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 flattened 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-
**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 recyclability also means that scrap and used pieces have **considerable value**, something the designer should consider when planning a demolition.

**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.

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.

Video on the intricacies of various metal alloys.

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

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*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.*

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**PROCESSING METALS**

Metalworking processes are divided into the following categories: 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 pushing metal through a shaped opening 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** is pouring molten metal into sand or ceramic 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 make the metal more workable by restoring ductility and malleability. 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** is the rapid cooling of a workpiece in water, oil, or air to obtain increased hardness and stiffness. **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.](image)
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.

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
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 800°F), 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 800°F), 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.
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** is a process that uses an electric current to coat a metal 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.
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. If the entirety of the earth is considered, iron is earth’s most common element; 80% percent of the earth’s core is iron. During ancient ages meteoric iron containing nickel was found from time to time; a material very strong but also very rare and highly valued. There are examples of Egyptian beads made from this material dating back to 3500 BCE. 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 0.08% 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 very 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.
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, erected in 1890, 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 11% chromium which produces a self-healing corrosion-resistant chromium-oxide film. 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 completely corrosion resistant, “almost”. 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 only 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 one 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 the basic building blocks of steel frame construction. Common types of structural steel such as wide flange, I-beams, and structural channels, are manufacture via hot working techniques such as rolling, extrusion, forging, etc. Steel is easier and 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 element, usually five or more triangular units connected through nodes, with the intention of balancing horizontal and vertical loads. 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. Sheet steels can be compressed into molds under very heavy pressures to manufacture stainless steel sinks.

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. Perforated panels are sheets of metal that have been manually or mechanically stamped or punched to create a pattern of holes, slots, or decorative shapes. 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. Thin sheets of galvanized steel can be cold-formed into steel studs for use as structural or non-structural building components. Corrugated metal decking is one such material; it is profiled to increase resistance 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.

Even though the melting temperature of steel is 2600 to 2800°F, the material loses its stiffness and strength way before melting. Prolonged exposure to temperatures above 1000°F 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.

**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.

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

**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. For example, copper pendants were found in northern Iraq, dating back to 8700 BCE. Egyptians succeeded in the first intentional manufacture of bronze by adding tin to copper, in around 3150 BCE.

**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. For recycling, only 5% of the energy required to produce virgin material is used, 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 has high strength-to-weight, is highly ductile and malleable, easy to machine, and 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, magnesium, manganese, 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 and door frames, railings, hardware, and even...
flooring. Sheet aluminum can be **folded** to attain structural strength and stability without increasing the 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 are lightweight but sturdy construction materials, a low-density core is sandwiched in between two thin sheets of aluminum. Aluminum honeycomb panels can be used as the core in sandwich panels to achieve extremely high strength-to-weight, a technique commonly utilized in the aerospace industry. Aluminum is completely impervious to light, gases, oils and fats, volatile compounds, and water vapor, chemically inert, and non-toxic with a modest price point, making it highly suitable for food packaging.

**Copper** is a soft, malleable, 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 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

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

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

*Fig.10/22* Constant visitor contact prevented the development of patina, revealing the true color of bronze.
number of bronze statues. Unlike the pinkish color of bronze, **brass** has a color and luster resembling gold. The hardness and softness of brass depend on the ratio of zinc; the addition of aluminum increases strength. **Mining wastes** of copper may contain substantial amounts of arsenic, lead, and other dangerous chemicals. Copper and its alloys have non-toxic and antimicrobial properties, highly suitable for healthcare applications. Bronze has many uses in interior spaces, mainly utilized for decorative purposes on components such as fixtures, doors, hardware, faucets, railings. 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, corrosion and tarnish resistance as well as 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 steel-gray, lustrous, hard metal that can take high polish, and resist abrasion. When exposed, chromium quickly forms a thin protective oxide layer. 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 as a chemical in the leather tanning process. Besides steel, other metals such as aluminum, copper, zinc, magnesium, and titanium can all be chrome...
Embossed tin ceiling tiles can retain intricate detail and introduce a unique sheen.

Nickel-chrome plating is produced by first electroplating an object with a thin layer of nickel and then a layer of chrome. **Nickel** is a hard, silvery-white metal that is malleable and ductile. It polishes well and does not tarnish.

**Tin** is lustrous and bluish-white, can take a high polish, and can be alloyed with or plated to other metals to provide various desirable properties. Tin has been used in decorative elements such as ceiling, wainscoting, cabinetry panels, etc.

**Titanium** is as strong as steel but less dense, 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 variety of brilliant 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** is an originally bluish-white metallic element, through weathering it gains a dark gray, 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 is the application of a protective zinc coating to iron or steel to prevent corrosion. The coating is distinguishable by the visible spangles or flakes on the surface. 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.