging components. High impact polystyrene is used in models and toys, and as sheet material in construction. ***Expanded polystyrene (EPS)*** *is a very lightweight product with trapped air consisting 95% of its volume, known by the trademark Styrofoam.* Used extensively in construction as insulation, molds for decorative spatial elements, or as the decorative elements themselves. There's another version known as ***Extruded Polystyrene (XPS)****, which has higher density and strength, with higher R-value and rigidity.* A better insulation material though relatively more expensive. Both materials can be shaped with computer-controlled hot-wire cutters and can be used for temporary spatial elements for exhibitions or events, or in model-making. There's an additional PS type named graphite polystyrene (GPS), with an even higher R-value, providing better insulative properties. PS is an extremely prevalent plastic. Even though polystyrene has its own resin identification code, #6, it is not feasible to recycle. The waste PS is often mixed and contaminated with other trash and difficult to separate. Due to its low weight and high volume, it is not economical to transport to a central recycling plant. PS is highly degradable under UV light and when exposed to chemicals, very susceptible to breaking down into micro-plastics.

Fig.11/15 The pink colored extruded polystyrene (XPS) is a common insulation material.

> *When combusted polystyrene (PS) produces* ***significant amounts of soot****, a dense cloud of impure carbon particles which pose health risks, therefore not very suitable for incineration either.*

POLYAMIDE (PA) ● ***Polyamide (PA)*** *is a high-performance thermoplastic with great wear resistance and flexibility.* It is extensively used in commercial fiber applications; rigid molded applications are also available such as part enclosures, tool handles, and medical implants as it can perform as a reasonable replacement for metal parts. *A very common version of PA is known by the trademark* ***Nylon****, which has several versions in itself, 6 or 6.6 being most popular* – these numbers are simply referring to the number of carbon atoms in its monomer form. Typically, polyamides contain hydrophilic amide groups, if untreated they can absorb water and moisture, swell, and stain. Nylon 6.6 exhibits a lower absorption rate, better chemical resistance, better flexibility, however, it is also relatively difficult to mold, color, and finish. Nylon is commonly blended with wool for increased strength. Aromatic Polyamides, known also as "aramids" are extremely durable and fire-resistant synthetic fibers, widely known by the trademarks Kevlar and Nomex. PA's resin identification code is #7, shared with many other plastics. Consequently, it is hard to separate and recycle. Separation is even harder for PA blended with other fibers for textile manufacturing or woven into other materials.

> *Nylon is a **highly durable** material. This creates a significant negative environmental impact. For example, it is widely being used for manufacturing fishing nets and due to the very slow decay rate, an estimated 10% of debris in the ocean is discarded nylon.*

POLYESTER (PET) ● *Polyester or **polyethylene terephthalate (PET)**, is a relatively inexpensive and versatile plastic with balanced properties, commonly used for food and drink packaging.* It is relatively non-toxic, free of bisphenol A (BPA), phthalates, and dioxins, resistant to many chemicals. It is inert and does not interact with alcohol, fat, oil, etc. However, when exposed to heat it becomes unstable and can start leaching anti-

Fig.11/16 The highly durable Nylon fishing nets are a significant source of pollution for the oceans.

Fig.11/17 Fiberglass reinforced polyester resin is being applied to a mold.

mony. Thanks to its high elasticity, impact resistance, and lightweight, high-quality thin-walled containers can be blow molded easily, making PET extremely widespread in disposable bottle manufacturing. Polyester fiber is commonly used in textile manufacturing, primarily in the apparel industry. PET is also highly suitable for medium to low traffic carpeting applications; Nylon is a better option for high traffic situations. PET bottles are commonly recycled to carpet fibers, *Polyester is a commonly used matrix for **glass fiber reinforced plastics (GFRP)**.* This material was widely experimented with by Charles and Ray Eames, who designed a number of molded furniture with this material in mind. There were some toxicity issues with earlier versions. Current versions mainly utilize polypropylene. Commonly used drafting medium Mylar® is also PET. The resin identification code for PET is #1,

Vid.11/06 Video on testing polyester security film on glass.

it is one of the most commonly recycled plastics. It is very easy to recognize and separate from waste streams, therefore easier to recycle and the resulting recycled plastic is of high quality. It is not uncommon to see trashcans dedicated to PET bottle disposal.

THERMOSETS

RUBBER ● ***Rubber****, or polyisoprene, is a thermoset polymer known for its elasticity and high resistance against chemical agents, heat, and abrasion.* There are two overarching types of rubber available: natural and synthetic. Natural rubber is tapped from the rubber plant grown in tropical regions, and synthetic rubber is synthesized from petroleum byproducts. Natural rubber features high tear resistance, tensile strength, and a relatively low melting point. On the other hand, synthetic rubber has excellent heat and chemical resistance. The properties of both rubber types are unique and they are often blended; the level of flexibility, as well as the performance properties, can be specifically tailored for the purpose of the end product, rendering rubber highly versatile. ***Vulcanization****, also referred to as mediated crosslinking, is a curing process for enhancing a thermoset polymer's properties.* The term is mainly used to refer to the process of treating rubber with sulfur after the resin is shaped. The cross-linking processes for silicone and polyurethane are also referred to as vulcanization. The process enhances the plastic's ability to revert back to its original form after sustaining significant deformation.

Rubber flooring is very durable and resistant against deformation and indentation, provides significant slip resistance, suitable for places that feature a lot of heavy traffic, especially rolling loads. Rubber flooring is also light on joints and mitigates occupant fatigue to an extent. Highly comfortable underfoot, rubber flooring is used in gyms, playgrounds, and in workplaces where employees spend hours standing. Initial costs may be relatively higher, however, the material is very resilient and its useful life is fairly long.

60% of all rubber production goes to tire manu-

Fig.11/18 Rubber flooring is highly suitable for gym environments, where heavy loads are dropped and rolled around continuously.

Fig.11/19 Used tires are not wanted in landfills as they can trap methane because of their shape.

Vid.11/07 Video on contemporary rubber recycling process.

facturing. Tires are discarded after a relatively short useful life, creating a significant source of waste. As a thermoset plastic, rubber is very difficult to recycle into useful virgin material. There are two alternative paths of recycling available. The first method is ***devulcanization**, which is a chemical and thermomechanical process to reverse the effects of vulcanization and partly replace the virgin material.* There are various methods still in development to increase the feasibility and quality of this option. The other recycling, or rather reusing, method is grinding rubber and using it as feedstock or filler in other products. There are many examples of high-end flooring finishes and carpet paddings utilizing this particular technique.

POLYURETHANE (PU) ● Polyurethane (PU) is one of the most popular polymers, available in two subtypes: thermoset (PU) subtype primarily as open-cell flexible foams and thermoplastic (TPU) subtype as rigid molded forms; the thermoset subtype is not melt-processible. ***Polyurethane** has great shape-retention and minimal creep. Even after receiving heavy loads for extended periods, it returns back to its original shape easily.* Its performance and properties can be fine-tuned via various additives. 1/3 of all polyurethane manufactured is flexible foam, mainly for upholstery use and highly efficient insulation. Polyurethane foam is manufactured as giant slabs in varying densities and hardness, commonly referred to as slabstock; these are then cut to the desired shape. ***Memory foam**, also referred to as viscoelastic polyurethane, is a very popular padding commonly associated with comfort.* The foam reacts to body heat and becomes softer, better accommodating the user. However, the price point of the material is relatively high and is rendered useless in very high or low temperature environments. Polyurethane has a wide spectrum of use beyond foam, can be molded as solid objects, flexible objects; can be used as core for sandwich panels, or can be manufactured into high-performance coatings, adhesives, or sealants. Thanks to its elastic nature, the fiber form can be woven, into stretchable garments. *Polyurethane in thermoset form **cannot be recycled**, however, it can be ground and used as filler for other products*, such as carpet underlays. Incinerating polyurethane is another option, however, this produces toxic gases such as carbon monoxide and hydrogen cyanide.

EPOXY ● ***Epoxy**, also known as polyepoxide, is a highly versatile thermoset plastic.* Epoxy by itself has limited mechanical performance, and *in order to achieve the high-performance it is widely known for, it needs to be mixed with a curing agent referred to as the **hardener***, enabling dense cross-links to form throughout,

Fig.11/20 Polyurethane spray-foam insulation is highly efficient but requires flawless installation to properly function.

Fig.11/21 Epoxy flooring is actually a thin resin layer and requires meticulous substrate preparation.

allowing the material to gain strength and rigidity. Different types of hardeners can be utilized for different purposes or to adjust curing times, also known as pot-life. After curing, the material gains superior resistance to chemical, thermal, and physical abuse. Epoxy is commonly known as a flooring finish, but it is also used for grouting, as an adhesive, a surface finish, and it is highly popular in DIY furniture design, among many other uses.

Before the application, the substrate needs to be carefully sanded, vacuumed, and washed. Epoxy is applied as layers of very thin film and it telegraphs any irregularity on the substrate. The leftover sand and dust particles can contaminate the film. This process needs to be carefully controlled and requires specialization. If the mix-ratio is not correct, there's a possibility of uncured resin or hardener being left out, deteriorating material performance. The curing process is exothermic, meaning it will release heat, however, since interior applications are thin films, the heat build-up does not cause problems. During curing epoxy releases VOCs, which can quickly build up in confined areas. A mask/respirator with a vapor/gas cartridge needs to be used for safety. Proper ventilation is necessary to control VOC buildup and for letting the excess heat escape. Uncured epoxy should never be sanded due to high toxicity. After curing the material is inert.

Vid.11/08 Video on decorative epoxy installation.

The key ingredients in most epoxy are epichlorohydrin (ECH) and bisphenol-A (BPA), though alternative formulations are available. Around 2% of the population tends to develop some form of allergic reaction and discomfort when exposed to epoxy. *Even though there are methods in development, currently, epoxy is* ***not recyclable****.* Epoxy waste should not be mixed with household waste.

> ***Uncured epoxy*** *is toxic. Unused material should be left to cure and taken to a local waste management center.*

FORMALDEHYDE ● Formaldehyde is one of the oldest synthesized plastic resins, known since 1855. It is brittle after it is cured, and displays somewhat poor moldability features, however, performs well as a resin matrix for panel products and objects with simplistic forms. Formaldehyde is also found in various adhesives, sealants, laminates, insulation, and coating products. There are three widely used versions, melamine-, phenolic-, and urea-formaldehyde each with slightly different properties. Phenol-formaldehyde resists moisture, is stable, and has better strength. Oriented strand board (OSB), and some plywood panels employ phenol-formaldehyde. On the other hand, the widely used urea-formaldehyde is cheaper. Urea-formaldehyde is commonly used for particleboards, MDFs, and some plywood panels. There is also melamine-formaldehyde, used in laminate manufacturing. Clarity of the

Fig.11/22 The transparency of melamine-formaldehyde resin enables a vivid representation of pigments.

resin enables vivid colors and accurate rendering of decorative layers.

Formaldehydes, especially urea-formaldehyde, are known to be substantial sources of ***VOCs****.* Phenol- and melamine-formaldehyde emits, comparatively less dangerous VOCs. Since they are still widespread in the market, the designer should pay attention if the materials being specified contain formaldehyde and what the emission levels are. It is best practice to seal the material properly. For instance, laminating a particle board panel, or applying urethane coating on an OSB panel minimizes VOC emissions as long as the sealing layer is intact and doesn't sustain damage. Another important precaution is the pre-occupancy ventilation period of the environment to disperse VOCs released during the initial, more dense emission periods.

> *The designer should make sure that the* ***temperature and humidity*** *of the application environment stay balanced, as an increase in these parameters exacerbates VOC emission levels.*

SILICONE ● Silicone, or polysiloxane, is unique among the popular polymers. Its building block is an inorganic monomer made up of silica and oxygen; however, it is still widely regarded as a plastic. Silicone is anti-microbial and hypoallergenic, highly durable, water-resistant, and chemically inert with no known toxicity. It is often used for heat-resistant cookware, it is flexible with great tear and scuff resistance. Silicone is commonly used for manufacturing adhesives and sealants in the construction industry, highly compatible with most materials. Like other thermosets, it is difficult to recycle, can only be downcycled in the form of silicone oil or shredded and used as filler.

MANUFACTURING METHODS

Plastics are ubiquitous in the modern world. For a designer, a fundamental knowledge of plastic manufacturing methods is exceedingly helpful, not only for designing custom components involving plastics but also when specifying plastic products. All thermoplastic manufacturing processes involve heated resin shaped to a mold, such as thermoforming, vacuum forming, drape-forming, injection molding, blow molding, rotational molding. Thermosets are cured through a chemical reaction after they are introduced to a mold. The appropriate manufacturing method depends on the shape, structure, and complexity of the product, output volume, and the type of plastic to be used.

Thermoforming *is essentially forming with heat.* Thermoplastics in sheet form heated to a temperature at which they become soft and pliable but not melted, then formed into the desired shape by use of a mold. *In* ***drape forming*** *heated plastic is draped on a piece of mold. In* ***vacuum forming*** *sheet plastic is heated and placed over a mold, then by sucking out the air, the plastic piece is forced to tightly envelope the mold, taking its shape.* Edge trimming is required for most of these applications. The degree of surface detail that can be attained with thermoforming is fairly limited. Sheet plastics can also be processed like paper: creased, folded, and

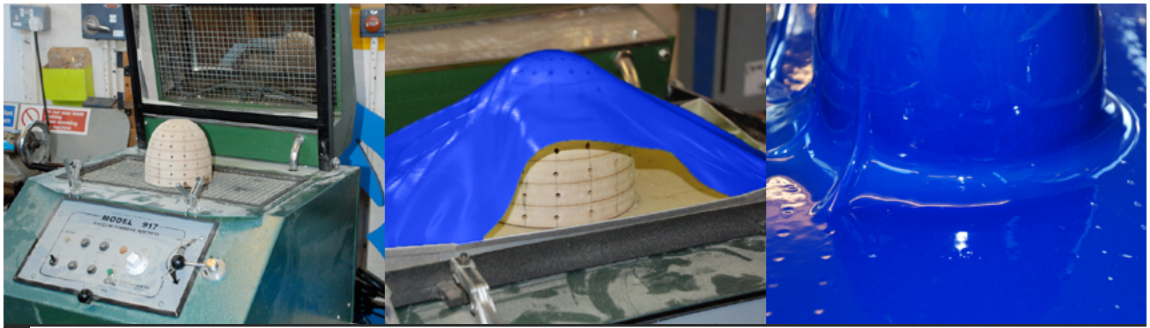

Fig.11/23 Vacuum forming involves draping a heated plastic sheet on the mold and sucking the air to give shape.

cut. Such techniques are widely employed in packaging.

***Extrusion** is when melted plastic resin is forced through a shaped opening to achieve a continuous profile.* Pipes, tubing, railing, sheet films, as well as some complex profiles such as window framing can be manufactured with extrusion. It is possible to directly form an extruded jacket around a wire. Thin sheets of acrylic and polycarbonate are extruded, thicker panels are molded. Calendering is a method similar to extrusion, it is used to produce plastic sheets and films by forcing the resin between two heated rollers; commonly used in non-woven textile manufacturing.

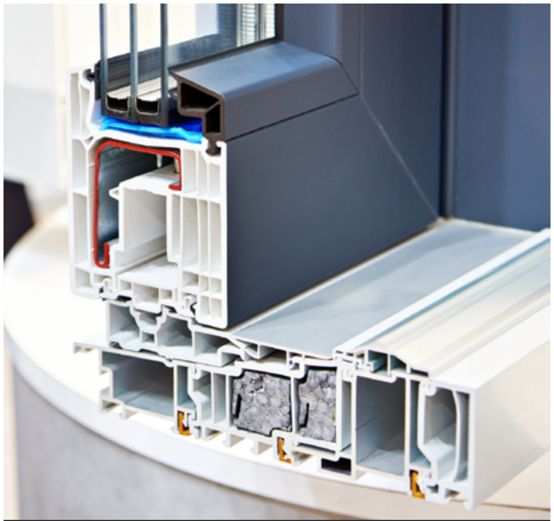

Fig.11/24 The highly complex PVC window profiles are one example for thermoplastic extrusion.

***Injection molding** involves forcing melted plastic pellets into a mold at high pressures. A common method for molding three-dimensional products with complex surface details.* This method gives the designer a lot of control, it is possible to adjust the wall thickness, and attain strength where needed, significantly saving manufacturing costs. Depending on the resin type, mold complexity, size of the cavity, and expected output, mold design and tooling can be very expensive. *It is justified only when a very **high volume of production** is expected.* Injection molding has very short cycle times and a very high output volume. Each year 60 billion LEGO pieces are manufactured with this method. The success of the final product depends on mold design as well as resin selection. Injection molding requires high melt flow and not appropriate for all types of plastics due to the possibility of defects. HDPE, Polyolefins, Acrylic, and Nylon are excellent for molding, whereas PVC, silicon, and rubber may require various additives for

Vid.11/09 Video on the intricacies of injection molding.

Fig.11/25 *A retired Lego injection mold.*

successful implementation. Furthermore, different types of plastic have different dimensional tolerances, and the output of the same mold can have different dimensions for different plastics. After molding, injection hole artifacts and resin flash are visible and must be sanded and removed. *It is possible to inject multiple resins from different injection units into multiple molds in close sequence with* ***multishot injection molding;*** different colors, surface qualities, and performance properties can be obtained on the same product. ***Overmolding*** *involves securing a previously manufactured plastic or metal component inside the mold, then injecting resin to cover part or entirety of the secured object, bonding both components.* Useful for creating a rigid internal support, embedding electronics, etc.

Unlike injection molding where melted resin is injected into a cavity at high pressure; *in* ***compression molding****, pre-heated resin is placed into a heated mold, which is then closed and compressed.* Appropriate for thicker parts with fewer details, mold costs are relatively lower, on the other hand, cycle times are slower, output is low, and cost per piece is higher. Appropriate when low to medium output volume is required.

Similar to mold-blown glass, *in* ***blow molding*** *air is blown into heated plastic, inflating it into the mold's shape*; bottles and containers with consistent thin walls or multiple layers are

Vid.11/10 *Video on the blow molding process.*

produced with this method. It is possible to utilize multiple molding techniques on the same plastic body, permitting some complex form-making. Some blow molded items start out as extrusions. It is possible to injection mold some details like complex handles or spouts with precise details and then blow mold the rest of the object.

Rotation molding *involves continuously rotating molds while heating powdered resin inside, essentially coating the surfaces with approximately equal thickness plastic.* It is possible to mold large objects that are completely sealed as well as with open ends, while achieving a constant wall thickness throughout. This method has low output volume. Large buoyant objects, inflatables, liquid containers, as well as sizable furniture pieces can be created with rotation molding, one famous piece being Marc Newson's Plastic Orgone Chair.

Fig.11/26 *In blow molding, the PET billet is heated, and after they are placed within the mold air is pushed in to expand the object into the shape of the mold.*

Fig.11/27 In this rotation molding example an open flame heat source is utilized.

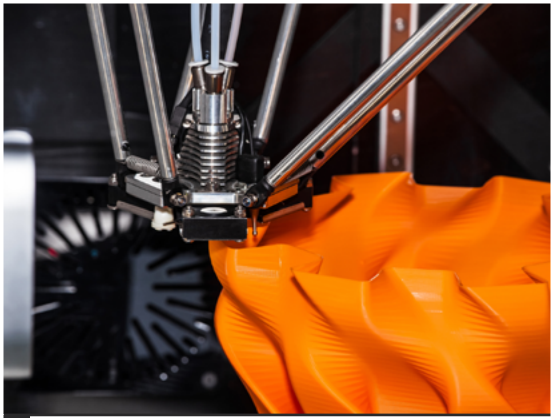

Fig.11/28 3d printing is great for prototyping. The performance of the fabricated object is relatively low.

***Dip Molding** involves dipping a mold into melted plastic such as PVC or polypropylene (PP), covering the mold with a consistent thin layer of plastic with an open end.* It is possible to dip-mold woven backing, which is commonly used in textile and apparel manufacturing.

Sometimes referred to as "growing" a product, ***3d printing** is an additive manufacturing process where the material is deposited in sequential layers to achieve the final form.* There are many types available, such as laser sintering and fused deposition or fused filament printing. It is great for prototyping and very low volume manufacturing. Various methods can provide down to 10 microns precision, enabling some highly intricate details to be achieved only with 3D printing. However, these high-precision techniques such as laser sintering and stereolithography can be very expensive, furthermore, the part might not have the same mechanical performance as a conventionally manufactured alternative. With the advent of low-cost 3d-printers directed towards enthusiasts, a potential health hazard became more apparent. *During the printing operation, the melted and deposited plastic material releases **toxic fumes**.* A National Institute for Occupational Safety and Health (NIOSH) study claims the emissions from heated ABS and PC feedstock as damaging to lung tissue.

***Plastic Welding** involves applying a heated thermoplastic or curable plastic to a seam between two plastic pieces for the purpose of joining the two.* The strength of the bond is dependent on the compatibility of joined plastics and the welding plastic. This method is very common in vinyl flooring applications, enables seams to be flush and non-permeable which is helpful for cleanability. It is also possible to join plastics by applying chemicals or heat to the seam.

COMPOSITES

In materials science, *the term **composite** refers to the combination of two or more materials in such a way as to create a new material with enhanced properties.* Composite materials offer excellent strength-to-weight, dimensional stability, increased useful life, and added functionalities such as thermal or electric insulation, etc. Composites have been used throughout history. Mudbricks, being one of the earliest examples, involved a combination of straws and mud to enhance the resistance of bricks against tensile forces while minimizing crumbling. The same fundamental principle is seen in the rein-

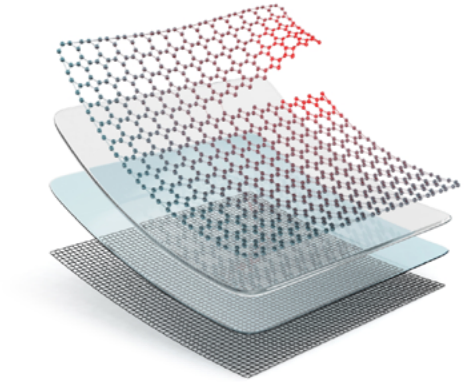

Fig.11/29 A composite material constitutes multiple materials that enhance each other's performance.

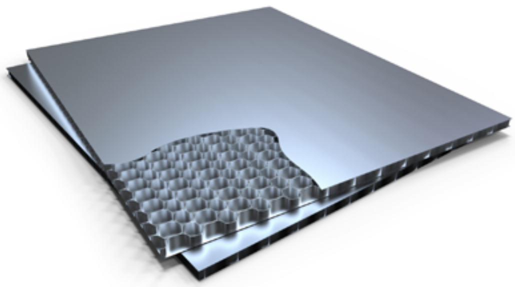

Fig.11/30 Sandwich panels typically feature a core layer sandwiched between protective sheets.

forced concrete today. The aggregate in cement matrix creates a stronger composite material by resisting compressive forces, however, this is taken one step further with the addition of a steel rebar reinforcement, creating a very strong construction material that can resist tensile stress as well. Another significant example is fiberglass. Developed in the late 1930s, fiberglass is composed of thin strands of glass, woven into fabric and then fused with a resin or plastic. Composites can even occur naturally. Wood is classified as polymer composite, where the cellulose fibers are bonded by lignin.

Composite materials can be constructed in various ways. It is possible to set fibers, flakes, chunks, sheets, or meshes in a resin to create a composite. In this type of composite, *the resin is called the **matrix** and it binds the added material that is called the **reinforcement**.* Essentially, the reinforcement enhances the mechanical properties of the matrix, while the matrix holds the material's shape and determines its surface quality. For instance, carbon fiber as a reinforced composite involves woven carbon fibers set in polymer resin; it can be five times stronger than steel while having only one fifth of the mass. In bioplastic composites, fibers can be added to compensate for inherent structural weakness. *Unlike alloys, the physical and chemical properties of each separate component of the composite material are **maintained**.* The naming conventions work both ways to include either the reinforcement or the matrix, such as fiber-reinforced composite, or metal matrix composite. ***Sandwich panels** are also considered composite materials; they feature a core, typically lightweight or insulative sandwiched between two sheets of another material.* For instance, an aluminum honeycomb panel can be sandwiched between two sheets of aluminum, creating a material that is much stronger and much lighter than an aluminum sheet of the same thickness. Another example would be glass wool insulation being sandwiched between corrugated aluminum panels. In this case, the corrugations give strength to the composite, while glass wool creates a heat barrier.

Vid.11/11 Video on the history of composite materials.

Composite materials have two significant shortcomings. *First is the long and costly **research***

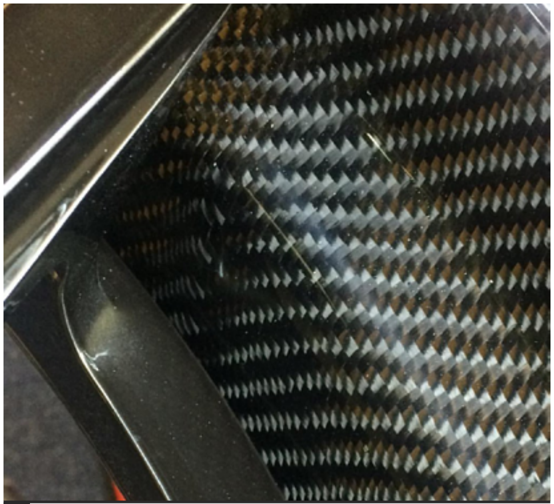

Fig.11/31 Typical carbon fiber implementation involves plain woven carbon fibers set in epoxy resin matrix.

Fig.11/32 Cork is categorized as resilient flooring, though it cannot perform as well as polymers alternatives.

***and development** processes.* It is exceedingly difficult to achieve a perfect combination of materials that will work in harmony without deteriorating each other's performance while improving the overall mechanical and chemical properties. It is very costly to develop and manufacture these complex materials. *Another downside is the **challenges to recycling** due to complex combinations of dissimilar materials.* Composites are often not feasible to recycle, though for some components' prohibitively excessive initial cost can incentivize the development of efficient recycling practices, one example being the very expensive carbon fiber.

INTERIOR SPECIFIC POLYMER PRODUCTS

RESILIENT FLOORING ● In materials science, *the term **resilient** is used to refer to materials that are strong, durable, and flexible enough to absorb impact and endure deformations, and return to their original shape following the removal of the load without experiencing creep.* This group of materials are either come in sheet or panel form, typically with a thin profile, they are relatively cheap. Materials such as vinyl, rubber, linoleum are considered in this category and show high resiliency. Compared to polymer-based alternatives, some natural materials in this category are less resilient such as cork or leather.

The history of resilient flooring starts with Linoleum in 1894, which was the precursor to modern resilient flooring materials. Between 1894 and 1904 various other tile floorings were introduced to the market, including rubber and cork. Vinyl composition tile wasn't introduced until 1943, though, it became increasingly popular as new variations on the material are introduced and the material became cheaper, more durable, and functional.

Today a number of material compositions are available with some variation in performance and sustainability characteristics. *A **printable layer** enables any material to be imitated, or **pigments and colorful flakes** can be introduced, not only for aesthetic value but also for hiding soiling and scuffing.* A strong wear layer enables the already resilient and durable materials to perform very well under heavy traffic loads. *Various seaming techniques such as hot rod melting and chemical welding with a variety* *of baseboard and threshold details enable a* ***consistently impermeable floor***, highly suitable for wet spaces and rigorous cleaning practices.

Building static charge is a significant problem with polymer-based flooring products, especially in spaces where flammable materials are stored or used, such as hospital operating rooms, or where electronic hardware is housed such as server rooms. For such environments, the designer should consider inherently antistatic solutions such as conductive rubber, or static dissipative tile.

SOLID SURFACE & QUARTZ ● *The term* ***solid surface*** *refers to a category of composite sheet products that utilize a polymer resin matrix such as acrylic, epoxy, and polyester, various fillers, and complex pigmentation that offer a wide range of colors and textures.* Some examples can even accurately imitate natural stone counterparts. These products are highly workable and can be processed with widely available woodworking techniques; they can be sawn, milled, and even bent with the application of heat. Solid surfaces are typically specified for countertops, however, the application possibilities are virtually limitless due to their high workability provided by the thermoplastic matrix. Application examples include high-end complex front desks, sculpted seating units, residential countertops with integrated sinks and functionality, wall paneling with depth, and flowing ceiling elements. On the other hand, the same polymer matrix carries most disadvantages of the original polymer, for instance, an acrylic matrix will be susceptible to surface scratching, or heat can cause damage. Acrylic, epoxy, and polyester matrices are not completely chemically inert, so when a solid surface material featuring these resins is to be specified, possible chemical exposure to strong acids, chlorinated solvents, and acid drain cleaners should be considered. Longer exposure means stronger staining and harder removal. However, thanks to their homogeneous color-through constitution the material can be easily repaired and patched,

Fig.11/33 Solid surface product being bent around a plywood mold, through utilizing a mixture of heat treatment and kerfing techniques.

many times over.

Solid surfaces are available in ¼” thickness for vertical applications, ½” and ¾” for other applications. The sheet size varies between manufacturer and product, but they are typically around 30” x 144” for thicker and 30” x 98” for thinner sheets. *One great advantage of solid surfaces is, despite the limited sheet sizes,* ***seams can be completely hidden*** *with the application of heating and buffing, which enables continuous stretches.*

The National Sanitation Foundation, or currently known as NSF International, is an independent organization that publishes various health, sanitation, as well as food and water safety standards. *Part of the standard* ***NSF 51*** *outlines various resin-based countertop materials that are deemed safe for commercial food production.* The designer should check if the solid surface material is NSF 51 compliant or not, especially in

Fig.11/34 With complex pigmentation techniques quartz panels can imitate natural stone convincingly.

Fig.11/35 Plastic laminates can feature solid colors, natural textures, as well as bespoke graphics.

cases where food contact is expected.

***Engineered stone**, also commonly referred to as quartz, is similar to solid surface, however, around 90% of the material composition is quartz used as filler*. Epoxy, polyester, or other resins are used to make up the matrix component. Quartz and quartzite are different materials. *Quartz is an artificial panel product and **quartzite** is a metamorphic stone with a granular texture and impressive hardness.* The hardness of quartz particles renders engineered stone highly resistant to abrasion and scuffing, equal to granites with the highest resistance. Moreover, the material does not require any sealing or other periodic maintenance. It is inherently NSF 51 compliant. Quartz is available in 2cm (3/4") and 3cm (1-1/4") thicknesses, and its workability is similar to granite, however, due to their homogeneous, or isotropic nature the possibility of breakage is much lower. One disadvantage of quartz over solid surfaces is that the seams cannot be hidden, also, cracks and other damage over time cannot be patched in a straightforward manner. Some quartz panels are marketed as heat resistant; however, ***excessive heat exposure** is known to cause cracks and at the very least discoloration. Undiluted use of **acidic cleaners** can also cause discoloration over time.*

PLASTIC LAMINATES ● ***Plastic laminates** are thin sheet products that comprise several layers of paper bonded together with formaldehyde resin, followed by a decorative layer that can feature any image, and a clear wear layer that provides protection against abrasion.* Owing to the combined effect of the visual decorative and tactile top layer, any material can be imitated to an extent, such as all solid woods with high-gloss, satin, or matte texturing; granites, marbles, travertines, metals with a variety of sheen levels. Bespoke designs are also possible, services provided by almost all laminate manufacturers.

*Plastic laminates are **intended to adhere to various substrates** such as particleboard, MDF, plywood, cement board.* Laminates are just thin sheets of material and unless the edge is continuous, i.e. rounded/filleted, the sides of the substrate will be exposed. These exposed areas can be closed off with edge bands appropriate for specific panel thicknesses or the same plas-

Vid.11/12 Video on laminate countertop application.

Fig.11/36 Plastic laminate edges and seams are prone to heat and moisture damage.

tic laminate can be applied.

Plastic laminates can be used for countertops, as long as the substrate's behavior against moisture is stable. *Plastic laminates have **size limitations**, typically matching common substrate sizes such as 4' by 8' or 6' by 12'; when there are turns, corners, or extended areas involved a seam is needed.* Typically, these seams represent weak points on the surface. The seam needs to be far away from water sources and all edges need to be sealed. In addition to moisture concerns, the designer should be concerned about heat exposure as well, as continual exposure to heat can cause plastic laminates to delaminate especially at the seams and edges.

***High-pressure laminates (HPL)** feature multiple layers of kraft paper, impregnated with resin consolidated via the application of high heat and pressure.* Compared to standard plastic laminates they contain 3 to 4 times more layers, providing extra durability and impact resistance. Similar to standard plastic laminates, HPL's also require a stable substrate. ***Compact laminates** feature a core that is completely consisting of resin-impregnated kraft papers, sandwiched between laminated sheets, via the application of intense heat and pressure.* Even though slightly expensive, compact laminates are highly durable and moisture resistant, very suitable for use in wet spaces as well as outdoors. Various compact laminates available in the market make use of colored core layers, enabling the designers to create various profile effects that work very well with CNC machined parts.

12 SPECIFICATION

- *The business and key professionals*
- *Common specification types*
- *Standardized specification content*
- *Project cost estimation*
- *Conducting field survey*
- *Criteria for successful specification*

For an interior architect or designer, design skills and technical knowledge only partly contribute to career building. The professional is also expected to build and maintain reputation, integrity, and credibility; always holding themselves to a high ethical standard. Networking, creating, and maintaining a team of professionals, including representatives, vendors, contractors, installers, as well as a number of consultants from specification writers to acoustical engineers, are also highly important.

In the context of interior architecture and design, *a **contractor** is an individual or a company that coordinates and supervises a project, develops a schedule, handles permit processes, acquires materials and services, ultimately ensuring that the design intent is realized accurately and on time.* Typically, the client hires the contractor, though it is possible for the design professional to hire the contractor or function as the contractor. Local laws might require licensure to perform contractor duties, for instance, the State of

Kansas requires the individual to be pre-qualified to work as the prime bidder. State laws for qualification and licensing requirements for contractors should be checked before committing to any contractor duty. The designer should understand that even though the contractor is responsible for realizing the design intent, the designer will ultimately receive the credit or the blame for the finished design product, and should be ready to assume responsibility and act accordingly.

> *As long as there is healthy competition in the market, with regard to the materials specified and the contractors and installers hired, the designer almost always* ***gets what they pay for***.

Contractors hire qualified professionals such as subcontractors and installers to finish various tasks required by a project and they also ensure that all teams are scheduled efficiently and working safely. ***Subcontractors*** *are specialized professionals who are hired by contractors to perform a specific group of tasks, such as electrical, plumbing, demolition, etc. work.* If the designer is the person hiring a subcontractor, beyond looking at a website or portfolio and reviewing photos of previous work, they should make sure to examine previous or ongoing work by visiting a job site as well as speak to references to assess credentials, work ethic, and quality of output. The designer should always clearly communicate expectations to the sub-contractor. ***Installers*** *are employees performing work on site, such as assembling and installing furniture, applying paint, or laying tiles.* They may be hired separately, through a contractor, or a sub-contractor. Whether they are directly hired by the designer or not, installers represent the designer on-site. Consequently, their attitude and manner of communication bears significance.

Link 12/01 Additional information on contractor pre-qualification.

Fig.12/01 Realizing a project involves a large team of professionals coordinated by the designer.

In the most simplistic sense, ***manufacturer representatives****, also referred to as sales representatives or "reps", act as intermediaries for manufacturers, promoting and selling their products to professionals.* Reps can represent a single product line for a company or multiple non-competing products from several companies. Representatives have extensive knowledge and experience about the materials they promote and can be a true ally to the designer.

> *Manufacturer representatives help designers by providing* ***product knowledge****, alerting them about discounts, provide pricing information, guidance and tips, suggest sub-contractors for processing and installing the materials as well as aiding in troubleshooting issues.*

Establishing a dialogue with manufacturer representatives is one important way to learn about and get help on material specifications. However, various other sources of information are also available to the designer. ***Dealers, distributors, and vendors*** *offer a selection of materials, prod-*

ucts, and supplies as well as related services in some cases often only to professionals. On the other hand, resellers and retailers sell products directly to end-users; designers can also assume this role. *The contract for* ***Furniture, Fixtures & Equipment (FF&E)*** *is separate from the contract for construction.* It includes services pertaining to storage, delivery, assembly, and installation of the products, signed between the vendor and the client. ***Showrooms*** *are wholesalers who promote product lines from multiple manufacturers.* A close relationship with these businesses is important as they can be helpful in securing trade discounts and solving issues with orders. *Custom items such as window treatments, bespoke furniture, and casework are often fabricated in* ***workrooms****.* Since workrooms provide specialization in one aspect of interior space, their feedback and advice are often highly valuable.

The designer can request samples from a wide selection of sources, including but not limited to, manufacturer representatives, vendors, and showrooms. ***Material samples*** *provide a relatively small section/piece of the actual material, generally around 2” by 2” to 8” by 8” in size,* though the sizes vary substantially between

Fig.12/02 Showrooms enable side-by-side comparison of multiple products.

Vid.12/01 Video on how workrooms function.

manufacturers and products. Samples are very helpful in assessing the exact look and feel of the material. An additional benefit is seeing the representation of the effect of various materials together. *Designers can prepare* ***material boards*** *to assess the synergy and impact of various materials in combination.* Material boards are also a great way to communicate ideas with clients as well as collaborators.

> *When building a material board, the designer should pay close attention to the* ***visual composition****; how the negative space is employed, how the sample relationships are defined via adjacency and overlaps, and how the organization of samples represents the final product.*

An important aspect of becoming an efficient designer is understanding that interior design involves far more than the individual effort of the designer. On the contrary, it involves the totality of expertise and efforts of many professionals throughout the process. *Consequently, the successful completion of any project heavily relies on a* ***healthy team dynamic****.* Keeping professional relationships in good standing is crucial for ensuring project success.

SPECIFYING MATERIALS

Within the context of spatial design, t*he act of* ***specifying*** *refers to determining the materials, furniture, fixtures, and equipment involved in realizing the design intent*. On the other hand, *the term* ***specification****, or spec, refers to a clear*

Fig.12/03 Material boards provide an abstract representation of the look and feel of the space (work by Darianne Conley).

and detailed written description of the materials, standards, tools, labor, and procedures required to fabricate and install the designed project. Specifications are provided as an intrinsic part of the construction document set and used in conjunction with construction drawings to accurately execute the designer's vision.

> *The construction drawing set and the specification documents should **coordinate perfectly**. In case there is a conflict, the specification document supersedes drawings according to the typical order of precedence.*

Like any other component of the construction document set, specifications are integral to the signed contract and are legally binding. Unclear expectations might return as subpar work or mistakes that might result in lawsuits. Badly written specifications are a major source of liability and a common source of legal claims. There are dedicated specification writers in the industry who can be hired as consultants, however, *it is essential for every interior architect and designer to understand what good specification writing entails; **the designer is still responsible** for the errors and omissions, as the consultant is working under an agreement with the designer, and not the client.*

There are 2 fundamental specification types, tailored towards two different purposes:

1. *An **open specification** outlines the expected properties of materials/products and results,*

gives bidders the flexibility to decide on the specific manufacturer or variation among possible alternatives, determines the way the material/product will be processed and implemented based on the given description. It is open for alternatives and substitutions. Government contracts are required to be open.

❷ *A* ***closed specification*** *states specific materials/products and their specific model and variation, requires specific processes, and declares the expected results.* It does not typically allow for competitive bidding. It is typically closed for alternatives and substitutions, however, it is possible to bypass this with specific wording, for instance, “equal products can be used with the approval of the designer and client”.

The fundamental specification types can come in different formats customized to serve different needs. 4 most common types are as follows:

❶ ***Performance specification*** *is an open type spec that describes a number of criteria and sets up expected results*, what the finished installation is expected to accomplish. e.g. fire resistance ratings, VOC emission levels, or thermal insulation values.

❷ ***Reference specification*** *is another open type spec that references standards and test methods set by widely recognized authorities*, such as ASTM E648, NFPA 701, or UL 1715. Since these standards are so clearly defined, errors and liability are minimized.

❸ ***Proprietary specification*** *is a closed type specification where exact manufacturer name and products, even specific suppliers, can be stated.* It is straightforward to write, relatively shorter and the designer is given absolute control.

❹ ***Base-bid specification*** *is another closed type specification; specific products are called out, however, the contractor is allowed to substitute other products.* These substitutions should be subject to the designer’s review and approval.

Vid.12/02 Video on specification types and their uses.

Developed and published by the ***Construction Specifications Institute (CSI)****, widely adopted by the construction industry,* ***MasterFormat®*** *is a guidebook that provides a standardized and systematically structured framework for specification, contract, and manual writing*, helping to create a common language across the industry and setting-up a reference that minimizes misunderstandings. MasterFormat® features a six-digit indexing system to simplify searching for relevant information. In the latest version, there are 48 divisions relating to many aspects of construction including materials, equipment, furnishing, etc., but also, services, site and infrastructure, and processes. This organizational methodology is especially relevant when writing specifications, and the content is tailored accordingly. E.g. 09.21.16 refers to “Gypsum Board Assemblies” – or – 06.18.13 refers to “Glued Laminated Timber”.

SectionFormat®, or PageFormat® in Canada, is a specification formatting standard, also developed by Construction Specifications Institute and widely adopted by the construction industry. SectionFormat® divides the specification content into the following three parts:

❶ ***General information about the project*** – this part is the general summary of the job, including which MasterFormat® division/section it relates to, references, the extent and frequency of submittals, shop drawings, mock-ups, also, site conditions, access to amenities such as electricity and heat, delivery, storage, and handling expectations, as well as warranty conditions.

❷ ***Information pertaining to products*** – this part outlines which material will be installed where, specific features, work to be performed prior to installation such as cutting, polishing, sealing; compliance with standards, certifications, and the general condition that the material should be in before installation.

❸ ***Information pertaining to execution*** – this part outlines the implementation, including the examination of the application substrate, expected work to be completed by other teams prior to installation, substrate prep work to be completed, intended installation result, allowable tolerances and deviances, quality control, what will be done with the scraps, debris, and waste; cleaning, sealing, and protection, and lastly the general condition the installation should be in before substantial completion, in other words, before the owner takes possession.

The contractor uses the outlined specification information as well as the provided construction drawings, schedules, manuals, and catalogs supplied by the designer to realize the project. Specifications might also include a clause dictating that the installation must be signed off by the designer.

COST ESTIMATION

For an interior design professional, project cost estimation is an important skill for two reasons. First, there often is a limited budget associated with virtually every project, and knowing how much a design decision will cost can prevent late revisions that can possibly alter the aesthetics and impact of a project. Second, the client might be interested in learning the cost of a project early on, to plan ahead. *A **ballpark estimate** or ballpark figure is the approximate cost of a project, can be given as dollar amount per square foot.* Contractors and subcontractors can always give the designer a quote upon request, however, depending on the complexity of the bid and how busy their schedules are, this process might take days or weeks.

> *A **quick cost estimate turnaround** is often important, especially in the initial stages of a project. This emphasizes the importance of the ability to self-estimate.*

There are many small but crucial aspects of estimation that require careful attention. First, an estimation includes more than the materials and workmanship; possibly transportation, handling, processing, purchase of various components, hardware, perishable tools, etc. Furthermore, the pricing of some of the items might fluctuate, one significant example being the threefold increase in lumber prices during the COVID-19 pandemic.

> ***Smaller costs add up** to considerable amounts, therefore creating a detailed spreadsheet and keeping track of all possible costs is extremely important.*

*The possibility of wastage and breakage should always be accounted for as unforeseen situations and **indirect costs** can add to substantial losses.* Before making any calculations, learning about the standard increments of material orders, such as sheet size, roll width, linear feet/yard, tiles per box, coverage per roll, box, gallon, etc. helps with estimating possible wastage. ***Mark-up** is used to cover the highly probable contingent cost, it should not be treated as a way to maximize profit.* Accurate estimation requires significant experience and it is a skill that develops over time, as it is practiced.

***Take-off** involves identifying and quantifying all the materials and items needed to complete a construction project in order to prepare the cost estimation.* Even though it is possible to obtain drawings of a project site, with some luck and good will, from various sources such as local building department, realtors, previously involved contractors, or architecture offices. However, these drawing sets might be incomplete, or they might lack crucial information. Moreover, for understanding the current state of the project site, a visit is mandatory. *Accurate and detailed **field measurements** are an essential requirement for reliable cost estimations.* Also referred to as field surveys or site surveys, field measurements are useful in creating a detailed understanding of the physical context of the design project by clearly documenting existing site conditions. The very first thing to understand before attempting any field measurements is that no building is built perfectly. *There are always **slight deviations** from the actual architectural drawings, whether due to imperfect construction practices or simply because the building settled over time.* Such deviations have the potential to affect fabrication and installation processes, during which mistakes and oversight can be very costly.

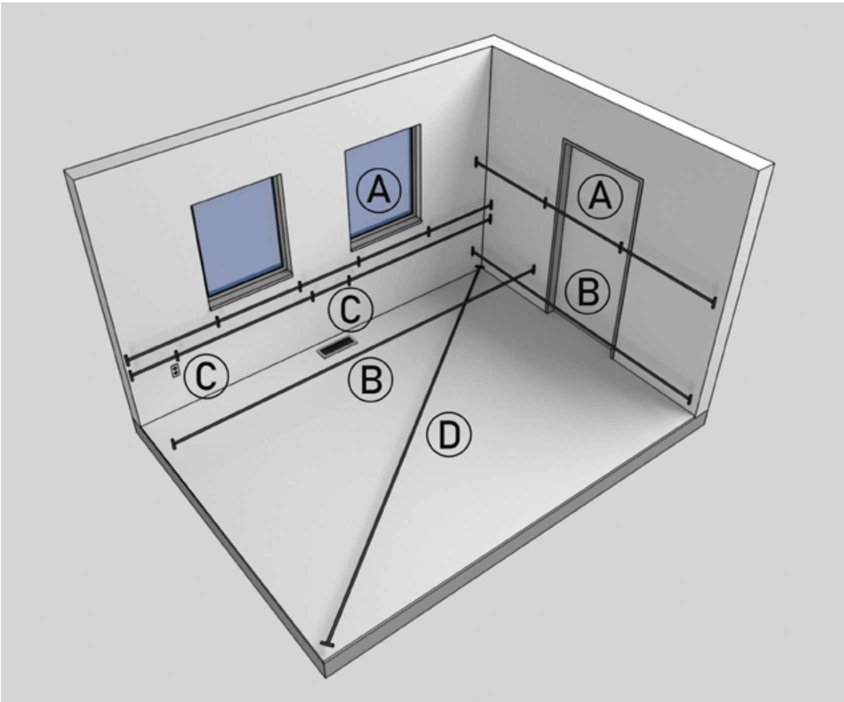

Fig.12/04 Points to measure: opening widths and distances to prominent features (A), total wall lengths (B), positions of electrical/mechanical details (C), diagonal lengths (D).

Fig.12/05 In order to reliably function, laser tapes require a flat surface to bounce the laser off of.

> *The designer should not rely on a single set of measurements; they should make sure to have the contractor, or if applicable, subcontractors and installers **take their own measurements**.*

The tools required for field measurements can be as brief as the following: a tape measure, clipboard, papers, pencils, and a camera. Tape length should be above 30’ if possible and if long distances are anticipated a reel tape may be included in the inventory. ***Laser tapes** are fast, precise, and very efficient in measuring long distances*, on the other hand, there is always a need for a surface to bounce the laser off and one cannot work around every obstruction or smaller detail. By themselves, laser tapes are not sufficient and should always be accompanied by a manual tape measure.

When conducting field measurements, *one should always consider taking as many **photographs** as possible for further reference, as*

Vid.12/03 Video on taking site measurements.

details and quirks of any space can be easily forgotten. These photographs should be augmented with specific notes. For instance, writing down if there is blocked site access, damp spots and mold growth on walls, or damaged electrical wiring, etc. ***Reference points** and **diagonal measurements** are other seemingly redundant and often overlooked methods of measurement.* Reference points can be any fixed point on site from which extra measurements can be taken and later compared. As buildings are not built perfectly, ***multiple-point measurements** and **corner-to-corner** diagonal measurements give the designer more data to work with*, therefore increasing accuracy. Lastly, ***smaller details** such as switches and outlets, small niches, or protrusions should not be ignored and should be measured like any other general detail*, as information pertaining to such details might later be needed.

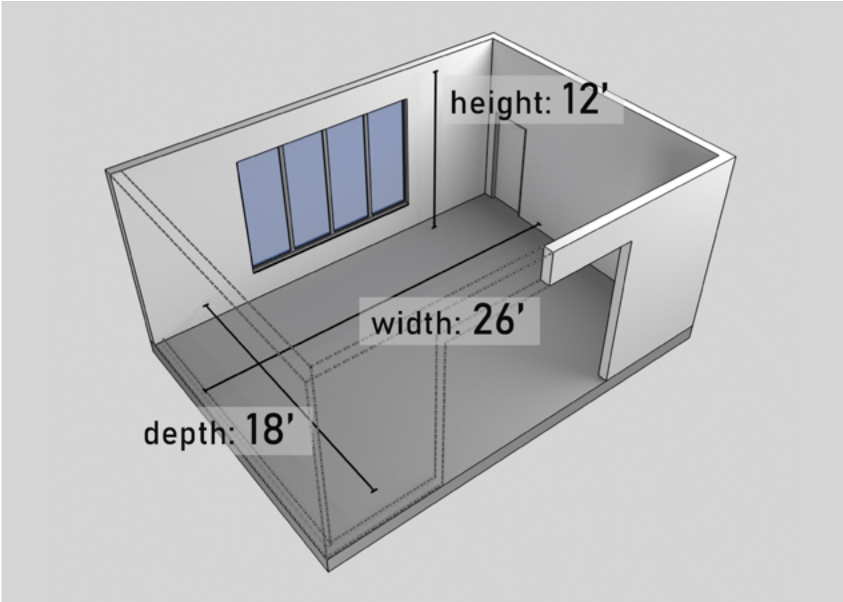

Fig.12/06 The imaginary space used for the example estimations.

> *When conducting field measurements, refraining from spending **10 extra minutes** might cost hours later on.*

There are two different methods to approach cost estimation: one involving a simpler "total application area divided by coverage per material unit" formula, and the other involving detailed calculation of coverage and wastage per material unit. The first method will not be as accurate as the second, as wastage can be fairly significant for some applications. The second method is time-consuming, prone to mistakes due to its complexity, and the designer will still need to make room for various contingencies; but the designer will know what they are getting into and design in a way to make better use of the materials, which can be a huge benefit and a learning experience. When working on cost estimation, planning for contingencies is always important. It is common practice to add a 10% allowance over the material needed, however, if the application is complicated with multiple unknowns, it may be a better idea to increase the allowance up to 20%.

*The **actual cost** of the installation is more than the cost of material alone; the designer should add labor costs which will include job supplies, transportation, demolition, communication, etc.* It is often possible to find out a price range for labor per square foot; or per hour, which can be a little less useful unless how much work is done per hour is known.

> *The **labor cost** will be higher than average if the job is complex, or slightly lower than average if it is straightforward.*

The following are simplified estimation steps for 3 different materials: paint, wallpaper, and carpet. In this example, the client wants to update their great room, which is 18' by 26', with a ceiling height of 12'; the room has a cased opening (12' by 10'), window opening (12' by 8'), and a door opening (36" by 84").

PAINT ● The room is expected to be painted with 3 coats of paint, with an average coverage of 350sqft per gallon. The amount of paint needed can be estimated with the following 5 steps.

First, the ***perimeter length*** of the room needs to be calculated. The perimeter of the room will be the total interior length of the given walls. In this case it is the length of two longitudinal walls (2 x 18') + two latitudinal walls (2 x 26') = 88' total perimeter. Following the perimeter calculation, the next step is finding the total ***area of the walls*** without considering any openings or details. The calculation is relatively straightforward for this room, which is a rectangular prism with a flat ceiling. The perimeter measurement of the room will be multiplied by the ceiling height. In this particular example, it is 88' x 12' = 1056sqft. In the case of an angled/vaulted ceiling this calculation methodology should be modified to incorporate the irregular wall area.

The third step is about determining ***opening deductions***. The height and width of each opening should be multiplied and the result should be subtracted from the total are calculated in the previous step. In this case, there's a cased opening (12' x 10' = 120sqft), a window opening (12' x 8' = 96sqft), and a door opening (36" x 84" or 3' x 7' = 21sqft). The total opening area is 120 + 96 + 21 = 237sqft. This is the area that won't be covered by any material. The actual wall area to be covered is 1056sqft (assumed total wall area) – 237sqft (minus the openings) = 819sqft. The next step involves finding out the ***total coverage*** needed based on the number of paint coats. If the number of coats required is 3, the total resulting area to be covered would be 819sqft x 3 = 2457sqft.

The last step involves dividing the coverage of the material per unit by the total area to be covered. In this case, the amount of coverage is given as 350sqft per gallon, so 2457sqft / 350sqft = 7.02 gallons of paint will be required. As previously mentioned, *it is common practice to add a **10% allowance** to most materials, as there will be mistakes and wastages.* 7 gallons x 1.1 (10% added) = 7.7 and rounded up to 8 gallons should suffice for the project. If you assume a high-quality eggshell paint is $35 per gallon, 8 x 35 = $280 worth of paint will be needed.

The total labor cost can be calculated based on the total painted area, which was previously calculated as 819sqft on the third step. For practicality, paint labor is assumed to be between $1 to $3 per sqft. Considering the job at hand is fairly straightforward, 819 x $1 = $819. A 10% additional budget can be dedicated for various other costs associated with the application, 819 x 1.1 (10% added) = $900. The total expected cost for the paint application including labor is 280 + 900 = $1180, approximately.

WALLPAPER ● The next problem is calculating the required materials for a wallpaper application for the same room. This is a residential project, *so researching and finding out the **common dimensions for available products** should be the initial task.* For simplicity, it is assumed that there are two wallpaper types available: 20.5" wide rolls with 33' double roll length, covering approximately 55sqft. The alternative roll is 27" wide rolls with 27' double roll length, covering approximately 60sqft.

Wallpapers are typically cut into strips and then

Fig.12/07 Wallpaper roll length determines how many useful strips can be extracted as well as the wastage.

applied. The height of the space is 12’, therefore, it is possible to extract 2 strips per double roll on the 20.5” wide type, covering 41” wall length per roll, with a 9’ strip left to spare; and 2 strips on the 27” roll with a 3’ strip to spare, covering 54” wall length per roll. However, considering that pattern matching might require 12”, 18”, or 36” strip offsets, the 3’ extra length might or might not be adequate.

The perimeter of the room is 88’, and there are two 12’ wide and one 3’ wide openings. 88’ – (2 x 12’) – 3’ = 61’ of the wall perimeter need to be covered with full height strips. Additionally, there’s a 2’ by 12’ area over the cased opening, 3’ by 5’ area over the door, and 4’ by 12” area around the window to be covered. 61’ x 12 = 732” perimeter to be covered by 20.5” wide strips, requiring approximately 732 / 20.5 = 36 strips, which will be extracted from 18 double rolls each with a 9’ strip to spare. The area above the door will require two 5’ high strips. The cased opening runs for 12’, that is 144” requiring seven 2’ high strips to cover. The area below and above the window are 12’ long, similarly, there’s a need for seven 2’ high strips to cover the top and the bottom section. All these strips can be extracted from the eighteen 9’ high leftover strips. If 10% contingency allowance is added 18 x 1.1 (10% added) = 20 double rolls, rounded up to the closest even number as wallpapers are commonly sold in double rolls.

A simpler but less accurate calculation would involve dividing the area ***coverage per double roll by the total area*** *to be covered.* According to step 3 of the paint calculation, a total of 819sqft needs to be covered. Considering the chosen wallpaper covers 55sqft per double roll, 819sqft / 55sqft = 14.8 double rolls will be needed at a minimum. However, considering the room height is higher than the average and there are numerous openings, substantial wastage should be expected. So instead of the usual 10% allowance, a 20% allowance will be added, 14.8 * 1.2 (20% added) = 18 double rolls, rounded up to the closest even number. As seen in this example, basing calculations on simple square footage might be slightly inaccurate and risky.

CARPET ● Finally, a carpet calculation will be done for the same room. A standard broadloom carpet roll is 12’ wide. Since the room for the application in question is 18’ by 26’, it is possible to set the carpet run on the longitudinal axis and get away with a single seam but there will be some wastage. For this particular room, a 12’ wide carpet roll and a 6’ wide carpet roll with a length of 26’ should suffice, at least in theory. However, *each time the carpet is cut, 6” width should be added along the length of the cut for a* ***clean edge***. As a result, 27’ x 2 = 54’ long broadloom carpet will be needed. There will be a 27’ by 5.5’ (due to 6” loss per cut) wastage from the application. So, with the 10% allowance, 54’ x 1.1 (10% added) = 60’ long broadloom carpet will be needed, rounded up to the closest number. *With a single seam it is easier to* ***adjust the nap***, however, it is also possible to apply the carpet on the perpendicular, latitudinal axis, creating more than one seam. This time three 18’ long carpet rolls will be needed, still amounting to the same length of carpet, 18’ x 3 = 54’. The wastage will be 18’ long and 9.5’ wide as opposed to the 27’ by 5.5’ previously calculated, an additional 22.5sqft carpet will be wasted and there will be more seams adding to the labor costs.

Fig.12/08 Seaming iron is one way to join carpet seams. More seams mean more labor and increased cost.

SPECIFICATION CRITERIA

When specifying materials, a wide selection of criteria need to be considered; and for each criteria, there are various questions, the answers of which affect the experience, impact, longevity, and overall success of the material choice. The specification criteria can be grouped under three broad categories: (1) Concept / Budget / Performance Concerns, (2) Health / Safety / Accessibility Concerns, (3) Sustainability / Maintenance Concerns. These categories contain several subcategories each with associated questions that can guide the designer to a more efficient material specification.

The designer should understand that, due to the complexity of the material specification process, *a **holistic approach** to the content is more appropriate than a sequential approach*. For instance, a seemingly suitable material might tick all the boxes but might fail to withstand the required cleaning practices, or it might be impossible to import, or it might release toxic fumes when combusted; basically a single criterion rendering the otherwise perfect match unsuitable.

> *The criteria provided here aim to remind the designer of the **comprehensive and complex** nature of material specification process, help prioritize between alternatives, and prevent any oversight.*

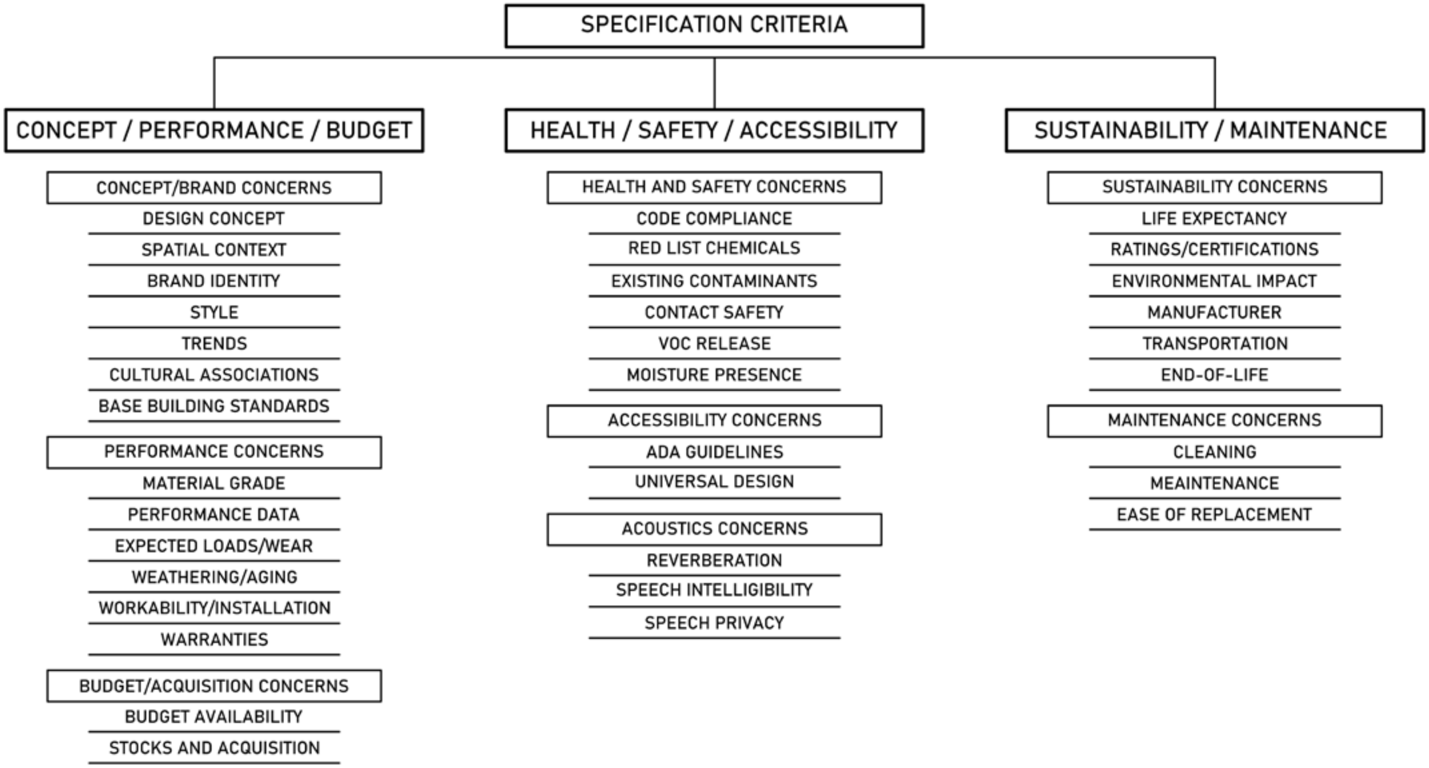

Fig.12/09 A holistic approach to the categorized map of material specification criteria is more beneficial for most projects.

CONCEPT/BRAND CONCERNS

DESIGN CONCEPT ● ***Concept*** *is useful for creating a consistent and coherent design language, and materiality is one part of it.* The designer should ask what category and type of material would strengthen the overall expression of the design intent, in a manner that would work with the rest of the design decisions. The designer should further consider that the impact of the material is also dependent on where and how much it is used. The same material used as an edge accent won't have the same effect as covering large surfaces. Moreover, materials have to work in conjunction with others and the total effect might enhance or weaken the impact.

Tab.12/01 Questions regarding design concept.

(1) What type/category of material does the concept suggest?
(2) What surface quality does the concept suggest?
(3) What kind of finish does the concept suggest?
(4) What material combinations does the concept suggest?

SPATIAL CONTEXT ● The designer should consider if the material specification is appropriate for the given spatial context. *The features of the space impact how the material will be* ***perceived***; the context can highlight positive qualities of the material, as well as exacerbate negative features. For instance, large format tiles might work better in larger spaces compared to the standard 12" by 12" tiles, due to a more sensible proportional relationship. Or a space with large south-facing windows might suffer from excess glare if the materials specified are mostly dark and polished.

Tab.12/02 Questions regarding spatial context.

(1) Does the space have any unique features to influence material perception?
(2) How will the material synergize with other materials that make up the space?

BRAND IDENTITY ● When working within a commercial context, the communication of corporate image and branding carries significant importance. ***Branding*** *is not limited to using the colors or forms implied through branding elements, such as logos, typeface choices, web design packaging, etc. but it is also about finding the right materials to communicate and reinforce the message, position, and reputation of the brand.* For instance, for a luxury apparel brand, using exposed OSB panels as part of a material scheme might be a wrong decision, unless some industrial and carefree brand implication is in place.

Tab.12/03 Questions regarding brand identity.

(1) Does the material choice enhance or weaken the brand message?
(2) Does the material scheme reference the branding elements?
(3) Does the material choice agree with user/client expectations?

STYLE ● *It is very likely for an experienced designer to develop a* ***formal style*** *over the years, based on what they believe works and distinguishes their work from the competition.* However, stylistic specification choices should not clash with other design considerations as they are primarily serving the designer and not so much the design product, user, and in most cases the client.

Fig.12/10 The logo is a great source for color, texture, and finish inspiration when specifying materials.

Tab.12/04 Questions regarding style.

(1) Do the stylistic choices enhance or hinder the design intent?
(2) Are the stylistic choices serving the designer or the design product?

TRENDS ● ***Trends** help the designer to identify what is generally accepted as a desirable design choice at a certain period in time.* Some trends last 10 years, others might last a season. The designer should follow what the current trends are, which materials or color schemes will be "in" at the time of project completion. However, trends do not apply to all projects. For a residential project, the trending paint colors might be a good choice depending on the client's wishes, but when designing the headquarters for a financial corporation, a more timeless and lasting choice might be better justified.

Tab.12/05 Questions regarding trends.

(1) How significant are the trends on the perception of the design product?
(2) Does the overall effect intended to be contemporary or classic?
(3) How well do the prominent trends overlap with client's identity and message?
(4) How much value is put on trends by the client and the targeted users?

CULTURAL ASSOCIATIONS ● Some materials have strong cultural associations and implications that can substantially affect user experience, in a positive as well as negative way. *The designer should be especially careful when working within a new cultural context they are **not familiar** with*, continuously calculating the possible negative and positive meaning that can be derived from material choices.

Tab.12/06 Questions regarding cultural associations.

(1) What are the cultural/sub-cultural sensibilities of the target users?
(2) Are there any religious/cultural values that disqualify certain materials?

BASE BUILDING STANDARDS ● The space to be designed might be located within a larger building or community, and it is possible that some standards have been established by the owners/ members; such as signage sizes, or style of the exterior facade, or the approved window treatments, or types of ceilings on the interior, or the times of day work can be done, or the size of materials, furniture, and fixtures that can be delivered, or how the construction waste will be removed.

> *The designer should request the associated **base building manual** and carefully inspect it before starting to specify mateirals and finishes.*

Tab.12/07 Questions regarding base building standards.

(1) Is there a base building manual available, and if so, how can it be obtained?
(2) Are there any items in the base building standard impacting material choices?

PERFORMANCE CONCERNS

MATERIAL GRADE ● *A very straightforward way to classify materials according to performance is indicating if they are manufactured for **residential** or **commercial** use.* Residential grade products are typically less durable and more prone to failure as they are expected to receive lighter traffic, abuse, and cleaning. On the other hand, commercial grade products are developed to withstand heavier traffic, abuse, and cleaning practices. The designer should be very careful in determining if the material being considered appropriate for the intended use.

Tab.12/08 Questions regarding material grade.

(1) Is the designed space categorized as residential or commercial?
(2) Can the traffic load be described as heavy, medium, or light?

PERFORMANCE DATA ● *The measured performance data of materials, often provided on the product label, are a crucial* ***indicator of the suitability*** *to the intended situation.* Hardness, colorfastness, UV resistance, lightfastness, expected deformation, or warping should all be considered carefully for the specific use context. The designer should be familiar with various technical terms, what they indicate, and how they might compare. For example, the Wyzenbeek Double Rubs, indicate the resiliency of a piece of textile-based on a particular abrasion method. On the other hand, the Martindale Abrasion Test involves a lighter abrader and a different movement pattern, and it takes more cycles for the fabric to fail. The designer has to know this information in order to make a healthy comparison.

Tab.12/09 Questions regarding performance data.

(1) How much the material can withstand the expected compression, tension, and shear forces?
(2) Is the material dimensionally stable, resistant against cupping, warping, bowing?
(3) What is the hardness, abrasion resistance, surface resilience of the material?
(4) How do the UV resistance, colorfastness, and lightfastness data of the material look?

EXPECTED LOADS/WEAR ● *Performance data is closely tied to the expected loads and wear and the designer should interpret them* ***in conjunction***. For example, the hardness of the product makes sense when it is considered in relation to the expected circulation traffic or rolling loads such as carts, task chairs, dollies, or wheelchairs. The abrasion resistance numbers make sense when the frequency of cleaning and the expected abuse is considered. Crocking resistance is similarly connected to expected abrasion and wear but refers to how well the color will be maintained on a textile. If UV exposure is expected UV resistance and lightfastness are values to carefully consider.

> *Products with higher performance values can be proportionally expensive and finding the most appropriate product is also a* ***budget issue***.

Tab.12/10 Questions regarding expected loads/wear.

(1) Is there an expectation of heavy cleaner or other chemical exposure?
(2) Is there an expectation of prolonged UV exposure?
(3)Is there an expectation of heavy foot traffic, rolling, and persistent loads?

WEATHERING/AGING ● Materials weather and age depending on environmental conditions, but also how they are finished and protected. The designer should consider conditions like UV exposure patterns, intensity of snow and rain, proximity to saltwater bodies, adjacent materials, etc. *Weathering and aging happen* ***over time****, and unless the material is chemically pre-weathered, and the designer should consider the imminent transformation.* Another issue is the maintenance and replacement of components, which might cause undesired visual inconsistencies.

Tab.12/11 Questions regarding weathering/aging.

(1) What is the expected weathering after 2, 5, and 10 years?
(2) How will weathering discrepancies impact adjacent materials?
(3) Will the weathering leave irregular patterns when fully exposed over extended periods?
(4) How often will the weathered components require replacement?

WORKABILITY/INSTALLATION ● The workability of a product directly affects fabrication and installation costs, but also the amount of wastage. ***Low workability*** *can negatively impact budget management while limiting possible design choices*. For instance, travertine is fragile and has a slow setting time, making it time-consuming and expensive to install. Complex matching patterns in upholstery can increase wastage while complicating the fabrication processes and straining the budget.

Material manufacturers typically suggest appropriate adhesives, finishes, etc. to be used for each product and the designer should make sure to review fabrication and installation instructions, moreover, they should also make sure these are noticed by the fabricator and installer. Not all materials are suitable for all available fabrication and installation methods. For example, a CNC cut carpet inlay won't work with a stretch-in installation.

The designer should consider how much risk they can afford when specifying an unpredictable product. Furthermore, *finding and scheduling the **right craftsperson or installer** might be another challenge when specifying less workable materials*. Another important consideration when specifying materials is the roll, sheet, tile, etc. sizes. Most materials are manufactured according to industry-wide size standards. Knowing these and designing accordingly can minimize wastage significantly.

Fig.12/11 Complex details with low tolerance require impeccable workmanship, often stressing project schedule and budget.

Tab.12/12 Questions regarding workability/installation.

(1) Is the material predictable or risky, in relation to fabrication complexity?
(2) What are the typical workmanship costs and craftsman availability?
(3) What are the manufacturer's suggested fabrication and installation methods?
(4) Will there be a need for test applications or prototyping?
(5) What is the typical roll, sheet, tile sizes for the material and expected wastage?

WARRANTIES ● The designer should consider the express and implied warranties associated with the materials and products being considered. *Warranties should be thought in relation to the expected **term of use***. For a pop-up retail that will be torn down after 12 months, using a product with a 10-year warranty may not be well justified. It is important to understand the conditions and guidelines that make up the warranty, including the conditions that void the warranty.

> *Longer warranties often indicate the manufacturer's confidence in a product, but the **initial cost** of the product will be naturally higher.*

Tab.12/13 Questions regarding warranties.

(1) What are the manufacturer's warranty conditions and guidelines?
(2) Are the warranty conditions and period overlap with intended use?
(3) How stringent are the listed conditions that void the warranty?

BUDGET/ACQUISITION CONCERNS

BUDGET AVAILABILITY ● It is always a good idea for the designer to know the budget they will be working with and assess what they can and cannot afford. *Failing to be conscious about the budget might result in **over-promising and under-delivering***. The designer should consider if they are aiming for visual impact or longevity of use.

Usually there's a more budget-friendly material alternative available, but one needs to consider that the cheaper alternative might not last as long, or it may contain more defects on average, or lack comprehensive warranties, or be less workable overall. *There's also the possibility of receiving* ***discounts****, which might affect what can ultimately be done with the budget*.

The designer should consider that elaborate designs with intricate details will end up inflating workmanship costs, might require higher quality materials, and in some cases drive up wastage as well. Such intricate and expensive ideas should be reserved for higher-priority spaces that are expected to receive heavy foot traffic and act as a showcase. Straightforward designs realized with commonly used materials can cut costs significantly. Lower priority spaces with minimal foot traffic such as storage or printer rooms can feature relatively lower quality materials to balance the budget.

Tab.12/14 Questions regarding budget availability.

(1) Are there any discounts available for the intended materials or alternatives?
(2) Will the overall impact of the implementation justify the associated costs?
(3) Can the design details be simplified and streamlined to control costs?
(4) What are the costs in the long run, regarding maintenance and replacement?

STOCKS AND ACQUISITION ● Besides the limitations posed by the budget, *the designer should also pay close attention to* ***stock availability, lead times, delivery times****, and the possibility of backorders.* Transportation and handling will add to the unit costs; for some materials and for some products this cost difference can be considerable. If the order is custom made, there's a possibility of delivery dates being pushed for weeks. Lastly, there's always a possibility of a product being discontinued. Even though most of the time alternatives are available, availability and delivery times still need to be considered for the alternatives as well. It may be important to order extra materials for future repairs and replacements, as products may discontinue or future orders might fail to match the calibration code or dye lot. This extra order of materials is sometimes referred to as the "attic stock".

Tab.12/15 Questions regarding stocks and acquisition.

(1) Is the material in stock and immediately available upon order?
(2) What are the associated shipping, transportation, and moving costs?
(3) What is the expected delivery time and are there any contingencies?
(4) If the material is rare or custom-made, what is the expected lead time?
(5) For a non-US manufacturer, is there a distributor or is importing possible?
(6) If the material acquisition is problematic, what are the alternatives?
(7) Should extra materials be ordered for future repairs and replacements?

Fig.12/12 Frequently ordered producs are often kept in stock and can be delivered relatively quickly.

HEALTH AND SAFETY CONCERNS

CODE COMPLIANCE ● It is important to know *if the designed space is **heavily or lightly regulated** and if there will be risky activities performed or hazardous materials to be present*, This is important to know from the get-go, to balance the budget and learn about material availability for some applications.

It is imperative to check the code requirements for the occupancy type(s) associated with the designed space (see IBC Chapter 3) as they dictate what standards need to be met (see IBC Chapter 8). For instance, a machined MDF panel application on a fire exit access corridor in a non-sprinklered multi-story restaurant (Occupancy Type A-2), needs to be rated ASTM E84, Class A. However, a typical MDF board is Class C. Class A boards are not only more expensive, they are also not immediately available. Therefore, planning early on for the code requirements can save costs and time.

> *It is always very useful to discuss critical codes with the **local building department** to understand how they will be interpreted.*

Tab.12/16 Questions regarding code compliance.

(1) Is the space lightly regulated (low risk) or heavily regulated (high risk)?
(2) What is the code requirement for the determined occupancy type(s)?
(3) When in doubt, has the local building department been contacted for clarification?

RED LIST CHEMICALS ● *The designer should know about **harmful chemicals** potentially found in materials.* The Living Futures Red List is a great source to learn about these chemicals, though there are other sources such as the Transparency Database by Perkins + Will. Some of these chemicals are deemed safe by the EPA when the exposure is limited, such as BPA and Formaldehyde. However, it may be a better practice to refrain from specifying materials containing these chemicals, especially when sensitive user groups are involved such as developing children and pregnant women.

> *Link 12/02 Visit the Living Future Red List database.*

Tab.12/17 Question regarding Red List chemicals

(1) Does any chemical component of the material included in the Living Future Red List?

EXISTING CONTAMINANTS ● *It is highly likely that buildings that were built **before the 1980s** contain harmful contaminants such as lead and asbestos.* Consequently, any project to be conducted in such buildings demands careful planning. Materials requiring the substrate to be demolished, replaced, scraped, or sanded may cause unwanted chemicals to resurface and be released to the environment in the form of invisible particles.

If the building is built before 1978, there's a chance that lead paint and plumbing components might be present. If the walls are expected to be demolished or at least scraped, it is important to get a lead removal professional involved. Similarly, for buildings built before 1986, there's a possibility of asbestos insulation materials and/or asbestos composite finishes being present. According to the current research, it is safe to leave asbestos sealed and undisturbed. However, as soon as a disruption is planned, it is important to get asbestos abatement professionals involved.

Tab.12/18 Questions regarding existing contaminants.

(1) Was the building to be remodeled constructed before the 1980s?
(2) Will any substrate be demolished, replaced, scraped, or sanded?

CONTACT SAFETY ● Certain user groups and activities require careful consideration when specifying materials. *If **infants or small children** are expected to be present in a space, the impact of harmful chemicals can be severe, and the designer should plan accordingly.* The US Consumer Product Safety Commission (CPSC) has published a broad range of guidelines on children's products.

*If **food contact** and preparation are expected on a surface, the material should be carefully specified.* For commercial food production, the designer should refer to industry regulations. For instance, Corian meets NSF/ANSI Standard 51 for food contact surfaces and safe to specify, but some alternative solid surfaces that may not meet the same standard and won't be suitable.

Tab.12/19 Questions regarding contact safety.

(1) Will there be developing children be present in the environment?
(2) Is frequent food contact expected with the specified surface?

VOC RELEASE ● *Even though the intensity may vary considerably, the designer should acknowledge that all materials **release VOCs**, whether directly or through utilized adhesives or sealers.* For most materials, it is often possible to find and specify alternatives that have lower VOC emissions that occur over a shorter period. Greenguard certification is a good reference for assessing VOC emissions. The designer should be careful that some materials can first absorb and then emit VOCs over a longer period than the original source. Drapery and upholstery often carry this particular risk, and it is better practice to introduce such materials to the space after an initial off-gassing period. Heat and humidity of the environment can also boost VOC emissions, and the designer should carefully consider the material's proximity to these elements.

*The ventilation conditions of the environment affect how well the VOC emissions can be tolerated; however, the designer should know that the **average occupant** does not ventilate as often as advised.*

Tab.12/20 Questions regarding VOC release.

(1) What is the expected VOC release intensity and fall-off over time?
(2) Is the schedule planned to accommodate an initial off-gassing period?
(3) Are there any absorptive materials expected to be present in the environment?
(4) Is the material in proximity to heat and moisture sources?
(5) Does the environment provide automated or easy-to-use ventilation?

Fig.12/13 Being in frequent contact with harmful chemicals significantly impair child development.

MOISTURE PRESENCE ● The designer should always consider that the presence of moisture and unprotected organic content create a risk for unwanted organisms to thrive. Therefore, *materials that might **absorb, retain, and transfer** moisture should be specified carefully, in relation to their environment.* The presence of moisture is not always obvious, it could be the water vapor produced during cooking, splashes of water when bathing, a leaking pipe behind a wall, or condensation through thermal bridges. The designer should pay attention to the moisture condition of the substrate, the amount of work needed to direct water away , curing requirements, corrosion or deterioration expectancy, etc. Below-grade applications should always assume moisture exposure and incorporate a moisture barrier.

Tab.12/21 Questions regarding moisture presence.

(1) Will there be excess moisture building up in the environment?
(2) Can the material absorb, retain, and transfer moisture?
(3) Can the material content be consumed as food by household pests?

ACCESSIBILITY GUIDELINES

ADA GUIDELINES ● *The designer should be aware of the various ADA **accessibility guidelines** that specifically apply to materials*, such as height difference between two flooring materials, transitions, slip resistance, pile depth, etc. Even though ADA guidelines outline the minimum, it is always possible to go beyond and exceed these requirements. For example, utilizing color and texture to enhance wayfinding for users with limited cognition or subduing reflected glare to accommodate people with declining visual acuity.

Tab.12/22 Question regarding ADA guidelines.

(1) Are ADA accessibility guidelines pertaining to materials met and exceeded?

UNIVERSAL DESIGN ● Universal design principles call for an awareness of the fact that *there are individuals with **widely varying abilities**, and a fully healthy person is never a good archetype to base design decisions on*. The designer should consider the impact of material specifications on a range of individuals, whether they are disabled or not. For example, forcing the elderly in a public building to walk and wait on granite flooring is hard on their joints, so a material that introduces some flexibility is justified. Furthermore, universal design often accomplishes higher comfort and enjoyment for all members of the society. It is very possible that this flexible flooring material will be comfortable for the fully healthy individual as well.

Tab.12/23 Questions regarding universal design.

(1) Are there any occupants with limited or different abilities expected to be present?
(2) Will there be elderly, or children present who can benefit from unique material properties?

ACOUSTICS CONCERNS

REVERBERATION ● *Acoustic properties of a room are important for the **comfort and wellbeing** of the user and should be considered in conjunction with the function and activities.* An excess of reflective surfaces within a high/deep volume would encourage the sound to travel farther before diminishing, reverberating for many seconds. Even though some amount of reverberance can be desirable in an environment like a chapel or a live concert hall, it is usually not desirable as the overlap of the reflected sound with the original source causes intelligibility problems. The designer should consider the size and shape of the room and envision how to balance reflective and absorptive materials to achieve a desirable acoustic environment.

Tab.12/24 Questions regarding reverberation.

(1) Is the shape of the room expected to intensify reverberation?
(2) What is the proportion of reflective surfaces to absorbent surfaces?
(3) Is there any expectation of live music to be performed in the space?

SPEECH INTELLIGIBILITY ● Most spaces will feature a speaker and a listener, and how clearly the sound is transmitted in between the two can be a significant concern. *The designer should first consider the distance at which the speech should be intelligible and employ **reflective as well as absorptive** materials to carefully direct* *the sound.* For example, in a large classroom, one would expect the sound to reach the back of the room but not reflect and come back. On the other hand, in an open office one might want to hear what their close-by team member is saying but wouldn't want the sound to travel far. In complicated cases such as conference halls or live music venues, it is highly beneficial to hire acoustics consultants.

Tab.12/25 Questions regarding speech intelligibility.

(1) Is the space open plan and is sound clarity at a distance a concern?
(2) Will there be a large audience to eb addressed from a distance?
(3) Is the acoustic quality of the environment vital, justifying a consultant?

SPEECH PRIVACY ● The designer should consider if there will be any private conversations occurring in the environment to be designed. *For some environments, where **confidential information** is exchanged such as examination rooms, meeting rooms, or bank booths, the conversation should only be intelligible to the people involved and should not be understood* by anyone else. The designer should consider utilizing absorption, blocking the path of the sound, minimizing flanking, and when needed, incorporating an ambient sound source for masking.

Tab.12/26 Question regarding speech privacy.

(1) Will the space feature an exchange of sensitive information?

SUSTAINABILITY CONCERNS

LIFE EXPECTANCY ● When specifying a material, *the designer should always consider the **expected useful life** of a material/product and the maintenance requirements to achieve the longest possible service.* The maintenance aspect is important because one might expect a wood countertop to last decades with good care. However, users can be neglectful or lack the knowledge and expertise for proper maintenance. For some cases, an extended life expectancy for the material is not justified. For instance, in spaces that are remodeled frequently, such as expo stands or retail displays. In these cases, recyclability and minimizing landfill contribution should be the goal.

Fig.12/14 Both speech intelligibility and privacy is an important concern in the modern office environment.

Tab.12/27 Questions regarding life expectancy.

(1) What is the expected useful life of the material under normal use?
(2) Will the material deteriorate quickly without strict maintenance?
(3) Is the material intended for temporary or permanent use?

RATINGS AND CERTIFICATIONS ● Most contemporary materials feature one or more of the many sustainability, health, and safety labels that are widely recognized. *The designer should be willing to learn what each label implies and use them as a **comparison tool** to make the best decision*. Another important concern related to material specifications is the sustainability certifications such as LEED, Living Building Challenge, and WELL Building Standards, all of which require a set number of credits to be earned or minimum criteria to be met. Materials often play an important part in achieving these certification goals.

Tab.12/28 Questions regarding ratings and certifications.

(1) Does the material feature any sustainability, health, and safety labels?
(2) Are the featured ratings and certifications recognized by the industry?
(3) Does the material contribute credits towards sustainability certification?

ENVIRONMENTAL IMPACT ● *The designer should consider the impact of how the material is* ***sourced, refined, and processed***. Some materials are rapidly renewable and do not deplete existing resources, whereas others cause deforestation, loss of habitat, and biodiversity. Some mining byproducts are bio-accumulative and can move up the food chain, whereas others can be filtered and reused within a closed-loop system. The designer should be careful when specifying materials that support destructive industry practices.

Tab.12/29 Questions regarding environmental impact.

(1) Is it possible to track how the material is sourced, refined, and processed?
(2) Is the source of the material rapidly renewable, or at least renewable?
(3) At any stage, does the material cause bio-accumulative residue output?
(4) Does the manufacturing of the material cause environmental destruction?

MANUFACTURER CONCERNS ● *The designer should always research and assess the manufacturer's* ***commitment to sustainability***. This ultimately reflects how much money, care, and attention has been invested in manufacturing a product in an environmentally friendly manner. Another issue is if the manufacturer provides humane working conditions or not. Some manufacturing processes can be especially toxic, even though the final product is not.

> *Continuing to specify products from manufacturers that employ unsustainable and unhealthy practices might* ***encourage others*** *to follow suit.*

Tab.12/30 Questions regarding manufacturer concerns.

(1) Does the manufacturer clearly express commitment to sustainability?
(2) Does the manufacturer provide humane working conditions?

TRANSPORTATION CONCERNS ● The designer should know that a material can be rapidly renewable and sourced with minimal embodied energy, however, *if it is being transported from the other side of the globe, it still generates a considerable* ***carbon footprint***. The designer should employ a holistic view and consider the overall impact rather than focusing on a single facet of sustainability at a time. Packaging is also a concern for some products. Manufacturers that employ fully recycled packaging practices generate much less landfill contribution compared to those that don't.

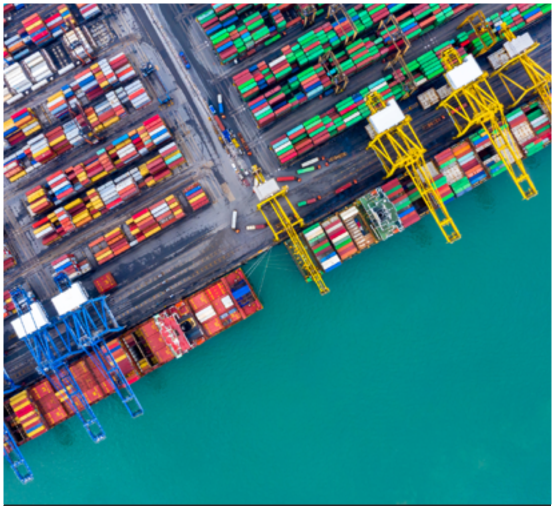

Fig.12/15 Transportation accounts for 21% of the global carbon emissions.

Tab.12/31 Questions regarding transportation concerns.

(1) Are there local alternatives for the material (within a 500-mile radius)?
(2) Does the manufacturer employ fully recyclable packaging?

END-OF-LIFE CONCERNS ● It is crucial for the designer to think about what is going to happen to a material/product when it concludes its useful life. Some materials can be refinished and reused, others can be repurposed, and others can be recycled at varying success rates. *The designer should try to specify materials that have **established and feasible** recycling practices in place.* For instance, inappropriately specified nylon carpet under heavy traffic would wear down quickly, and with no option to be repurposed and only partially recycled it will end up in a landfill.

Tab.12/32 Questions regarding end-of-life concerns.

(1) Can the material be reused or repurposed at the end of its useful life?
(2) Are there established and feasible recycling practices for the material?

MAINTENANCE CONCERNS

CLEANING CONCERNS ● The designer should consider if the cleanability features of the material are appropriate for the specified context. For instance, if mud tracking, spills, and staining is expected, a porous and absorbent material like cork would not be appropriate. Furthermore, *some **cleaning practices** are highly abrasive and rely on the use of heavy-duty chemicals,* such as those utilized in healthcare. These cleaners might corrode or disintegrate some materials.

As a rule of thumb, complex/organic/randomized patterns tend to hide soiling and wear better than solid flat colors/geometric patterns. This is especially useful when heavy traffic loads

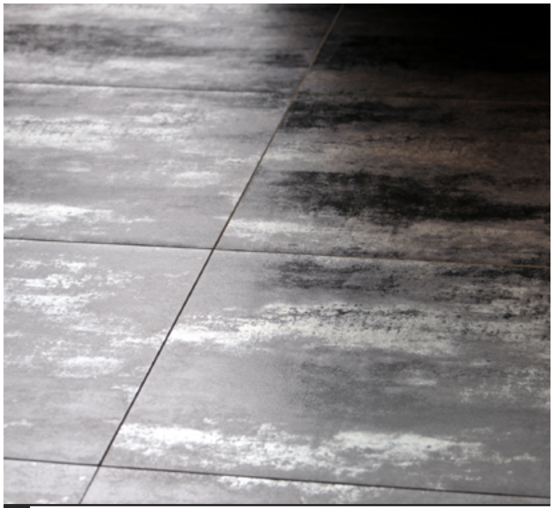

Fig.12/16 A complex organic texture can help in hiding dirt and wear.

are expected. Additionally, carpets with dense piles and fuzzy appearance help hide soiling and track marks.

Tab.12/33 Questions regarding cleaning concerns.

(1)Is the material compatible with common green cleaning strategies?
(2) Does the expectation of spills, dirt tracking, and staining justify high cleanability?
(3) Will the material undergo heavy cleaning with highly abrasive cleaning chemicals?

MAINTENANCE CONCERNS ● Some materials require very specific care and periodic maintenance over their lifetime, in order to sustain their look and performance. For instance, silk is famously hard to care for, on the other hand, cotton can take significant neglect and abuse. The same is true for hardwood flooring vs. porcelain flooring.

> *The **average user** is not very capable of maintaining materials, and professional attention can be costly and should be a factor when deciding material specifications.*

Tab.12/34 Questions regarding maintenance concerns.

(1) Can the client afford the time and money required to maintain the material?
(2) Will there be a need to store additional materials (attic stock) for future repairs?

EASE OF REPLACEMENT ● Some parts or sections of an application can abrade under load or break quicker than other parts, requiring replacement. *If it is possible to easily remove and **replace worn sections** with little effort and visual inconsistency, it can save the cost of replacing the entire surface.* For instance, solid surfaces can be spot patched and buffed repeatedly, and gain a new look without limitations posed by unit size or color calibration. On the other hand, patching a laminate is countertop is not possible, at least in a reliable and desirable manner. It is also important to consider that in some cases, replacement or disassembly might be necessary and design details should also be developed accordingly, without compromising the integrity of the application. For example, the peelability and strippability properties of wallcoverings can determine how much damage the substrate will sustain during removal.

Tab.12/35 Questions regarding ease of replacement.

(1) Can the design benefit from modular units and installation?
(2) Can the worn parts or sections be repaired, patched, and buffed repeatedly?
(3) Can the material be removed without damage to the substrate or assembly?
(4) Can the materials be disassembled and repurposed for another project?

SELECTED BIBLIOGRAPHY

Allison, Diana. *Estimating and Costing for Interior Designers: A Step-by-Step Workbook*, Fairchild Books, 2014.

Ashby, Mike. *Materials and the Environment: Eco-informed Material Choice*, 3rd Ed. Butterworth-Heinemann, 2021.

Ballast, David Kent. *NCDIQ Reference Manual*, 6th Ed. PPI a Kaplan Company, 2013.

Ballast, David Kent. *Interior Construction & Detailing for Designers & Architects*, 6th Ed. PPI a Kaplan Company, 2019.

Bell, Victoria Ballard. *Materials for Design*. Princeton Architectural Press, 2006.

Bingelli, Corky. *Materials for Interior Environments*, 2nd Ed. Wiley, 2013.

Borden, Gail Peter and Michael Meredith. *Matter: Material Processes in Architectural Production*. Routledge, 2012.

Brownell, Blaine. *Transmaterial: A Catalog of Materials That Redefine our Physical Environ-*

ment. Princeton Architectural Press, 2006.

Brownell, Blaine. *Transmaterial Next: A Catalog of Materials That Redefine our Future*. Princeton Architectural Press, 2006.

Dent, Andrew H. and Leslie Sher. *Material Innovation: Product Design*. Thames & Hudson, 2014.

Dent, Andrew H. and Leslie Sher. *Material Innovation: Architecture*. Thames & Hudson, 2014.

Ermann, Michael. *Architectural Acoustics Illustrated*. Wiley, 2015.

Gibbs, Nick. *The Real Wood Bible: The Complete Illustrated Guide to Choosing and Using 100 Decorative Woods*. Firefly Books, 2012.

Godsey, Lisa. *Interior Design Materials and Specifications*, 3rd Ed. Fairchild Books, 2017.

International Code Council. *International Building Code 2018*. International Code Council, 2018.

Kennon, Katherine E. and Sharon K. Harmon. *The Codes Guidebook for Interiors*, 7th Ed. Wiley, 2018.

King, Bruce. *The New Carbon Architecture: Building to Cool the Climate*. New Society Publishers, 2017.

Kolarevic, Branko and Kevin Klinger. *Manufacturing Material Effects: Rethinking Design and Making in Architecture*. Routledge, 2008.

Lefteri, Chris. *Plastic Materials for Inspirational Design*. RotoVision SA, 2001.

Leppo, Holly Williams. *LEED PREP: What You Really Need to Know to Pass the LEED AP Interior Design & Construction Exam*. Professional Publications, Inc., 2009.

Lupton, Ellen. *Skin: Surface, Substance, and Design*. Princeton Architectural Press, 2002.

Postell, Jim and Nancy Gesimondo. *Materiality and Interior Construction*, Wiley, 2011.

Reed, Ron. *Color + Design: Transforming Interior Space*, 2nd Ed. Fairchild Books, 2017.

Reznikoff, S. C. *Interior Graphic and Design Standards*. Watson-Guptill, 1986.

Riggs, Rosemary J. *Materials and Components of Interior Design*, 3rd Ed. Prentice Hall, 1992.

Smith, Ronald C. *Materials of Construction*, 4th Ed. McGraw-Hill, 1988.

Thallon, Rob. *Graphic Guide to Interior Details for Builders and Designers*. The Taunton Press, 1996.

Thompson, Rob and Martin Thompson. *The Materials Sourcebook for Design Professionals*. Thames & Hudson, 2017.

Thompson, Rob. *Manufacturing Processes for Design Professionals*. Thames & Hudson, 2007.

Tucker, Lisa M. *Designing Sustainable Residential and Commercial Interiors: Applying Concepts and Practices*. Fairchild Books, 2014.

Tucker, Lisa M. *International Building Codes and Guidelines for Interior Design*. Fairchild Books, 2018.

Wiewiorra, Carsten. *Materials and Finishings: Construction and Design Manual*. DOM Publishers, 2020.

Winchip, Susan M. *Sustainable Design for Interior Environments*, 2nd Ed. Fairchild Books, 2011.

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