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 as Plexiglas for acrylic, Teflon for polytetrafluoroethylene, Cellophane for cellulose-acetate, Fiberglas for glass fiber reinforced polymer (GFRP), and Nylon for polyamide.
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, consequently, how products and spaces were designed. Celluloid was the first synthesized thermoplastic, patented in 1859. It was hard yet flexible, transparent, moldable when heated, and retained shape when cold; offered great versatility, surpassing all-natural alternatives. Rayon was first developed from cellulose to imitate silk fiber, in 1891. Bakelite was the first entirely synthetic material invented in 1907. It was resistant to heat, acids, and electric current. By 1976, plastics were the most used type of material in the world and today there’s a plastic component in almost every product and space.

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.

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. Epoxy and plastic dust are among many identified 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 **8-10 percent is recycled** and almost the same amount is incinerated for energy. 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 CO₂ and some toxic gases and it may be doing as much harm as it is creating benefit.

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-
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 higher impact strength, 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 plant sources such as maize, sugar cane, potato starch. The more popular and relatively feasible examples include Cellulose Acetate, Starch Plastic, and Polylactic Acid.
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, the raw material input incentivizes extensive farming 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 Kuramata 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.

**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 googles, break-resistant...
glass, 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 polyethy-
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, 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.
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
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 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
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.

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-monoy. 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,
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-
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,
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.

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
The transparency of melamine-formaldehyde resin enables a vivid representation of pigments.

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.

Fig.11/22 The transparency of melamine-formaldehyde resin enables vivid colors and accurate rendering of decorative layers.

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 put over a mold, then by vacuuming out the air, the plastic piece is forced to tightly cover 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 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.

**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
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, expanding it to the shape of the mold; bottles and containers with consistent thin walls or multiple layers are 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.
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 reinforced
A composite material constitutes multiple materials that enhance each other's performance.

Sandwich panels typically feature a core layer sandwiched between protective sheets.

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 consists of fine glass fibers woven into a cloth then bonded together with a plastic or resin. Composites can even occur naturally. Wood is a polymer composite, within which the long fibers of cellulose are held together 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 weight. In bioplastic composites, fibers can be added to counter the lack of structural strength. Unlike alloys, the physical and chemical properties of each constituent of the composite material remain distinct in the new material. 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.

Composite materials have two significant shortcomings. First is the long and costly research
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 functionaity, 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, many times over.

Solid surfaces are available in $\frac{1}{4}”$ thickness for vertical applications, $\frac{1}{2}”$ and $\frac{3}{4}”$ 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
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-
Plastic laminate edges and seams are prone to heat and moisture damage.

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.