INTERIOR MATERIALITY

kutay guler

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Kansas State University

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PREFACE

The knowledge of materials and finishes is the bridge that links conceptual design to real-world application. It is among the core content of virtually all interior architecture/design curricula, moreover, access to up-to-date information on emerging technologies and trends is a key exigency for the contemporary designer. Accordingly, this book is authored to form a comprehensive resource for the "hows" and "whys" surrounding the functional and aesthetic contributions of a wide selection of materials and finishes used in multiple spatial design contexts. The knowledge base presented here is not only useful in shaping spatial experience, ensuring occupant well-being, and employing sustainable thinking but also beneficial in managing budget and schedule while enabling the delivery of top-quality work.

The book investigates fundamental material properties, performance criteria, as well as sector-specific standards, regulations, and guidelines, with a special focus on concerns surrounding occupant health and safety as well

as environmental impact and sustainability concerns. Furthermore, fabrication, installation, and maintenance issues were explored in detail. Various information collection and organization conventions are also discussed with regard to detailing, specification, estimation, and documentation of materials and finishes.

The goals of the book can be listed as follows:

- Developing a vocabulary and knowledge base to comprehend and communicate concepts and paradigms associated with the history, classification, manufacturing, evaluation, fabrication, installation, and maintenance of materials and finishes.
- Identifying a broad range of materials and finishes, considering their aesthetic and performance properties, and understanding their utilization with regard to creative design intent, client expectations and requirements, user needs and experience, and incorporating life cycle implications.
- Providing a basis for achieving physical and psychological well-being for occupants, understanding the impact of changing social, cultural, economic, and ecological context, and eliminating negative environmental and social outcomes.

The book is structured around building a solid foundation first, and subsequently, exploring each material category separately. The first four chapters are dedicated to the comprehension of fundamental vocabulary, material perception, health and safety considerations, accessible design, and sustainable thinking. Each subsequent chapter is dedicated to a specific category of material: paint and wallcovering, concrete and masonry, wood, glass and porcelain, textile, metal, and plastic. The last chapter is dedicated to the specification of materials and the responsibilities of the designer in the process. The chapter also emphasizes the importance of cost estimation and provides a step-by-step guide. Finally, a large selection of material specification criteria is outlined in detail with examples, to help the designer identify the best possible materials for their project.

Tab.00/01 Detailed content of and related CIDA 2020 accreditation criteria for each chapter.

Chapter	Content	Accreditation
01	**INTRODUCTION** | Definition of material and materiality; relevance of material knowledge; a brief history of materiality; performance properties; surface attributes; foundational terminology; weathering and aging.	*CIDA 10b, 10e, 13a,*
	PERCEPTION | Perception of materiality; understanding design trends; historical, cultural, and design context; concept driven material specification; visual elements and principles; balance, dynamism, and composition; non-visual senses.	*CIDA 4a, 4b, 6c, 12a, 12i, 13a, 15d*
03	**HEALTH & SAFETY** | Building codes and standards; fire safety; the Americans with Disabilities Act; ADA accessibility guidelines; universal design principles; indoor air quality (IAQ); harmful chemicals; room acoustics and reverberation; sound transmission and flanking.	*CIDA 4b, 13c, 14a, 14b, 14c, 14f, 14h, 14i, 16c*
	SUSTAINABILITY | Sustainable thinking and design; carbon footprint; embodied energy and recycling; life cycle assessment (LCA); green building certification; eco-labels; green cleaning practices.	*CIDA 4a, 4b, 13c, 16b*
05	**PAINT & WALLCOVERING** | Typical paint components; paint history and types; gypsum and plaster; paint application and disposal; wallcovering history and types; wallcovering application.	*CIDA 13a, 13b, 13c, 14h, 14i, 15d, 16c*
	CONCRETE & MASONRY | Vocabulary for concrete; concrete types and application; terrazzo and installation; brick types and installation; vocabulary for natural stone; quarrying and environmental impact; stone types and finishes; stone installation and maintenance.	*CIDA 13a, 13b, 13c, 15d, 16c*
07	**WOOD** | Vocabulary for wood products; forest management; performance properties and behavior; prominent wood species; processing and finishing; wood veneers; engineered woods.	*CIDA 13a, 13b, 13c, 14h, 14i, 15d, 16c*
	GLASS & CERAMIC | Glass - history and vocabulary, light transmission, environmental impact and recycling, specification and fabrication. Ceramics and porcelain - manufacturing process, environmental impact, ceramic types and properties, specification and installation.	*CIDA 13a, 13b, 13c, 15d, 16c*
09	**TEXTILE** | Textile vocabulary; environmental impact of textiles; fiber types and yarn construction; natural and synthetic fibers; textile manufacturing and performance; leather; carpet construction and types; carpet installation; upholstery and soft goods.	*CIDA 13a, 13b, 13c, 14h, 14i, 15d, 16c*
	METAL | Core terminology for metals; metal alloys; corrosion, weathering, and patina; processing metals; finishing metals; ferrous metals; non-ferrous metals.	*CIDA 13a, 13b, 13c, 15d, 16c*
11	**PLASTIC** | Polymers and plastics; synthesis and key additives; environmental impact of plastics; resin identification code and recycling; common thermoplastics and thermosets; plastic manufacturing methods; composites; polymer products specific to interiors.	*CIDA 13a, 13b, 13c, 14h, 14i, 15d, 16c*
	SPECIFICATION | The business and key professionals; common specification types; standardized specification content; project cost estimation; conducting field survey; criteria for successful specification.	*CIDA 5a, 6a, 6c, 6d, 13a, 13b, 13c, 16c*

**Criteria 13d and 13e are omitted above as they require a student application example.*

01 INTRODUCTION

- *Definition of material and materiality*
- *Relevance of material knowledge*
- *A brief history of materiality*
- *Performance properties*
- *Surface attributes*
- *Foundational terminology*
- *Weathering and aging*

*The word **material** refers to a substance that can be manipulated through industrial processes and procedures, into components, finishes, products, or structures to realize design intent.* Whether a doorknob, or a flooring tile, or a movable room divider, every part of the interior space is manufactured involving at least one material, but more commonly a combination of several materials working together in a way that best utilizes their performance and aesthetic qualities.

The important question is "why is it crucial to learn about materials?" The design process typically involves developing an initial conceptual idea to an extent that it is ready to be fabricated, manufactured, or built as a useful real-world entity. *This **"realization"** of the design intent requires a knowledge of how various materials are manufactured, processed, combined, and finished.* The designer's career depends on their ability to understand and evaluate materials' aesthetic and performance parameters,

Fig.01/01 Materials and finishes, by working in conjunction, determine the overall impact of the interior space.

while maintaining an ethical, exploratory, and creative outlook. This is true even when working on purely conceptual designs; as soon as the intent needs to be realized, for instance an artistic vision as a conceptual art piece to be exhibited, the designer is required to tap into their knowledge of materials. Among many successful contemporary artists Anish Kapoor has worked with top materials scientists and engineers to realize his art, Richard Serra developed a deep understanding of the materials that he utilized as a medium of expression, or Carl Andre dedicated his art to exploring and understanding what various materials were about.

*In summary an ability to creatively and successfully **realize design intent** depends on an extensive knowledge of materials.*

Materials can be categorized in various ways. A categorization system that is highly relevant for interior architects and designers is the ***MasterFormat®***, the specifications writing standard for most large-scale design and construction projects in North America. Developed and published by the Construction Specifications Institute (CSI), *MasterFormat® is organized around categorizing*

the construction requirements, products, and activities related to various materials, products, components, and systems.

Within the context of interior architecture and design, one can simply classify materials as they relate to floors, walls, ceilings, and millwork/casework. This is especially useful when trying to specify materials for interior surfaces, every relevant option is categorized together and alternatives can be compared relatively quickly. The downside for this categorization approach is the repetition of each class of materials for each particular interior component.

*A more **traditional** and straightforward categorization of materials would be metals, ceramics, minerals, polymers, composites, plant-based, and animal-based materials.* This book is structured around this particular categorization logic. However, some categories such as paint and wallcovering, concrete and natural stone, wood, and textiles are separated for clarity and convenience, even though each of these added categories can fit in one or more of the mentioned traditional categories. For example, wood is in fact a polymer composite.

Litracon© - Light-transmitting concrete | www.litracon.hu

Fig.01/02 The translucent Litracon® is utilizing the same fundamental principle as mud brick.

A BRIEF HISTORY OF MATERIALITY

Soon as a stone fragment was chipped by a human to form a sharp edge, materiality became relevant. So relevant that there are whole periods in history named based on the impact of certain materials on how historical events unveiled and how people sustained their day-to-day activities. Humanity lived through the stone, copper, bronze, and iron ages; and, maybe in the future the contemporary times will be referred to as the semiconductor or nanomaterial age.

Every material has an association within the collective memory of a society. ***Zeitgeist** is a popular term that is often translated as the ghost/spirit of the time/era, which implies that meaning and significance of any notion, including the creative use of materials and manufacturing methods, is a product of their time and they will be engrained in culture accordingly.*

> *The knowledge of the **semantic associations** of when, why, and in what context a material and manufacturing technology became popular can be utilized to construct meaning and atmosphere, create a sense of place and time, and evoke an emotional response.*

For instance, mahogany wall paneling might evoke a feeling of Victorian sophistication, or a glossy, bright and colorful vinyl fabric can be used to set a futuristic atmosphere, or polished white marble can reference neo-classic ideals.

HUMBLE BEGGINNINGS ● Even though there are much earlier examples of straw huts and cave paintings created with prepared pigments, if the manufacturing of an actual building product is considered, it can be said that the humble beginnings of materiality coincide with sun-dried bricks around 7000 BCE in Mesopotamia. With the integration of plant fibers into a mud mixture,

Fig.01/03 A view from the Ishtar Gate reconstruction situated in Pergamon Museum, Berlin.

early bricks became the first composites. In 2006 Litracon®, a translucent concrete building material permitted the passage of light through concrete via latitudinally integrated glass fibers. It presented an impressive marriage of ancient and contemporary materials and techniques to create unexpected effects in a highly traditional material.

GLAZED TILES ● Throughout the globe from Africa to North America, pottery is chief among the most common archaeological findings, along with tools and fossils. Pottery is simply formed and fired clay. The firing process helps the material withstand decay over time, early archaeological evidence dating almost 10,000 years back.

Vid.01/01 Video on making bricks with primitive technology.

Glazing, the fused glassy coating on fired clay products, came much later. The Ishtar Gate, built around 575 BCE features one of the first uses of glazed tiles. Kiln-dried bricks were applied with a coating and through exposure to intense heat, various vivid colors, as well as protection, was achieved. This ended up being the precursor of the modern ceramic tile.

OPUS CAEMENTICIUM ● Concrete is part of virtually every contemporary construction, whether it is used to set a foundation or to create a tube structure for a high-rise building, board-formed for decorative finishing interiors or poured over to create a durable substrate. Ancient Romans were the first to successfully implement concrete on an industrial scale. Cement, a heated and ground limestone and clay mixture, enabled Romans to develop concrete and build the 142 feet wide dome of Pantheon in 126 CE. After the fall of the Roman Empire, the technology was almost lost until the end of the 18th century.

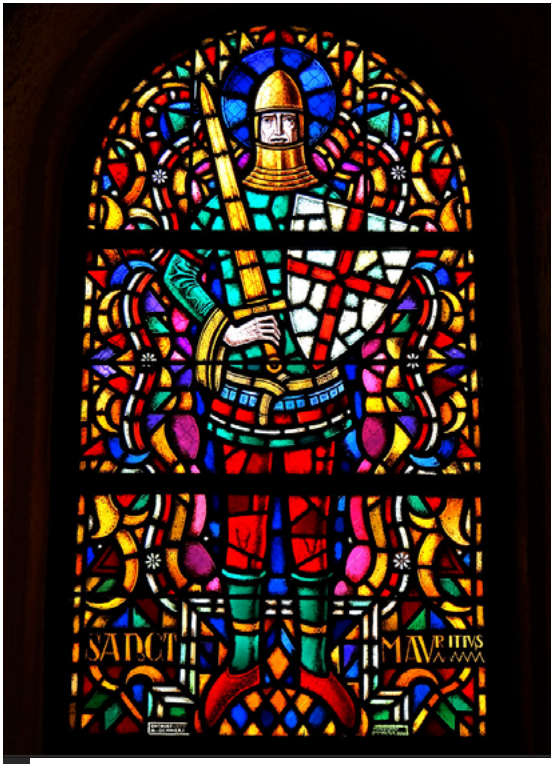

Fig.01/04 Stained glass windows often depicted religious stories or figures in vivid colors.

LETTING LIGHT IN ● Glassmaking requires very high temperatures, mainly to melt and purify silica, the major raw constituent of glass. Humankind did not achieve the required technology until medieval times. The naturally occurring volcanic glass, which is known as obsidian, or glass formed after a meteoric impact such as Moldavite were the first glass materials to be used since Stone Age. Around the 12th century, the Romanesque stained glass expressing religious themes, became a precursor to the large stained glass windows that were later associated with Gothic cathedrals. Glass became part of the architectural language with the mass manufacture of broad sheet glass in 1226, in Sussex, UK. Today, manufacturing became so reliable and feasible that whole skyscrapers can be enveloped with glass.

AUTOMATION REPLACING JOBS ● The industrial revolution enabled the manufacture and widespread use of some known materials in extraordinary quantities, chiefly among them, iron and later steel, replacing the traditional wood, brick, and stone. Entire buildings were made from iron, one of the most famous being the Eiffel Tower, still standing in Paris, France. As the Industrial Revolution ensued, textile manufacturing technology also advanced. In 1784 Edmund Cartwright invented the power loom, mechanizing textile production, enabling cheap access to a variety of textile products, but also impacting a whole branch of skilled labor by automating a process ultimately catalyzing civil unrest and social change.

NATURAL VS. SYNTHESIZED ● Rubber as a naturally occurring polymer has been known since 1300 BCE, however, following the industrial revolution, new venues of use for this flexible and resilient material were discovered, such as transmission belts and pneumatic tires, which

Fig.01/05 Latex being extracted from a rubber tree.

Fig.01/06 Bakelite considerably shaped product design of the early 20th century.

Fig.01/07 The curves and flowing lines of the Thonet chair is achieved by steam bending wood.

skyrocketed demand. Rubber plantations in various regions with tropical climates became widespread around the late 19th century. In addition to intense deforestation, some of the plantations, such as those in Congo, were associated with deep human drama. Starting from the 1910s until the 1940s synthesized rubber was perfected to become a feasible alternative, not completely replacing but greatly reducing dependency on natural rubber.

BETTER LIVING THROUGH CHEMISTRY ● The first example of synthesized polymers started appearing as early as the 1830s. Like many other early polymers, formaldehyde was discovered in 1859, while attempting to synthesize something else. The commercial production of formaldehyde took off towards the end of the 19th century. Phenol-formaldehyde resin became an important component for Bakelite manufacturing, the world's first totally synthetic thermosetting plastic, invented in 1907. Bakelite was advertised as a "material with a thousand uses", with only two colors available at first, brown and darker brown. In the 1930s melamine based on melamine-formaldehyde, became a replacement for Bakelite enabling vivid colors and a smooth finish. It is somewhat ironic that plastics replaced completely unsustainable and at times cruel rubber, ivory, silk, etc. manufacturing, however, today they became a sustainability problem due to overproduction and their persistence in nature.

MANIPULATING WOOD ● Even though it was possible to cut and carve wood into any desired shape, it was time-consuming manual labor and required skilled craftsmanship. The Thonet Chair introduced by Michael Thonet in 1859 utilized steam to bend wood pieces, achieving components with true curvilinearity. More importantly, it was possible to mass-produce these components. Millions of Thonet chairs were produced in the subsequent years. Similar bending and molding methods were successfully applied by many designers including Alvar Aalto, Eero Saarinen, and more famously by Charles and Ray Eames. Steam bent plywood is an important aspect of the Eames Chair and Ottoman, which is still a valued addition to high-end offices and living rooms today.

STEEL REPLACING STYLE ● The very durable Damascus steel was being manufactured a thousand years before the industrial revolution and used

for building swords and armor. However, it took a technological breakthrough to mass manufacture steel. The Bessemer Conversion, enabled its feasible production in industrial quantities. Cheap steel ended up transforming architecture by successfully replacing masonry and timber. With the advent of International Style, steel along with glass and concrete became an expression of material potential, replacing previous stylistic conventions, at least for a while. Furniture design was also being transformed by reliable and cheap steel. Wassily Chair (Model B3), designed by Marcel Breuer in 1926 employed steel tubing in furniture first time.

WEAVING CARBON ● In 1940, the development of the combination of polymer resin and glass fibers resulted in Glass Reinforced Plastic (GRP), a lightweight and high-performance material to be used in structural applications. The aeronautical industry pushed the development of different types of composites, including high-performance metals in the equation. Carbon-fiber, which is essentially a carbon lattice set in resin, is one of the most widely known composites, partly due to its unique look, outperforming many metal alloys in terms of stiffness and strength-to-weight. Even though it started out as a very expensive material, carbon fiber is much more affordable today due to the increasing demand over the years and refined manufacturing techniques.

Fig.01/08 Charles and Ray Eames deeply explored Glass Reinforced Plastic (GRP) in furniture design.

LIGHT EMITTING DEVICE ● In 1977, the discovery of electrically conductive organic polymers led to significant advancements in the field of electronics, including the development of light-emitting devices or LED – formerly known as light-emitting diode. These tiny light sources enabled surfaces and textiles to be lit and even to form screens, in a wide range of colors. Their high efficiency enabled large architectural surfaces as well as thin reveals to be illuminated, transforming the look of contemporary architecture. Recent examples of material integration include LED woven into a metal fabric, such as in GKD's MediaMesh®, or set in resin such as in Sensitile's Lumina®.

COMMITMENT TO SUSTAINABILITY ● From the 1950s to the end of the 20th century, the consumption of finite resources, pollution caused by manufacturing and transportation practices, the amassing of persistent waste in landfills, and the overall negative impact on the environment and diversity of life created a growing awareness that a prevalent sustainable mindset is needed. The first conference on "green goods" was held at the Hague, Netherlands in 1993; one of the first steps for a sustainable and green future. Today sustainable thinking is an integral part of the design process, and many leading manufacturers are committing to sustainable practices;

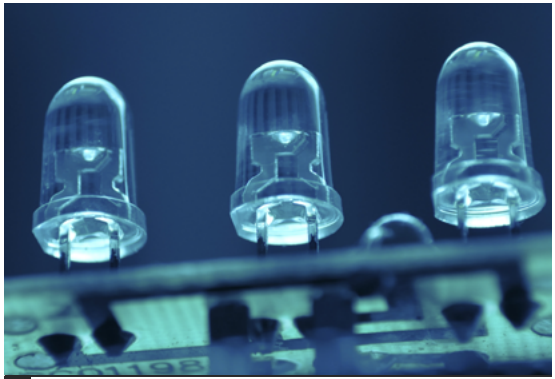

Fig.01/09 Today, Light Emitting Devices (LED) are a common source of artificial illumination.

which is ultimately transforming how materiality is understood and applied.

SMART AND RESPONSIVE ● Today, new materials are continuously being introduced featuring nano-technology, programmability, light-mapping, phase changing, etc. Designers have more options to explore and are given more capability to increase the quality of life, create unique experiences for users, and ensure sustainability. Many of these materials are in daily use; electrochromic glass can convert from transparent to translucent instantly with the flick of a switch, thermochromic coating on a mug can change appearance when heated by the hot liquid in it, or photochromic lenses develop a dark tint with exposure to UV light. Similar to composites, it is not hard to imagine that smart and responsive materials will be further enmeshed into daily life in the future.

Vid.01/02 Video on improving electro-chromic glass performance.

MATERIAL PERFORMANCE

Material performance refers to various physical and chemical properties that determine the behavior of a material under various conditions. Understanding performance parameters is key for specifying the best material for a particular surface, design detail, or finish. *The performance properties of materials are systematically investigated by the field of* ***Materials Science.*** A piece of metal feels cold to the touch due to its high thermal conductivity, or the injection molding success of a thermoplastic resin is determined by its melt flow index. Materials science employs an engineering mindset to solve manufacturing issues. On the other hand, an interior architect or designer is more involved with aesthetic implications, psychological impact, sustainability concerns, maintenance and life cycle costs, and end-of-life processes of materials. Therefore, a basic understanding of the foundational terminology and related performance parameters is important to make sense of materials, but more often than not, designers don't have to understand the exact physics and chemistry behind the parameters.

A material's performance, visual quality, and workability is determined by the specific arrangement of its ***molecular structure****.* For example, steel has a homogeneous distribution (isotropic) and wood has a heterogeneous distribution (orthotropic). Based on its molecular structure, a material can be hard/soft, elastic/stiff, porous/impervious, transparent/opaque, conductive/insulative, flammable/fire retardant etc. In general, a combination of multiple properties determine the performance of a material.

To assess the behavior of a material under stress, it is important to understand the various forces that can act on the material. Compression, tension, and shear are the most prominent three of such forces. ***Compression*** *refers to pushing onto or squeezing the material. On the other hand,* ***tension*** *refers to to pulling or stretching the material apart.* Lastly, ***shear*** *refers to applying opposite forces on the same body.*

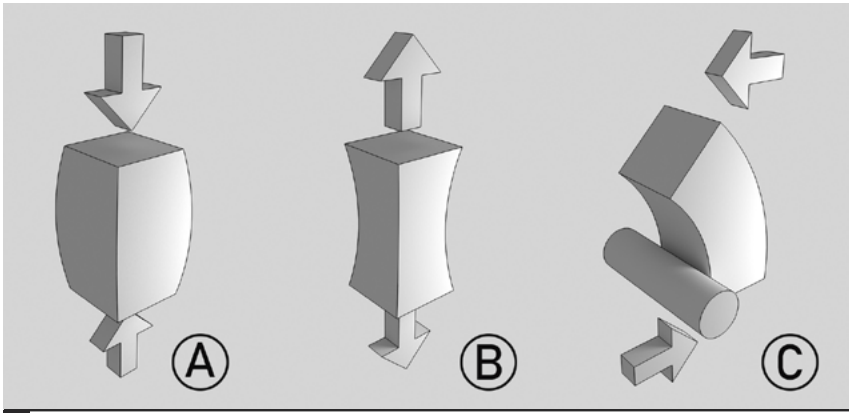

Fig.01/10 Compression (A), tension (B), and shear (C) forces acting on a simple object.

As opposed to isotropic materials such as steel, porcelain, or acrylic, the properties of a wood piece are not homogeneous in all directions, conversely, being an orthotropic material the mechanical properties are distinct and independent on each axis. Imagine a piece of wood with a prominent and fairly parallel grain structure; considering that wood is highly sensitive towards the directionality of the applied force, it can relatively easily split along the grain. Now, compression applied across the grain (tangential) might create failure, as opposed to compression applied along the grain (longitudinal). On the other hand, tension applied along the grain is tolerated much better than across the grain as it would split the material at the weakest grain. Some sources mention up to 20 times the difference in resistance. Lastly, shear strength will be higher against the grain than along the grain. Grain direction is one among many properties when considering the strength of wood, along with wood species, density, drying method, or the presence of knots. ***Ductility*** *is a material's ability to withstand tensile stress.* Ductal®, the ultra-high performance concrete (UHPC) manufactured by Knauf is one example used in demanding structural applications. Ductility also determines impact strength in materials, their ability to deflect instantaneous loads.

Vid.01/03 Video on the reasoning behind concrete reinforcement.

Materials can display improved performance when they are ***combined*** *to work together.* For instance, concrete is a material that performs well under compression but poorly under tension. In order to augment the performance of concrete, a material with high tensile strength is needed and steel possesses the necessary properties. Reinforced concrete is developed with this principle in mind, so as many other composite materials. Aside from acquiring a strength and stability benefit, the specific pH of the concrete wrapping the steel reinforcement keeps it from corroding. Together these materials achieve substantially better performance.

Density *is the ratio of a material's mass to its volume.* It should be noted that high density does not always mean high stability or durability. For instance, gold has very high density but it is so soft that pure gold can be bent and scratched with bare hands. Low-density materials are

Fig.01/11 Concrete mixture poured over rebar lattice.

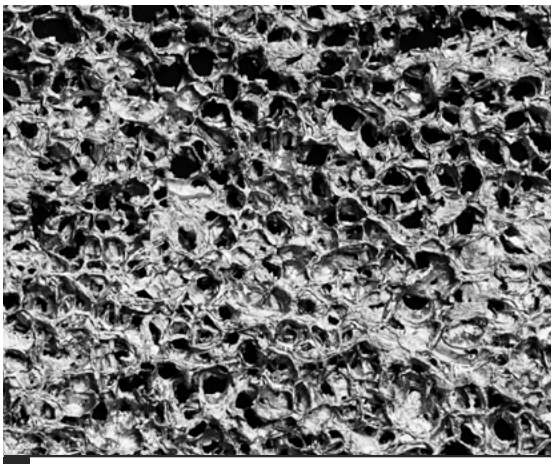

Fig.01/12 Foamed aluminum features tiny gas bubbles.

often ideal for thermal insulation; even some highly conductive metals such as aluminum can be highly insulative when foamed. ***R-value*** *indicates a material's capability for resisting the flow of heat.* ***Hardness*** *refers to the ability of the surface of a material to withstand scuffing, scraping, scratching, denting, and various other physical abuse.* Porcelain has a higher degree of hardness compared to common ceramic tiles which makes it appropriate for areas with high traffic. ***Stability*** *refers to the ability of a material to maintain its properties and structure in the face of environmental changes,* including but not limited to moisture, temperature, or UV exposure. Compared to medium density fiberboard (MDF), chipboard is far less stable as it will quickly deform and deteriorate when exposed to moisture. ***Durability*** *is similar to stability, but focuses on the longevity of resisting change.* As an example, introducing fly ash to a concrete mix will increase its durability as well as cold weather resistance, cracking problems, and permeability. ***Elasticity*** *refers to the ability of a material to completely recover from deformations produced by physical exertion after the load is removed.* Rubber is highly elastic and resists denting and deforming when heavy equipment is placed or dropped on it, making it a great choice for gym flooring.

Workability *refers to a material's tendency to resist being physically shaped and processed, being cut, folded, hammered, drilled, milled, welded, planed, sanded.* It is an important concern when specifying materials as it will impact workmanship costs and final product's success. ***Malleability*** *is one aspect of workability that is defined by the material's ability to be permanently and predictably deformed under compressive stress.* For instance, sterling silver is highly malleable, it can be manipulated easily and predictably so that it is commonly used for handmade jewelry. On the other side of the spectrum, glass after it is tempered cannot be drilled or cut as it will simply shatter. Marble is especially fragile along its veins and susceptible to breakage. It is difficult to weld copper as the heat output will also substantially distorts the workpiece. Workability is a serious issue for anisotropic and orthotropic materials, those that don't have homogeneous properties on different axes. For instance, cherry wood, despite its desirable grain patterns, exhibits directional changes known as grain reversal, making it difficult to work, plane, and join.

Vid.01/04 Video on the outcome of drilling tempered glass.

SURFACE ATTRIBUTES

Within an interior space, the user primarily experiences the surface features of materials. Beyond their immediate visual qualities, surfaces can be felt through skin, soak up or exude various odors, absorb or reflect sound in unique ways, determined by their make-up and finish. Surfaces will require cleaning, conditioning, sealing, protection, and maintenance. Most surfaces will weather, wear, abrade, and fade.

Fig.01/13 Water can easily cause destruction behind wall finishes, without the occupants ever noticing.

Water is claimed to be the source of all life but when it comes to the construction business it is the source of all ***decay and degradation****.*

Moisture needs to be carefully calculated and controlled throughout a building, including within the envelope: the boiling water on a range, a hot shower in a small bathroom, splashes from a powder room sink, leakage from a water tank, the water smeared on baseboards when mopping, or seeping through old grout. After it is absorbed, water will easily diffuse through materials, and vapor in the environment can condense at cold spots, creating opportunity for mold growth.

Absorption coefficient *is an important property determining the ability of a material to absorb liquids and vapors when it is exposed.* Absorption coefficient has a significant influence on the possible uses of a material and the various ways it can be treated, sealed, and finished. For instance, wood is a porous material with an ability to retain moisture and react by deforming or it can simply rot. Sealing the wood with a coating of varnish would extend the life expectancy of the material significantly. One should also consider that absorption levels substantially differ between wood species. For instance, due to its naturally oily constitution teak repels water and is a popular material for high-end shipbuilding. Untreated fabrics not only absorb vapors, organic compounds, and odor from the environment, they tend to release them back, sometimes over many years. Another important example is granite, the surface of which appears impermeable to the naked eye, however, it harbors microscopic pores and a yearly sealant application is required to inhibit bacterial growth. For this reason, granite countertops cannot be used in commercial kitchens as they cannot satisfy the National Health and Safety Foundation's NSF/ANSI Standards developed for food contact materials, unlike stainless steel, quartz, and some other resin bonded countertops such as terrazzo. Metals are non-absorptive, however, their surfaces chemically react to the environment often eventuating in tarnishing, staining, oxidation, and corrosion. Therefore, they need to be alloyed with more resistant metals, or a protective surface finish is required; their non-absorptive nature may dictate an alternative paint finish such as powder coating.

Vid.01/05 Video on how to seal granite countertops.

WEATHERING AND AGING

Extended exposure to various environmental conditions, such as humidity, pollution, sunlight exposure, abrasive contact, cleaning agents, etc. causes materials to weather and age. Inappropriately specified materials, coupled with poor protection and maintenance practices, can age very quickly and badly. On the other hand, with proper surface treatment and appropriate care they can age in a very desirable manner.

When specifying materials, the designer should consider how the material will ***transform*** *due to environmental conditions in the next 2, 5, and 10 years from the project completion date.*

Patina *refers to the transforming surface condition of a material, that develops over time as it is exposed to physical or chemical actors whether through natural or artificial means, until an equilibrium is reached.* Some of these actors are moisture, UV light, caustic or alkaline chemicals, surface abrasion, etc. Patina development is closely tied to the specific environmental conditions, for instance, the same copper roofing can develop a slightly different color and

texture in a seaside city where the air is more acidic and corrosive compared to an industrial inland city where the air is more polluted. Pre-patination and pre-weathering are common among construction materials, enabling visually consistent weathering effects without the time commitment. Nevertheless, the unique visual signature of a building's site cannot be attained through artificial means.

*Many materials are **sensitive to daylight**, or sometimes even artificial lights such as Xenon. Light exposure causes materials to deteriorate, some lose color and vibrancy, others lose flexibility, and some simply disintegrate.* The effects of UV light on wood components are well known. Wood slowly darkens and grays out as it is exposed to UV light, sometimes creating an uneven and undesirable look if the exposure is irregular. Careful specification, UV inhibiting finishes, a deeper stain finish, or installing low-E glass on openings can help control the effect; simply sanding and refinishing wood after several years of use might be another answer, depending on the species of wood. Other materials such as high-density polyethylene become brittle with extended sunlight exposure and starts to crumble; on the other hand, some plastics, such as acrylic, largely stay unchanged.

Dimensional movement is another significant consideration when specifying materials. *Materials **deform over time** as the environmental moisture level changes, building settles, temperature fluctuates, or continuous weight, force, or vibrations are exerted.* For instance, expansion joints in cast-in-place concrete finish are utilized to mitigate cracks due to dimensional movement; a shiplap or tongue and groove joint work in a similar way especially useful when a species of wood, highly susceptible to warping, is used, such as Douglas fir before it is stabilized in its environment. ***Creep** is the permanent deformation of a material due to the exertion of a constant force over time.* If a material is expected to support constant loads over long periods, the designer should make sure that it is ductile enough and properly supported. One serious issue regarding dimensional movement is the degree of compatibility between different materials that are specified to interface together. *It may be necessary to **allow for the relative movement** of different components that are expected to respond to environmental conditions differently.* For instance, if relative movement is expected when attaching wood to a metal frame, washers can be utilized to screw the wood piece through larger holes on the metal frame. This will allow for some movement, minimizing the chance of damage over time.

Fig.01/14 Every naturally developed patina features a unique look based on its location and surroundings.

02

PERCEPTION

- *Perception of materiality*
- *Understanding design trends*
- *Historical, cultural, and design context*
- *Concept driven material specification*
- *Visual elements and principles*
- *Balance, dynamism, and composition*
- *Non-visual senses*

Materiality refers to the perception of the quality and state of each material applied to components of a space or a product. ***Perception*** *of a material is a complex cognitive process, involving the engagement of multiple senses as well as the mind.* It simultaneously stimulates visual, tactile, auditory, and olfactory senses; colors and texture, being shiny or matte, feeling of cold or warmth, being taut or loose, etc. Furthermore, it also incorporates the end-user's experiences, expectations, preconceptions, upbringing, and culture; it can be highly subjective. For instance, the amount paid for a product affects its self-constructed value, it influences how the quality and refinement of the finish is perceived. A similar bright colored and reflective vinyl finish might be perceived as plasticky on a $15 skirt, or tasteful and refined on a $500 one. The success of the end product in terms of material selection depends not simply on finding the material that fits the budget and performance criteria well and has the most aesthetic appeal, the designer has

to anticipate how the material will be perceived by the intended end-user as well.

Individuals develop an understanding of the materials that constitute their environment through visual, tactile, auditory, and olfactory senses. Each sensation shapes their expectations and affects the overall experience of a space, component, or product. For instance, perceiving an oversized puffy pillow will create an expectation of comfort or the view of a brick fireplace will create a sense of hominess, coziness, safety, and relaxation. On the other hand, transparency may create a sense of invasion of privacy, or the reflections suggesting wetness might create discomfort due to an impending accident, or glare from intense reflections will create a more direct and discernible source of disturbance. One would know that velvet will be pleasurable to touch or intuitively understand that the smooth surface of the handrail will be safe to hold on to. Bits sticking out a surface will contribute to the perception of discomfort, or stickiness might evoke a sense of disgust. Wooliness will support a sense of warmth, or steel will feel cold as it quickly drains the heat away from the body. Hearing a lot of reverberation in a space will suggest openness and eeriness, whereas hearing no reverberation will suggest restriction and confinement. A sense of achievement can be instilled with the "new car smell" or the smell of mold & mildew can urge the user to run away.

> *Understanding how users perceive materiality with distinct senses bears substantial importance for the designer, so that the designer can* ***effectively manipulate*** *how the end-user will experience the design product.*

Exactly where and in what way a material is utilized plays a significant role in how it will be perceived. *User* ***expectations and preconceptions*** *play an important role in the perception of materiality, shaping the situation into a positive, negative, novel, or bland experience.* The reaction of the end-user to a glass floor will be much different than to a glass wall. The same goes for using polished aluminum for a shoe, where a softer material is expected instead of a rigid metal. The designer needs to remember that, *for a space that is visited once every while, such as an expensive restaurant or a retail store, a* ***novel experience*** *will stay to be novel; and the downsides can be tolerable. But using this novel material in a residential setting might lose its novelty over time, as it will be experienced on a daily basis; the sense of novelty might quickly transform into annoyance.*

Fig.02/01 Wool creates an expectation of warmth and in some cases itchiness.

Fig.02/02 The glass facades of Farnsworth House have been a major source of privacy related controversy.

Reflecting upon the history of materials can inspire innovative uses and combinations. The designer can foster connections among materials, fabrication, users, and place. For instance, once very demanding wood inlays can be fabricated by precise laser cutting and CNC milling today for a fraction of the cost. Though, the perception of delicacy and lavishness can still be present. Another example can be "béton brut" or raw concrete's association with the Brutalist movement mindset. Breaking free of any such associations requires innovative thinking. Social and cultural norms are another important component of the overall design context. Different social groups with different cultural idiosyncrasies will perceive materials differently. For instance, Bamboo is a material that has many cultural associations reflecting traditional Chinese values, or a Muslim individual might avoid wearing pigskin leather for religious reasons.

Fig.02/03 Brutalist architecture features substantial amounts of unfinished concrete surfaces.

Vid.02/01 Video on the Barbican and transformation of Brutalist Architecture.

***Context** is the physical, socio-cultural, or financial conditions and constructs that surround a design problem, affecting how it is perceived and approached.* Historical context, cultural context, and environmental context affect how materiality is perceived. Context also includes the clients' or prospective users' needs and requirements, building program, ongoing trends and preferences, human factors, sustainable thinking, etc. Furthermore, perception of materials doesn't occur in isolation, per surface or object. Each material within a space affects the overall context. *When specifying materials, the possible synergy and the overall **combined effect** should be carefully considered.* Imagine a large wooden conference table in an otherwise minimalistic and sterile conference room. It should bring a sense of warmth and a connection to nature to the environment, via an easily perceivable contrast. On the other hand, the same conference table might not work as well in a room with elaborate wooden paneling, even though it has the exact same physical properties. The perception also involves paying attention to not only surface quality but also color scheme and the lighting conditions of the environment. A chrome-plated metal border on a polished granite wall may not create the same impact compared to when it is combined with a vein cut travertine cladding, as the contrast in texture and sheen will help it stand out. It is the overall effect that counts and it requires careful thinking.

*The designer should always ask, "how will this material be perceived **within this context** and what kind of synergy it will create with its adjacent surfaces?"*

Trends are another important notion that influences end-user's perception. *In the context of spatial design,* ***trends*** *can be defined as a specific color, material, or finish inspiring collective attention and desirability for a period, owing to exposure, popularity, or association.* Trends can be relevant for some contexts, such as a trade expo stand or a retail space, whereas in others not so much, such as a government office or a history museum. For some types of materials, such as fabrics and wallcoverings trends are highly relevant. Oftentimes products that were released around the same season seem to resemble each other and companies invest large amounts of money to track and set trends. The designer needs to know about existing trends and forecasts but also needs the skill to manipulate user perception and generate interest. For example, subway tiles are deemed as classic and timeless by some but in a modern interior, they can easily look dated. However, a contemporary re-imagining of a subway tile with an elegant finish might be a good nostalgic touch or a clever throwback/reference.

Fig.02/04 The concrete cantilevers in Fallingwater House sets a stark contrast with nature.

> *A recently trendy material, color, and texture can look* ***distinctly dated*** *when it goes out of vogue.*

A ***design concept*** *is an abstract framework for design development, a tool for outlining design intent, distinguishing a design product from a mere object of function or decoration.* A conscious and methodical approach to the material scheme is key for meaningful and impactful design; one area where the design concept will manifest itself. In his 7132 Thermal Baths project, Peter Zumthor's linear use of Vals quartzite and still water creates a sense of serenity and relaxation that is in line with the overall idea of creating a place for respite. Frank Lloyd Wright's choice of concrete in Fallingwater House is not only a novel use of the then untested material, but also a statement to stand out from the surrounding lush natural environment.

Tab.02/01 Examples of translating a concept keyword to design decisions pertaining to materiality.

Concept Keyword	Possible Translation to Materiality
Tension/Release	Contrasting a rigid material, such as marble, with a loose and soft one, such as felt
Growth	Highlighting solid wood with very prominent grain, stained for effect.
Interdependence	Specifying a composite with a transparent matrix, showcasing the reinforcement.
Outreach	Ensuring uninhibited transparency, via the utilization of glass or acrylic.
Anti-Organic	Using molded concrete to produce angular/geometric volumes.

Vid.02/02 Video on material use in Peter Zumthor's Therme Vals Spa (enable close captions).

Another important consideration that affects user experience significantly is emotional response and assigned value. The famous adage, "form follows function" is one way to look at the design process. However, *anticipating an **emotional response**, placing an emotional value, building memories and ownership around a product or space can be as important as its functionality.* The end-user doesn't always act on purely logical reasoning on how a design product functions. Most beloved spaces and objects have a story attached to them, and their function may not be a principal consideration. One might remember their underlit attic bedroom fondly because it gave them privacy and shelter during their sensitive teenage years. Linoleum kitchen flooring might be preferred by some demographics due to the associated sense of nostalgia. Custom made brass door handles might be completely unnecessary in terms of function but it signifies financial achievement and can improve overall user experience and enjoyment.

VISUAL NATURE OF MATERIALS

When perceiving materials, human beings primarily rely on their sense of sight. Within one's field of vision, a material is conveyed first through optical perception followed by other senses. A key component of visual perception is the manner in which light strikes a material's surface and the effect that ensues. The nuances of the visual perception of materials can be described using the following specific terms: color, hue, depth, light transmission, luster, reflection, shade/tone, tint, value, sheen, texture; these constitute a useful vocabulary for professional expression of one's ideas.

*An accurate understanding of what each specific term mean will enable the designer to **communicate ideas** clearly with their peers, providers, contractors, and even clients; minimizing the risk of misunderstandings and mistakes.*

Fig.02/05 The use of leather in high-end car interiors is less about functionality and more about emotional impact.

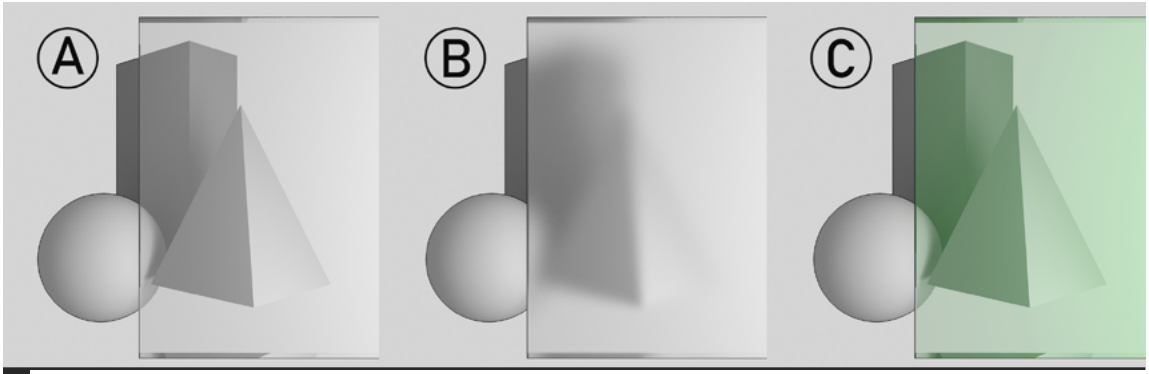

Fig.02/06 Examples of transparent (A), translucent (B), and tinted (C) glass.

LIGHT ● Light is the principal requirement for visual perception. The incident light on a surface can be reflected, absorbed, or refracted in various amounts, defining general visual properties of a substance. Based on the proportion and transformation of light passing through the material, or light transmission, a material can be referred to as opaque, translucent, transparent, or tinted. ***Opaque*** *refers to a surface that completely blocks the passage of light.* Even though transparent and translucent materials allow light to pass, ***transparency*** *provides a clear view through, whereas* ***translucent*** *material diffuses light creating a frosty look.* Tinted materials only let certain parts of the color spectrum to pass, creating the transparent or translucent material as well as everything behind it to be perceived as a certain color.

Reflection *refers to the unabsorbed returning light wave bounced off a surface.* Every surface reflects light to an extent. Even the darkest material, currently Vantablack®, reflects 0.02%. The nature of reflection, whether diffuse or direct, provides valuable clues about surface quality. For instance, polished steel will reflect light in a more uniform manner whereas brushed or sand-blasted steel finish will in a more diffuse manner. ***Luster*** *refers to the specific way a material reflects light.* ***Sheen*** *is luster manifests as shine, glow, or gloss on a surface. The* ***shade/value*** *of a surface you perceive depends on the angle of light striking a surface.* As the angle becomes more perpendicular the surface will receive and reflect more light. ***Shadow*** *is an area deprived of light due to obstruction and can be perceived as an extension of an object that is casting it.*

Vid.02/03 Video on identifying the effect of luster on various minerals.

Vantablack© - Surrey Nanosystems | www.surreynanosystems.com

Fig.02/07 Vantablack® absorbs 99.8% of incoming light, to such an extent that surface detail can be perceived.

Fig.02/08 The glare in this environment is exacerbated by the contrast of the dark material around the windows.

*Shadows are instrumental to the perception of the **3-dimensional nature** of a surface.*

Exposed to high-intensity light sources, reflective surfaces are prone to generating glare. For instance, polished marble flooring in an atrium would strongly reflect any light source; and any high-intensity source would create glare depending on the angle of the viewer. When openings are considered, if the framing material or surrounding drapery is darker, it might generate glare due to the contrast with outside lighting levels. ***Glare** is not only uncomfortable but can be dangerous, requires special attention.*

Daylight and artificial light are two broad categories of light that create significantly different visual effects. The diameter of the sun is 109 times of Earth's diameter. As a result, the rays of sunlight received by earth are parallel and the intensity is fairly uniform over large distances. This affects the nature of daylight shadows. On the other hand, artificial light can be emitted from a point, line, or an area outwards. The shadows are elongated and distorted. Depending on the initial power of the source there will be areas of comparatively more light, and intensity will be lost quickly. Shadows will also be softer, more diffused, they might lack definition. There can be multiple sources of light, which create multiple shadows with multiple intensities.

*The designer can **manipulate the spatial experience** through the interaction of light and materials; they can break the monotony and create dynamism, create an ambiance to support the design intent, direct attention with light and define borders, or support wayfinding.*

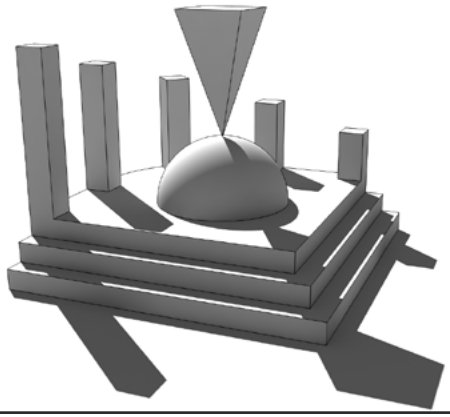

Fig.02/09 Sunlight casts parallel shadows and the light intensity is consistent, it does not fall off.

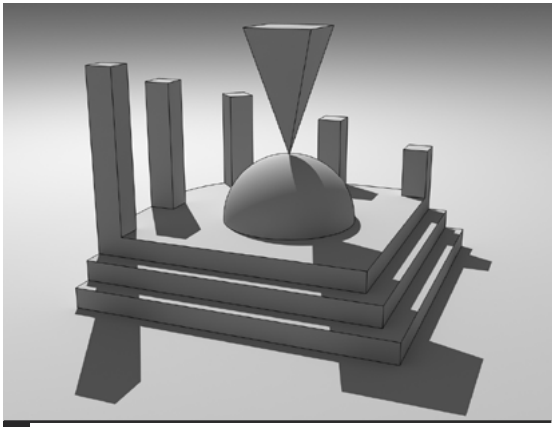

Fig.02/10 Artificial light casts shadows that fan out and the light intensity drops exponentially.

The perception of color enables the viewer to make sense of the intricacies of the three-dimensional environment around them. Wavelength of light reflecting off a surface determines if the particular surface will be perceived as red, green, or violet. This perceieved aspect is often referred to as the color or the hue of an object. However, ***hue is different from color*** *as hue refers to a overarching category determined by wavelength whereas color encompasses several properties including hue as well as saturation, value, etc., referring to the actual combined wavelengths.* For example red is hue and pink is the color. In most sources, the primary colors (red, blue, yellow) are referred to as hues, and in others secondary (green, violet, orange) and tertiary colors (blue-green, yellow-green, etc.) are also included. The basic idea of hue is to identify a color family by using a color with no variation in saturation, shade, tint, or value, intensity. There are various terms that define the nuances of color further. ***Shade*** *or tone refers to the presence of black in a color or hue.* On the other hand, ***tint*** *is the presence of white in a color or a hue.* ***Value*** *is the overall degree of lightness and darkness of a hue.* ***Saturation*** *refers to the intensity of the hue,* or oppositely desaturation is the amount of gray perceived.

Vid.02/04 Video interview of Rem Koolhaas on the Melbourne Pavillion and use of light.

Fig.02/11 Hue refers to the broader color category. Here, pink is the color whereas red is the hue.

Fig.02/12 Red, green, and blue pixels light up at different intensities to form the image.

Fig.02/13 Plastic pellets are one example where subtractive color mixing rules apply.

Depending on the medium color, mixes show different characteristics. ***Additive color mixing*** *is combining light sources of different colors and creating a mixture that is moving towards white.* One prominent example that exploits this principle is the pixels on a laptop or smartphone screen; any color is generated by combining red, blue, and green light of different intensities. Understanding how light mixes is important for establishing ambiance and creating effects. On the other end, ***subtractive color mixing*** *is combining dyes, inks, pigments, or colorants to achieve mixtures that are moving towards black, or dark as light is subtracted.* It is specially important when considering achieving various colors with plastic pellets or paint.

Fig.02/14 Color can be utilized for attracting attention (A), grouping elements (B), indicating meaning (C), enhancing aesthetics (D).

There are a number of websites and software where you can find custom color schemes. You can also check artworks for inspiration. Designers should use color intentionally: ***to establish form, create dynamism, generate interest, and ensure balance.*** Controlling the proportions of color in an environment is also as important. The designer should ask which colors are dominating, which colors are supporting. ***Limiting the color palette is often good.*** The use of color should be deliberate and impactful, rather than turning into background noise and getting lost in the mix. Due to changing trends, certain colors become more popular at certain times. Many paint companies publish color forecasts to report the changing trends.

Color can be used in design for the following

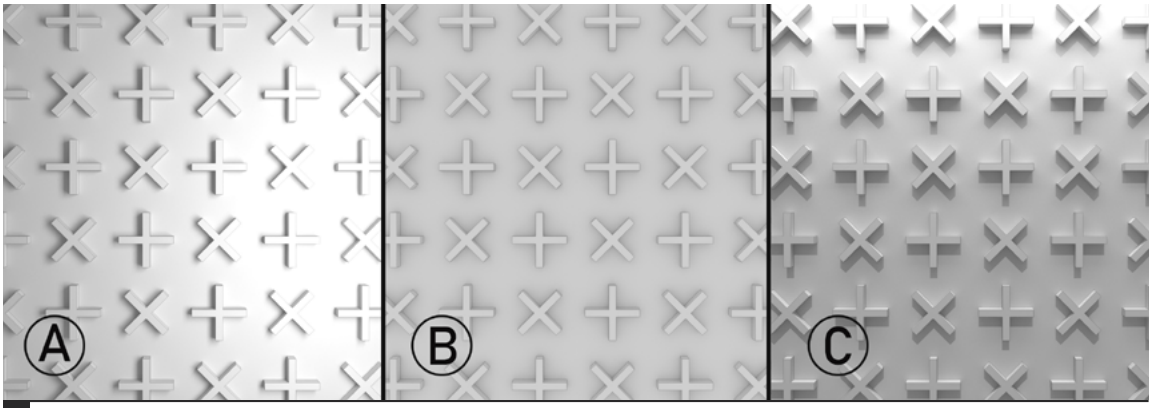

Fig.02/15 Examples of relief receiving light from various angles: sunlight (A), diffuse light (B), wall washer (C).

purposes of ***attracting attention, grouping elements to indicate meaning, and enhancing aesthetics.*** Color can be utilized to drive the attention of users, but also an excessive use of color would weaken the effect. As a result, other design elements may become the target of attention. The designer can indicate or emphasize a relationship among different design elements. *Meaning of color can be very subjective, where* ***context and nuances*** *are important, and the designer should anticipate the effect.* Earth tones might indicate a sense of permanence, experience, rootedness, or the use of red might introduce a sense of dynamism and excitement. A lack of color can be tied to solemnity and spirituality, or a multiplicity of color ties to a sense of playfulness, youth, and energy.

TEXTURE ● ***Texture*** *is a visual construct that has an approximate repetition and a sense of continuity among its parts, even* though for some textures distinguishing this exact repeating visual unit might be difficult. Texture gives the viewer clues about the nature of a surface and finish, simplifies comprehension of surface topology, enhances spatial perception and sense of depth, introduces variety and interest, and as previously mentioned, it also implies tactility. Texture enables the viewer to identify the nature of a material, if it is soft or hard, slippery or rough, stretched or loose. Furthermore, based on previous experiences it is possible to establish a sense of scale with the use of texture and proportionally relate elements of an environment. Texture can have three-dimensional qualities. ***Relief effect*** *is the perceived depth of a materials surface.* Oftentimes the relief effect can be enhanced or dimmed by adjusting the direction of incident light and controlling shadows.

Perception of texture *is affected by light intensity and direction, size of the visual units comprising the texture, the contrast between units, the reflectivity of the surface, and the distance of the viewer.* Context is key in texture perception. The visual environment surrounding a texture profoundly affects its perception. The term texture should not be mixed with pattern. ***Pattern*** *is very consistent and predictable whereas texture have random variations, appearing more natural in comparison.* For example, wallpaper pattern typically refers to a

Link 02/01 Link to colorpalettes.net pre-made color schemes.

Fig.02/16 The repeating visual unit of a texture can sometimes be hard to distinguish.

Fig.02/17 The visual unit of a pattern is distinctively repeating and easier to discern

consistent graphic application on the other hand a wallpaper texture refers to a more varied and stochastic visual.

OTHER VISUAL COMPONENTS ● Usually, movement in design is an implied component. *The **suggested movement** of surface materials creates dynamism and directs attention.* On the other hand, movement can be literal too. Some materials can move in reaction to wind, for instance, movement of drapery with a slight breeze might enhance the ambiance. Motion can be introduced and controlled through sensors and automation. Movement can also imply the movement of the viewer. A space can be revealed through movement. Distance determines the perception of movement in the fore-, mid-, and background.

*This effect is called **parallax depth** and it can be used to create depth in space by utilizing varying textures on fore-, mid-, and backgrounds.*

***Rhythm** is crucial in creating a sense of coherency and grouping elements.* Due to the repetition aspect, every texture inherently has an implied rhythm. Rhythm should especially be a consideration when using materials in combination.

Vid.02/05 Video on Lotus Wall, a kinetic wall finish responding occupant movement.

Fig.02/18 Rhythm establishes a sense of continuity.

Fig.02/19 Symmetry can be a powerful design tool.

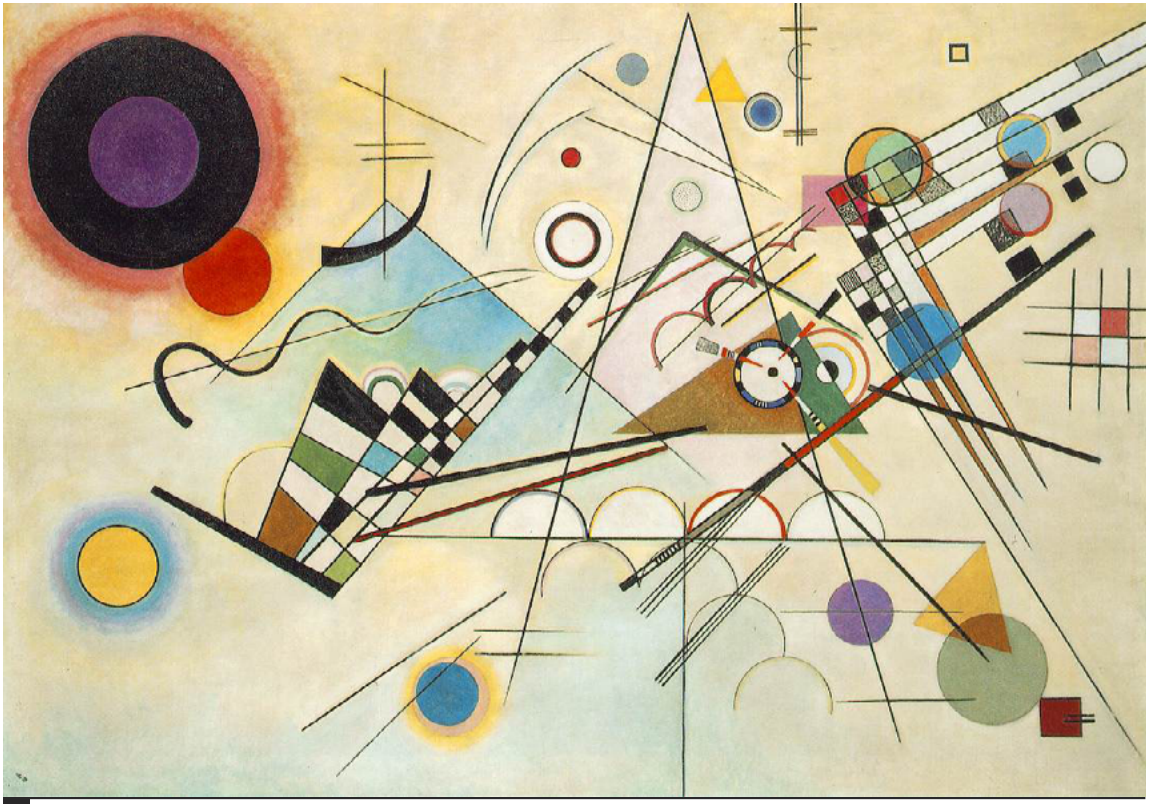

Fig.02/20 Vassily Kandinsky's Composition 8 is a good example of achieving a complex and dynamic balance.

Monotony is an important concern when working with materials. For example, when finishing large surfaces with a single material. Unless dictated by a strong concept, seeking a sense of balance when specifying materiality and minimizing a sense of monotonicity is key. *In order to* ***control the build-up of monotony****, it is possible to break down large surfaces to create rhythm and dynamism.* Texture variation can also be utilized, by including different finishes of the same material to break the monotony.

Symmetry *is often taught as something to stay away from as symmetrical compositions are visually less sophisticated and the repetitive nature often lacks interest.* However, there are times symmetry would come in handy as a conceptual tool. For example, if you intend to express equality and justice a perfectly symmetrical composition may be the answer.

COMPOSITION ● The design elements and principles covered until now are the foundation for good visual composition practices. Balance is a key aspect of visual composition. *The designer has to be able to use form, materiality, texture, color, light, structure, movement in conjunction with contextual information to create* ***balanced dynamism****.* However, one should also be careful as too much balance will hinder interest; imbalance sometimes is a good tool for conceptual expression.

NON-VISUAL SENSES

Even though the sense of sight is very important for the perception of materiality, *it is a combination of sight, smell, sound, and touch that fully determines how a material is* ***experienced***. A hierarchy is present on the immediacy of each, and also the ability of how far each sense can reach. Nonetheless, each sensation augments the other and forms a robust perceptual construct; while providing aid when one of them is weak or missing. For instance, under dim light, an individual will rely on the sense of hearing and touch to direct themselves, as the visual stimuli would be unreliable.

Haptic sensations*, or sensations related to touch, can be defined broadly as the tactile impression of interacting with materials, products, or finishes.* Due to the number of nerve endings and purpose appropriateness, hand and feet are the primary sources of tactile information, even though the whole body contributes to forming the overall sensation. Thermal sense is also part of haptic perception, besides three-dimensionality, roughness, wetness, flexibility, etc.

There are two crucial concepts related to thermal sensation that can help the designer better specify materials: conductivity and emissivity. ***Conductivity*** *in this context is the capability of a material to transfer heat through its body.* ***Thermal bridges*** *are the result of a conductive material creating a path of least resistance for heat transfer.* The more efficient a material is in transferring heat from a hot to a cold region, the colder it will feel to the touch. For example, metals feel cold to the touch not because they are actually cold, but because they drain away heat efficiently. In reality, they most likely have reached equilibrium with the environment and at virtually the same temperature as everything else around them.

Fig.02/21 The observer knows the ladle is hot based on their previous observations of glowing hot metals.

Vid.02/06 Video on creating a rough granite finish through flaming.

Emissivity *is the ability to radiate thermal energy to the environment.* A blackbody is defined as the perfect emitter; on the other hand, a shiny surface will have zero emissivity. Even though a shiny aluminum railing isn't actively sucking heat away from the environment, it has zero emissivity and will almost always be cold to the touch. On the other hand, a dark stained smooth oak railing will feel warmer and inviting. With an understanding of these concepts, the perception of warmth can be manipulated via materiality.

> *The impression of cold and warmth can even be determined by looking at an image as the viewer already has* ***sensory expectations*** *based on previous experiences.*

Materials can be finished in different ways to create varied sensory experiences. Marble can be brushed, chiseled, sanded, or buffed – each method results in a unique haptic feedback. Moreover, utilizing different parts of a material source such as hairs, underfur, or various layers of a hide; or the bark, hartwood, or sapwood of a tree can yield diverse tactile sensations.

03

HEALTH & SAFETY

- *Building codes and standards*
- *Fire safety*
- *The Americans with Disabilities Act*
- *ADA accessibility guidelines*
- *Universal design principles*
- *Indoor air quality (IAQ)*
- *Harmful chemicals*
- *Room acoustics and reverberation*
- *Sound transmission and flanking*

The designer is responsible for ensuring the health, safety, and wellbeing of the occupants, accordingly they should carefully think about the impact of each material and component specified. Building codes and various legislation ensure that the intended design product does not cause any harm; they are enforced through permit processes. However, *building codes are based on minimum acceptable risk*, they can be slow to respond to the newly emerging findings and they don't cover all possible facets of design thinking and realization. The designer should continuously strive to further their knowledge on the possible negative impacts of their design choices.

Building codes *outline practices for minimizing risk.* ***Standards*** *are a procedure, test method, classification, or requirement that is outlined by an independent organization.* Building codes reference standards to be more explicit and accurate. ***Rating systems*** *are voluntary procedures conducted by independent organizations,*

culminating in labels that facilitate informed design decisions. ***Guidelines*** *outline the best practices for various aspects of design products.*

First published in 2000 as a consolidation of three separate sets of codes, *the* ***International Building Code (IBC)*** *is developed as a model code by the International Code Council (ICC), referencing a large number of standards and guidelines to explain minimum performance and risk requirements for construction projects.* ***Model codes*** *are intended to be adopted by local jurisdictions,* either completely or partially, with changes introduced through amendments. For instance, even though IBC Chapter 11 is dedicated to accessibility, it is not uncommon for local jurisdictions to reference Americans with Disabilities Act, Accessibility Guidelines Title III.

The designer has to consider the way a space is used, the possible risks associated with spatial functions and occupant number and behavior. Based on the presence of risks, spaces can be lightly or heavily regulated. ***Lightly regulated*** *spaces are shared by a smaller number of people and the functionality is deemed fairly less risky.* One example for a lightly regulated space would be a small coffee joint with less than 10 people present at all moments. On the other end of the spectrum, ***heavily regulated*** *spaces serve occupants in high concentrations including vulnerable individuals, or there are risks associated with hazardous materials or processes.* Examples would be restaurant kitchens and hospital operation rooms.

The exact content of regulations that apply to a project is determined by occupancy and construction type, often in proportion to associated risks; though, there are various additional conditions and exceptions present. ***Occupancy type*** *is a way to categorize an environment based on the presence of safety risks and combustible content.* There are 10 occupancy types and many sub-types. For example, office environments are categorized as business (B), high schools are categorized as educational (E), retail stores are categorized as mercantile (M), if flammable or combustible content is present over a set amount in an environment, it is considered high-hazard (H). Each occupancy type poses requirements and they vary in stringency. When multiple occupancy types need to be considered together, the designer should either adhere to the most stringent type or provide separation with a fire barrier. ***Construction type*** *is a method of categorizing buildings in accordance with their ability to resist fire over a set period.* For instance, it would be time-intensive to evacuate a high-rise, or a detention center, therefore the designers involved in the project need to adhere to more stringent safety criteria. At the other end of the spectrum, unprotected wood

Fig.03/01 Restaurant kitchens are considered risky environments in terms of fire safety.

Vid.03/01 Video on the International Building Code.

frame structure is adequate for a single-family home as a limited number of people will be living in the building, and in case of fire, they can be evacuated fairly quickly. Interior architects and designers often expected to work with an already set construction type, affecting material and finish decisions from the start.

Depending on the code and legislation in question, material selection guidelines include fire resistance, slip resistance, acoustic performance, insulation level, ability to be cleaned or sanitized, visibility, ease of use (particularly in panic situations), and air quality. The codes themselves are freely available, however, they might not be always obvious to the designer. One way to improve understanding of the content is to read illustrated commentaries prepared by the model code publishers.

*It is always a good idea to **get in touch with the local building department** to ask questions, discuss your design decision, and learn about the local amendments and requirements and their interpretation of specific codes, as early as possible,*

The local code limitations have a possibility to alter the design. An example would be, the minimum conditions for when a permit is required. For some local departments this is as soon as you demolish or build a wall, for others it starts with repairing a fence.

STANDARDS

Standards set voluntary guidelines for product specifications, practices, and systems; describe procedures and conditions, overseen by independent organizations, usually signified by certification marks presented on a label or data sheet. The Underwriters Laboratories (UL) tests and certifies a wide range of products, components, materials, systems and publishes the materials' performance, identified through various labels in the UL Building Material Directory. Manufacturers can hire accredited third-party testing organizations to conduct these standardized tests. Standards do not have legal standing, they are typically referenced by codes through a combination of publishing organization's acronym, number, and edition.

In the U.S. there is a number of relevant standards organizations that significantly influence the material specification processes for interior architects and designers. American National Standards Institute (ANSI) as well as ASTM International, or formerly American Society for Testing and Materials are major publishers for voluntary standards and guidelines. National Fire Protection Association (NFPA) develops codes and standards aimed at reducing the risk of fire and related hazards. National Sanitation Foundation (NSF) creates and publishes standards for products and services related to public health and safety.

There are separate organizations for flooring material manufacturers such as the Tile Council of North America (TCNA) or the Carpet Rug Institute (CRI). The Consumer Product Safety Commission (CPSC) is an important independent authority that issues safety and performance standards that address product-related illness and injury. For instance, 16 CFR Part 1252 deals with the limits of harmful content in engineered wood products that might be interfaced or used by children. The CPSC website can be searched for unsafe products and recalls.

Link 03/01 Link to the Consumer Product Safety Commission product search site.

FIRE SAFETY

There's a large number for fire safety standards and related tests. Some of these are very significant and can influence design decisions substantially. Moreover, they are also an important part of the tested knowledge base for professional certification exams. ***Fire tests*** *often involve controlled burning of various materials and assemblies within specific environmental conditions, measuring the burning rate, fire spread, heat increase, material loss, smoke production, and toxicity. An* ***assembly****, or a* ***construction assembly*** *in this context, refers to a specific combination of materials serving a singular function.* For example, a door assembly can feature multiple materials in combination such as steel frame, wired glazing, or rubber gaskets; it is the combination of all that is tested and rated. Beyond burning characteristics, ***smoke generation*** *is also tested during some fire tests due to the fact that the smoke generated by burning materials is the primary reason for fatalities in fires.* For most materials, it can be said that the toxicity of the smoke is relative to the smoke produced during burning. The most important fire tests are described below, understanding what these tests entail should help the designer make sense of codes and eliminate late revisions.

ASTM E119 ● This is a collection of test methods for "fire test of building construction and materials". Floor, wall, and roof assemblies are tested for their ability to withstand the transmission of heat and hot gases, as well as how much the assembly can maintain its structural integrity when exposed to fire. A pressured hose stream test is also applied on the heated surface at the conclusion, to simulate standard fire response procedures. Assemblies are given an "hour-rating", designated as 1-, 2-, 3-, 4-hour(s) based on their fire resistance over time. The final hose test is pass/fail.

ASTM E84/NFPA 286 ● Being one of the most prominent, this test measures the "surface burning characteristics of building materials". Also known as the "Steiner Tunnel Test", the flame resistance and smoke spread characteristics are measured against the performance of fiber cement board (0) and a select grade of red oak (100), and given one of the following ratings: Class A (<25), Class B (25-75), and Class C (>75). A high rating indicates poor performance.

Fire tests can have multiple names, referring to the exact same procedure. This particular test is also known as UL723. It was actually first developed by the Underwriters Laboratories and then adopted by ASTM.

In IBC Section 8, Table 803.11 is based on this particular test and it designates minimum fire resistance characteristics for various types of surface finishes to be utilized within different occupancy groups. There are limited restrictions for trim work such as handrails, door frames, etc., and other decorative details such as wainscoting

Tab.03/01 A section of the IBC Table 803.11 content, Interior Wall and Ceiling Finish Requirements by Occupancy.

Occupancy Type	Sprinklered			Non-sprinklered		
	Interior exit stairways and ramps, exit passageways	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces	Interior exit stairways and ramps, exit passageways	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces
Movie Theaters (A-1), Restaurants (A-2)	Class B	Class B	Class C	Class A	Class A	Class B
Business (B), Educational (E), Mercantile (M), and Hotels (R-1)	Class B	Class B	Class C	Class A	Class A	Class C
Hospitals (I-2)	Class B	Class B	Class B	Class A	Class A	Class B
Long-Term Care Facilities (R-3)	Class C	Class C	Class C	Class C	Class C	Class C

Fig.03/02 Fire sprinklers provide significant amount of protection, at a relatively reasonable cost. Especially for new construction, while lowering the fire resistance requirements for materials and assemblies.

or suspended combustible fabric when certain conditions are met.

> *Almost always, automated sprinklered environments are subject to **less stringent conditions** compared to non-sprinklered environments. Typically, the resistance requirements are lowered by one hour in sprinklered environments.*

NFPA 265 ● Widely known as the "room corner test", devised for "evaluating room fire growth contribution of textile or expanded vinyl wall coverings on full height panels and walls". In this test, the fire growth contribution, smoke release, and the potential of flashover of textile or vinyl wall finish are measured in a full-scale mock-up. ***Flashover**, is a phenomenon that occurs when the flames reach a certain temperature intensity, known as the flashpoint, an autoignition temperature for surrounding materials. It is approximately 1100°F, a temperature at which the flames spread rapidly across large gaps.* This standard is different from NFPA 286, in the sense that it is limited to vertical surfaces, and the test is conducted in a vertical setup.

NFPA 253/ASTM E648 ● Known as the "radiant panel test", measures the "critical radiant flux for floor covering systems using a radiant heat energy source", or in other words the fire resistance of horizontally-mounted floor covering systems, such as carpets, resilient floors, etc. Materials are given a Class I rating if they have higher resistance; or a Class II if they have lesser fire resistance, based on their performance characteristics. In sprinklered buildings, Class II materials can be allowed where Class I materials were originally required.

ASTM D2859 ● Also known as the "methenamine pill test", measures the "Ignition Characteristics of Textile Floor Covering Materials", specifically carpet and rugs. After the test sample is placed on a horizontal plane, a methenamine pill is ignited and placed on the material, simulating

Vid.03/02 Video of fire testing at the Underwriters Laboratory.

Vid.03/03 Video of a flashpoint demonstration from 1948.

lit cigarette contact. The charred portion of the sample, at any point, should not extend to 1" from the edge of an 8" steel circle frame the center of which coincides with the pill's location. It is a pass/fail test. All carpets and rugs sold in the US should comply with this standard.

NFPA 701 ● Also known as the "vertical ignition test", this test measures the "flame propagation of textiles and films" or in other words inherent flame resistance for drapery fabrics. Applies to all vertical window treatment components including shades, curtains, table linens, etc. as well as vinyl-coated fabrics such as blackout linings. It is a pass/fail test. The fabric is exposed to flame for 12 seconds and the burning characteristics are noted.

CAL TB, which stands for California Technical Bulletin, is a series of technical standards adopted by the state of California. The content is not always related to fire safety, however, the following CAL TB items related to furniture flammability have been adopted nationwide.

CAL TB 116/NFPA261 ● This test measures the "flame retardance of upholstered furniture". This test measures cigarette ignition resistance, fire propagation, and an overall flammability risk. The test is applied to upholstered furniture mock-ups and actual lit cigarettes are used.

CAL TB 117/NFPA 260 ● Also known as the "cigarette test", measures the "flame retardance of upholstered furniture". A complete mock-up is tested. The whole furniture including the filling materials such as polyurethane foam is expected to be smolder resistant. The added flame retardant chemicals are expected to be disclosed on the product label.

CAL TB 133/NFPA266 ● This test measures the "flammability of public seating", furniture to be used in public spaces that are expected to be occupied by ten or more people. In a full-scale mock-up furniture heat release, smoke density, weight loss, CO emission are measured.

Fig.03/03 Higher fire resistance and smoke spread ratings should be considered for hard to evacuate environments.

ACCESSIBILITY AND UNIVERSAL DESIGN

Accessibility *dictates that every individual whether they have any disabilities or not, should be able to access all key functions and amenities in a space without any obstruction or barriers; at the very least an equivalent experience should be provided as an accessible option.* For instance, there should be an accessible stall in every public restroom, regardless of location. In a privately own café serving the public, having a reading nook that is only accessible with a stair with no equivalent accessible experience present would be subject to a class-action lawsuit. One such recent lawsuit is filed against the Hunters Point Library, designed by Steven Holl Architects.

> *One important thing to consider about accessibility is that,* ***it is not only about wheelchair users****. According to the US Census Bureau, 73% of people who live with a severe disability do not use a wheelchair.*

The spaces should be more accommodating to other individuals with disabilities as well, such as using high contrast signage, or under-stair barriers for the visually impaired, or installing

Vid.03/04 Video on ADA compliant bar design.

door beacon with LED light or visual/audio smoke detectors are for the hearing impaired.

The accessible design guidelines are outlined by the ***Americans with Disabilities Act (ADA)***. ADA Accessibility Guidelines (ADAAG) is not a code or standard, but a piece of civil rights legislation enforced at the federal level and at the local level through enactment. *ADA not only addresses federal, state, or local government facilities, but also* ***privately owned and operated*** *facilities, basically any accommodation open to public use is regulated.* Same ADA guidelines prevail across the nation, regardless of jurisdiction. The International Building Code (IBC) Chapter 11 contains codes regarding accessibility issues, however, it is not uncommon that local jurisdictions amend the model code and use ADA Title III instead.

The earliest precursor to the ADA Accessibility Guidelines is the ***Architectural Barriers Act (ABA)***, of 1968. It was apparent that the infrastructure was quickly becoming an obstacle for the members of the society with physical limitations to be productive and function like everyone

Tab.03/02 Several material specification requirements as outlined in ADAAG.

(1) Flooring materials should be securely fixed, provide smooth transitions without any abrupt level changes.
(2) Slip resistance should exceed a dynamic coefficient of friction (DCOF) greater than 0.45.
(3) changes in height ¼ inch or less are permitted, changes up to ½ inch should be beveled with a ratio of 1:2, and changes greater than ½ inch should be ramped.
(4) Carpet pile height cannot exceed ½ inch and should be securely attached and shall have a firm backing or padding.

Fig.03/04 ADA was introduced to the congress in 1988 and signed in 1990 by President George H. Bush.

else. ABA was fairly limited and only applied to facilities that received funds from the federal government, falling short of being truly inclusive. Another important iteration trying to ensure accessibility is the renowned Section 504 of the 1973 Rehabilitation Act, which later become the ADA Accessibility Guidelines through ongoing development, after the long and painful labor of the Disability Rights Movement. Today, the Architectural and Transportation Barriers Compliance Board is the independent agency responsible for regulating accessibility issues in the United States, including but not limited to the issues regarding the built environment. In residential context, *accessible housing requirements were addressed in the* ***Fair Housing Accessibility***

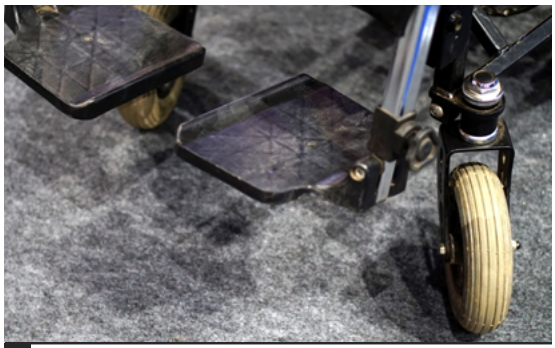

Fig.03/05 ADA accessibility guidelines require carpet pile depth of to be less than 1/2".

***Guidelines**, which cover accessibility issues pertaining to multi-family housing, clustered dwellings, and separate buildings with common use spaces.*

The designer is not a proper user archetype; a vast number of human sizes, shapes, and capabilities, including the children, elderly, people who are pregrant or with temporary disabilities, etc., should always be considered. ***Universal design**, is a holistic approach that addresses the broadest spectrum of human needs, promoting equitable access and engagement for all individuals.* The term universal design was coined by Ron Mace in 1985. ***Human factors** is an area of study that involves collecting and analyzing scientific data on the interaction between the human body and the designed objects and environments, with regard to performing a task.*

Universal design is not enforced by any government body, but it is more of a mindset to improve the quality of life of the users and occupants. Following the universal design principles not only renders spaces and products more accessible for people with limited physical capabilities, but it will make it more convenient for the able-bodied individuals as well; oftentimes addressing the problems that caused difficulties or inconveniences, forcing the designers to think more creatively. Universal design principles are as follows: (1) equitable use, (2) perceptible information, (3) flexibility, (4) tolerance of error, (5) simple and intuitive use, and (6) low physical effort, (7) size and space for approach and use.

Vid.03/05 Video on the principles of universal design.

PRINCIPLE 1: EQUITABLE USE ● This principle recommends providing the same means and provisions for all users, regardless of their abilities, or disabilities. These should not seem like an afterthought, reluctant, poorly integrated, or open to ridicule. Designers should avoid segregation or stigmatizing users. For instance, the use of stair-lifts in the home is being seen as a sign of frailty and incapacity, despite their contribution to the quality of life. There is a need to consider not only instantly recognizable disabilities like wheelchair use, but also parents with strollers, elderly with walkers, or people with temporary injuries needing the use of a crutch.

Fig.03/06 Public stairlifts are dreaded by some wheelchair users due to perceived stigma.

Fig.03/07 Japanese santoku knives feature a single edge and can only be utilized by right-handed chefs.

PRINCIPLE 2: FLEXIBILITY IN USE ● Users can have different abilities, body types, anthropometric features, habits, or preferences. It is often a very bad idea for a designer to design based on their own features and preferences. *A product that is adjustable or responds the needs of multiple groups with **differing features and preferences** is good design.* Even though left-handedness is not considered a disability, cameras, chef knives, power tools, or musical instruments designed for right-hand use make it clear that a more inclusive design outlook should be incorporated.

PRINCIPLE 3: SIMPLE AND INTUITIVE USE ● It is bad practice to assume a range of users will all meet predetermined, experience, knowledge, skill, and attention requirements. It is best to simplify interfaces, make sure the use is clear, intuitive, and consistent with the user's previous experiences and expectations. For instance, there's a possibility that users might be illiterate, or wouldn't know the native language at all. By relying on written explanations, such users would be excluded.

> ***Complex design does not mean good design**, it is often much harder to create something simple, intuitive, and efficient.*

PRINCIPLE 4: PERCEPTIBLE INFORMATION ● *Using **multiple modes of communication** such as pictorial information accompanied with tactile and verbal is preferable as it is more inclusive.* The designer should think about the possibility of various sensory limitations, such as limited vision, hearing, etc. Not every individual has the same visual acuity, therefore high contrast, sizable fonts, legible typefaces are all possible considerations. The instructions, directions, or essential information should be easily distinguishable and placed in an obvious location. The designer should not assume that the user will be able to locate it, simply because they can.

PRINCIPLE 5: TOLERANCE FOR ERROR ● All users won't have the same level of attention, hand-eye coordination, or manual skill to operate and interact with a design product, meaning that there will be accidental or unintended actions and *how the designer accommodates the users, minimizing any safety hazards, isolating, or shielding them, marking them clearly and incorporating **fail-safe features**, is important.* For instance, a metal grill on a dense walkway might be extremely hazardous for women walking in high heels, anybody with lowered attention due to being preoccupied may experience an accident.

PRINCIPLE 6: LOW PHYSICAL EFFORT ● *An aged body has a different response to fatigue than a younger body.* The design should be operated comfortably from a neutral body position without straining the body, overreaching, and overexerting. Repetitive and sustained effort should be avoided. Softer surfaces are easier on joints and easier to walk and stand on. But it also has to

Fig.03/08 An example of user tolerance, the typical electrical outlet features one slit slightly longer than the other, so the plug is inserted correctly every time.

be flat and level. Trims, details, joints, etc. are obstructions that require raising the legs higher. Another example, it might be harder to control a chair with casters on a deep pile carpet than a wood floor, so material choices should be considered accordingly.

PRINCIPLE 7: SIZE AND SPACE FOR APPROACH AND USE ● The designer should consider that users with variance in abilities and anthropometric features, or users relying on various devices to aid their mobility, and the people accompanying them, as well as parents operating strollers or carrying children will require more space to comfortably utilize an environment. *People can have different heights or sizes, or they can be in a standing or seated position within a space, and the* ***visibility and usability*** *of spatial elements should be planned accordingly.* A child's features and abilities are quite different from an adult's.

INDOOR AIR QUALITY (IAQ)

People spend the majority of their time indoors, according to some sources up to 90%. Even though most of the interior environments have an influx of outdoor air either supplied from natural or mechanical ventilation, they are fairly confined and particles can linger for extended periods. *The amount of air pollutants is reported to be between 2 to 100 times higher within indoor spaces.*

Most ***materials engage with their immediate environment*** *either by emitting or absorbing and then re-emitting pollutants; this is primarily determined by their ingredients, make-up, processing, and finish, degrading the overall indoor air quality.* Designers should be careful when specifying materials that can potentially contribute to indoor air pollution. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines acceptable indoor air quality as *"air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and*

Fig.03/09 A simple particulate meter for residential use.

within which 80% or more people exposed do not express dissatisfaction." The potential of toxic emissions from each material, product, and equipment to be specified should be carefully considered. This goes beyond during and immediately after installation, but also during extended periods of exposure to occupants. The designer can always reference product rating systems, tests, and classifications such as flammability, and acoustic or thermal performance values. A ***material safety data sheet (MSDS)*** *is a report containing information on the composition and ingredients of a material as well as potential health, fire, chemical reactivity, and environmental pollution hazards, first aid and storage measures.* Designers also need to outline appropriate cleaning and maintenance protocols as well as pediodic treatment and ventilation needs. A material might be considered safe with regular ventilation of the environment, however, toxicity can quickly build up if the user neglects ventilation over an extended period.

Environmental Protection Agency (EPA), *is an independent executive agency functioning at the US federal level, featuring multiple programs*

Link 03/02 Link to Corian material safety data sheet (MSDS).

related to health, safety, welfare, and environmental issues surrounding the limited and broader impact of toxic substances, pollutants, and industrial practices, in addition to water and air quality. ***Sick Building Syndrome*** *can result from the buildup toxic chemicals in the environment, typically off-gassed by the materials in the environment.* As they spend time in the building, the occupants start suffering health problems such as coughing, fevers, and chills, as well as an overall lack of comfort. However, no specific cause for illness can be identified. ***Building-Related Illness (BRI)*** *is a similar condition, however, the symptoms are directly attributable to building, according to the EPA.*

Volatile Organic Compounds (VOCs) *are toxic chemical gases that evaporate at room temperature and cause short- and long-term adverse health effects for occupants.* Plastics and products containing plastic elements such as particle board, plywood, varnishes, laminates, paints, synthetic fibers are all typical emitters. VOCs contain at least one carbon atom, thus the identifier "organic". Even though some VOCs feature sharp odors, others don't and require specialized equipment to detect. Hence for VOCs, ***a lack of smell does not assure safety.***

The period following the installation/ application of a material is the most critical for VOC emissions. ***Adequate time for off-gassing and proper ventilation*** *should be allowed before occupancy.*

It is also possible for multiple VOCs to react to or interact with existing materials in the environment and create further health detriment. *VOCs can easily permeate absorptive materials such as carpeting, acoustic panels, drywall, unfinished wood, etc.They remain absorbed for months, even years; being slowly re-released to the surrounding environment.* Depending on the length of exposure, VOCs impact on health can be serious, and in some conditions, including severe allergic reactions, they can become a significant health detriment. High-Efficiency Particulate Air (HEPA) filters can improve overall air quality in a space but cannot trap VOCs, which are typically around PM2.5 and PM10, too fine to be filtered.

Wrong material specifications and poor maintenance practices can cause microbial contaminations such as ***mold and mildew****, which are important sources of VOCs and they are capable of deteriorating indoor air quality significantly.*

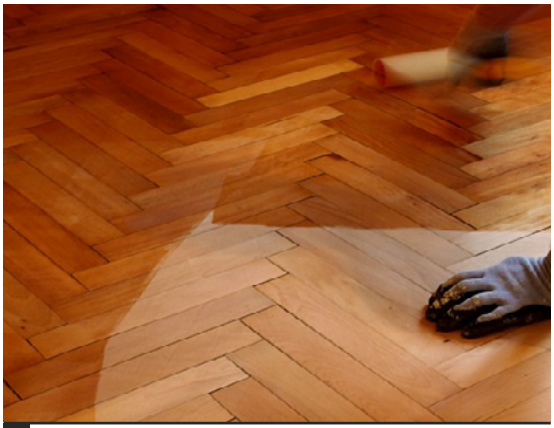

Fig.03/10 Polyurethane topcoat emits VOCs intensely for 4 days, and with decreasing intensity for up to 30 days.

Fig.03/11 Black mold can be fairly inconspicuous sometimes appearing as dirt or stain.

Fig.03/12 Before the devastating health impact was known, asbestos was used everywhere, even as fake snow in movies.

Mold can grow hidden behind walls, ceilings, and even underneath the flooring, as long as there's a moisture build-up. Good amount of ventilation, preferably exhausting directly to the outside, use of vapor retarders on the exterior walls, eradication of thermal bridges or dew points, routine dehumidification, as well as minimizing exposure to known mold food sources are important for prevention. The food sources include materials with cellulose content such as wood, paper facings, and even organic leftovers such as skin cells or uncleaned human food.

HARMFUL CHEMICALS

ASBESTOS ● Asbestos is a highly carcinogenic mineral that was, up until the 1980s, regarded as a highly useful material and utilized in buildings as thermal insulation, for fireproofing, or indirectly as part of other products, such as filler for vinyl composite tiles. The presence of asbestos fibers in older buildings is not unusual, though these are largely undisturbed and sealed behind walls, ceilings, etc. Inhaling asbestos fibers is highly dangerous. The asbestos fibers lodged in lung tissue can cause inflammation, a condition known as asbestosis, that can develop into a number of deadly complications, most prominently lung cancer.

There are two categories of asbestos: friable and bonded. ***Friability*** *means a tendency to break down, crumble, and chip;* particles that are easily disturbed, get loose, and become airborne. This type of asbestos is highly dangerous and when exposed, has to be immediately dealt with. ***Bonded*** *type involves asbestos being used as reinforcement or filler within another material*, such as the previously mentioned vinyl composite tiles or asbestos cement roof tiles.

Fig.03/13 Lead advertisement from 1939, praising the weather resistance and durability enhancements.

These may not be as risky but in time fibers can get loose and airborne due to weathering.

> *Asbestos can be released to the environment through careless removal or damaging of components in buildings constructed* ***before and during the 1980s****.*

During renovation or demolition, possibility of asbestos presence requires special attention. *The Asbestos Hazard Emergency Response Act (AHERA) of 1986 outlines the inspection, identification, and removal processes.* The removal and mitigation of asbestos and many other hazardous materials are regulated by Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA). *The* ***removal of asbestos*** *can only be performed by certified asbestos abatement contractors, a process outlined by the EPA.* The department of health in every state often publishes the information of certified professionals.

LEAD ● Lead is a highly malleable metal with a very low melting point. Before its adverse effects on health were known, it was referred to as the "miracle metal" and was even used as a food additive and make-up component. Lead was commonly used in plumbing due to high malleability and low melting point, before it was replaced by copper, steel, and eventually plastic. The word plumbing comes from the Latin word for Lead, which is Plumbum (Symbol – Pb). Today,ilt is still possible to find lead pipes in city water service line connections of older buildings. ***Along with other heavy metals*** *such as arsenic, cadmium, mercury, and hexavalent chromium, lead has been identified as a carcinogen, a poisonous neurotoxin, and an endocrine disruptor.* Lead causes serious and well-documented developmental problems. All heavy metals are harder to break down and destroy, which is true for lead too. They are very persistent, accumulate in the environment as well as in animals, move up the food chain, or stay within recycled materials.

Lead was commonly used as a paint additive, it helped stabilize the paint, increased durability and moisture resistance. ***Lead-based paint*** *was present in three-quarters of U.S. homes built prior to 1978.* Over the years the paint in older homes has been painted over or covered with wallpaper and buried. Any demolition process, or even sanding down a substrate can disturb the lead underneath and release lead dust that can be inhaled or ingested. *Therefore, the indification, removal, or sealing of old lead paint must be performed by* ***specialized professionals*** *in an approved manner.* Lead plumbing requires urgent and careful removal as well. The EPA has established a ***Lead Renovation, Repair, and Painting Rule (RRP)*** *requiring the contractors that might disturb lead-based paint in homes,*

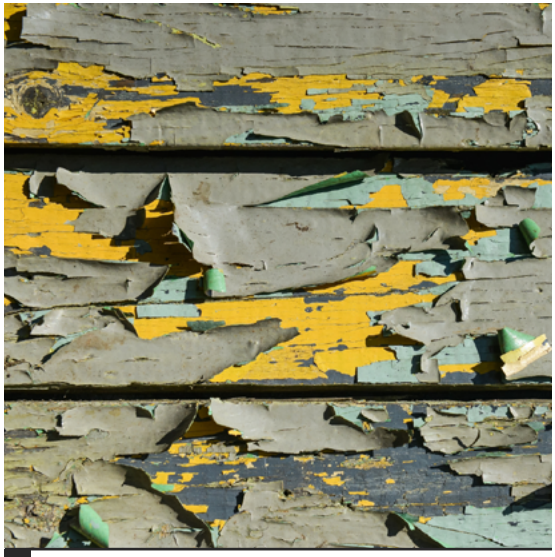

Fig.03/14 Flaking lead paint particles create serious health risks.

Vid.03/06 Video on asbestos removal.

child-care facilities, and pre-schools built before 1978 to be certified by EPA.

FORMALDEHYDE ● Formaldehyde-based resins such as melamine-, phenolic-, and urea-formaldehyde are among the oldest synthesized resins, known since 1855. Urea-formaldehyde is highly common in building products. Urea-formaldehyde is the binding resin in many engineered wood products such as hardwood plywood, medium density fiberboard (MDF), and particleboard. Formaldehyde is also found in adhesives, sealants, laminates, insulation, and coating products, like lacquers, paints, and varnishes.

*Labeled as a hazardous air pollutant by EPA, formaldehyde is a **serious irritant** especially for sensitive individuals with allergies and asthma, a **known carcinogen**, have developmental toxicity effects.* Permissible exposure limits have been outlined by the Occupational Safety and Health Administration (OSHA). The California Air Resources Board also published a standard regulating the formaldehyde emissions from wood products. Furthermore, the emission levels of wood products such as plywood and particle board have been regulated by the EPA since December 12, 2016. Phenol-Formaldehyde is taking over urea-formaldehyde use in some industries due to significantly lower emissions.

Fig.03/15 Formaldehyde is utilized as the binding resin matrix in most particleboard manufacturing.

When products with formaldehyde must be used, the material must be sealed properly and the environment should be well ventilated before occupancy, until VOC release is significantly lowered. However, this can take around a month, and up to 2 years.

> *Designers should keep in mind that **higher temperatures and humidity** cause higher VOC emissions.*

BISPHENOL A & PHTHALATES ● ***Bisphenol A**, also known as BPA, is a chemical that is an additive in the manufacturing of a variety of plastics*; commonly used in the polymerization of polycarbonate (PC) and epoxy resins, but also found in many other materials such as quartz and solid surface countertops, paints, and plastic laminates. Based on FDA reports, BPA may be tolerable in lower concentrations for adults. However, the research has been revealing BPAs negative impact on health including permanent hormonal development problems observed in infants or pregnant individuals who were exposed to the chemical. Also, links have been found with cardiovascular problems. Currently, food packaging appears to be one of the main sources of exposure. Designers should look for the presence of BPA when specifying materials and try to gravitate towards BPA-free alternatives, especially when food contact is expected.

Another plastic additive with associated health risks is Phthalates. ***Phthalates** are very common in plastics manufacturing as they are used to give products various desirable properties.* Especially found in Vinyl derivatives, in order to increase flexibility and strength of the material as the actual plastic is hard and brittle. Since PVC resin is typically not very tightly bound and

stable, it deteriorates over time and phthalates tend to seep to the outer perimeter of the material. Phthalates can solve into the water when in contact (leaching), evaporate, or if abraded can hold onto dust particles. *It is possible to **inhale** the chemical or **absorb** it through skin contact while walking over improperly treated vinyl products.* Research have found phthalates to affect the endocrine system, specifically sex hormone levels. They are especially impactful during pregnancy causing permanent development problems. Designers should try and avoid materials with phthalate content as much as possible.

CHLORINE ● Mainly known as a common household cleaner, chlorine is also associated with vinyl products, specifically with Polyvinyl Chloride (PVC). Chlorine is produced through the electrolysis of saltwater and combined with ethylene, which is then converted to an unstable, highly flammable, and carcinogenic intermediate building block, which is polymerized to create PVC resin. *When chlorine is processed or combusted **dioxin** is generated, which has severe health implications and downright poisonous when inhaled.* Dioxins are a family of persistent and bioaccumulative environmental pollutants with severe health implications for humans. Chlorine is also persistent in the environment and does not break down, tends to move up the food chain.

In addition to chlorine output, PVC manufacturing also makes use of the previously mentioned phthalates to increase flexibility and attain various useful properties. However, these are unbound to the original polymer and tend to move towards the surface and leach, vaporize, or abrade into the surrounding environment. The polymerization of Vinyl is not perfect and VC monomer might stay within the plastic and migrate to the surface over time as well. While burning, PVC is capable of releasing highly toxic Hydrogen Chloride (HCl) and Chlorine gases as a result of thermal decomposition.

Specifying non-chlorinated vinyl alternatives

Vid.03/07 Video on chlorine and chlorine exposure.

are safer for human health and minimize environmental impact. Some of these alternatives are Polyethylene Vinyl Acetate (PEVA), Polyvinyl Alcohol (PVA), Polyvinyl Ethylene (PVE), as well as Polyurethane (PU), and cross-linked polyethylene (PEX). However, these alternatives can have their own limitations and disadvantages, a chief one being their price point.

HALOGENATED FLAME RETARDANTS ● *Halogenated flame retardants are products used to treat various materials for fire resistance; either **as an additive or as part of the coating**, in order to prevent burning and development of fire.* These products include insulation, carpeting, gypsum boards, furniture, and especially polyurethane (PU) foam cushioning as the entire furniture construction is expected to resist fire. In additive form, unless chemically bonded to the polymers. These chemicals can migrate outward and be released into the surrounding environment.

***Health problems** include delayed development in infants and children, immune system, and thyroid function disruption.* They are persistent

Fig.03/16 Office smoking is one reason why flame retardancy rules are so stringent.

and bioaccumulative, won't break down. It is better to avoid these chemicals, especially where exposure to infants and children, or pregnant individuals is a possibility. These materials are very helpful in saving lives and due to stringent fire safety regulations, they become ubiquitous over the course of the last 50 years before their health impact is completely understood. There are safer alternatives such as organophosphate group retardants.

ROOM ACOUSTICS

In addition to its shape, the acoustical behavior and performance of a space is largely influenced by material specifications for each surface. Beyond the simple specification of materials, how they are layered, connected, mounted, suspended, treated, and finished determine their overall acoustic performance. *The acoustics of a space is highly important, a good acoustic environment helps manage stress levels, contribute to wellbeing, improve productivity, and increase overall comfort thereby* ***justifying the additional investment****.*

The first step in specifying materials that would improve a space acoustically, is understanding the basics of how sound behaves. *Sound can be imagined as* ***variation of pressure or vibrations*** *on the transmitting material, such as air.* The sound we hear is made up of a combination of overtones, or partials, of different amplitudes spread over a large frequency range including bass, mid-range, treble; ranging from 20Hz to 20KHz. This is based on the number of vibration cycles each second. Unless it is a simple sine wave, *the frequency content of any sound wave is diverse, heterogeneous, and transforms over time.* A typical female voice will contain 250Hz to 6KHz content peaking at 2.5KHz, the sound of thunderclap peaking at 100Hz and diminishing in upper frequencies based on distance, or a contemporary music recording utilizing the entirety of the audible spectrum balanced according to the genre and the artist's style.

Sound diffusion refers to the way sound energy disperses throughout an environment. *The* ***different frequencies of the spectrum behave differently****. Low-frequency sounds behave more like waves and higher-frequencies more like rays. Low-frequency sounds can travel farther and around objects.* or high-frequency sounds are more easily directed and absorbed. Curved and angled surfaces can be used to direct sound. Irregular reliefs or textured surfaces can be used to disperse sound throughout a space, minimizing direct, harsh reflections, and echo-y-ness. Low frequencies don't reflect off of

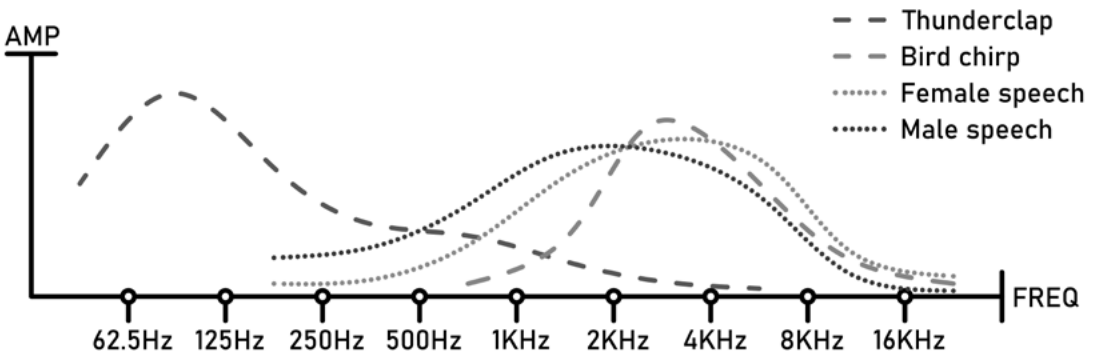

Fig.03/17 Frequency distribution of various sounds.

smaller surfaces, so larger protrusions or details like coffered ceilings are needed for redirection. Sound diffusion is less significant in smaller rooms as space is needed for sound to diffuse.

Not to be confused with echoes, ***reverberation*** *refers to the persistence of sound reflections in a space after the sound source stops.* Reverberation establishes a sense of space, for instance, a smaller room sounds confined or a large concert hall sounds roomy. Relatively high reverberance is desirable in live music venues as there's added fullness to the sound, however, this will negatively impact the clarity of transients which are key to ***speech intelligibility,*** *which can be defined as the level of clarity in the communication of speech in a given environment.* Comprehension of speech is a very complex process and ***transients,*** *a distinct short burst of energy at the beginning of a sound,* has a very important role in this process. Keeping the transients above the ambient noise levels, and preventing smearing, or overlapping of transients as a result of direct reflections are key to attaining speech intelligibility. So, *in spaces where understanding speech is important, such as classrooms, offices, meeting or consultation rooms, lecture halls, or even theaters,* ***lowering reverberation levels****, especially between the 1KHz -4KHz range would be desirable.* For some rooms, the ability to modify the reverberation time for specific function may be relevant, such as a concert hall being used for a string quartet concert, for a lecture one day later, and for a rock concert one day after that.

Vid.03/08 Video on the effects of long reverberation time.

Too much reverberance is a symptom of not enough sound absorption, exacerbated in larger volumes, resulting in a cave-like ambiance. Increasing the number of absorptive surfaces by using carpets, plump furniture, acoustical floating slats, or batting in the plenum would help with controlling reverberance.

Too much reverberation might cause ***sonic chaos*** *as everyone will be raising their voice to be heard. On the other hand, a completely dead space sounds unnatural and unsettling.*

The complete elimination of reverberance is incredibly expensive and should never be the

Fig.03/18 Curved wood paneling in this concert hall ceiling is used to direct and diffuse the sound.

Fig.03/19 The long protrusions in an anechoic chamber are necessary for absorbing lower frequency content.

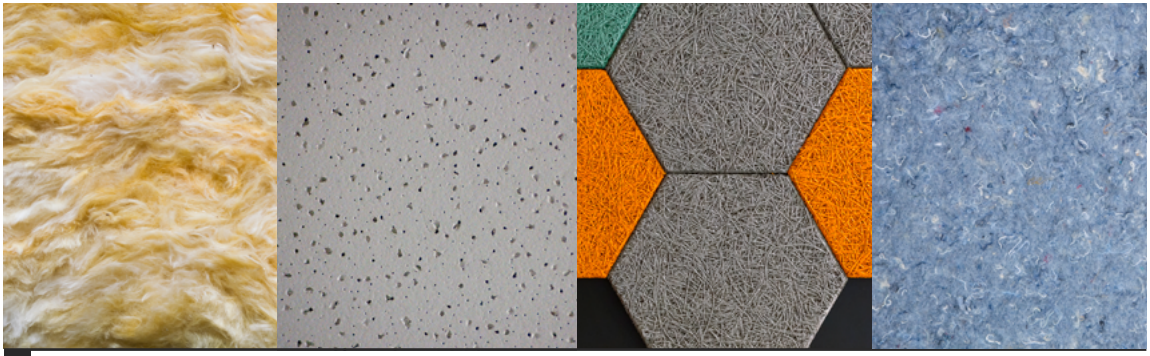

Fig.03/20 Four common sound absorptive materials: (from left to right) mineral wool, acoustic composite tile, wood wool, and recycled jean batting. Their common feature is the highly porous structure.

goal. *Such rooms are called* ***anechoic chambers*** *and they are used for highly sensitive testing, calibration, recording, and security applications.*

Contrary to sound reflection, sound absorption occurs when the incident sound energy is trapped within a material and converted to heat. *The* ***ability of a material to absorb sound*** *is dependent upon the porousness, fuzziness, and flexibility of a material, and for lower frequencies, mass, and depth of the material becomes important.* Fiberglass, mineral wool, spray foam, hemp, or even shredded old jeans are great materials for achieving good sound absorption, as well as thermal insulation in some cases. However, with these materials, there's a tendency for fibers and particles to break off and mix with room air. It is good practice to cover these materials with an acoustically transparent fabric or provide perforations on the facing material. ***Acoustically transparent*** *means that the sound can pass through unimpeded and unchanged,* if air can be blown through a piece of fabric it will also allow sound through. For instance, the center speaker in movie theaters can be located behind the curtain, which is acoustically transparent.

Depending on their physical make-up, different materials can absorb different frequency ranges efficiently. ***Absorption performance*** *is expressed by alpha value or absorption coefficient, a number between 1 for total absorption or transmittance and 0 for total reflection of incident sound energy.* ***Noise Reduction Coefficient (NRC)*** *is a single number that signifies a material's overall absorption performance, calculated by averaging the absorption performance at specific frequency bands, specifically 250hz, 500hz, 1000Hz, and 2000Hz.* NRC can give a general idea about what the sound absorption performance will be, but it is not completely accurate. For example, a 6mm pile carpet with foam underlay may have an NRC of 0.3 but the absorption coefficient at 125Hz is 0.05 meaning that most of the sound energy at this frequency band is reflected back. On the other hand, carpet tiles on a raised floor can have an NRC of 0.4 depending on the assembly, moreover, the air gap underneath, the absorption coefficient at the 125Hz band is higher at 0.27.

Textiles are not absorptive when stretched, however, when pleated to half area or more, a thick fabric like velour can ***help control high-frequency content*** *with an NRC at 0.35 to 0.4.* A common misconception is thinking that wood is a good sound absorber. A typical NRC at 0.07, wood is rather a great sound reflector, especially for higher frequencies. That is why in some high-end recording rooms, diffusers on walls feature wood. Wood can be perforated to let sound pass through to an absorbent batting behind, and since it can flex, the wood panel itself can act as

a tuned damper for lower frequencies. However, this is not a common application and would require consultation with an acoustical engineer.

> *In any case,* ***if acoustics is a major concern*** *in a project, an acoustical engineer should be involved.*

Controlling bass content is especially difficult in almost all cases. *High levels of absorption at the lower frequency bands can only be achieved via* ***thick and massive materials or deep airspaces****.* The bass content that dwells around the 125Hz band is very hard to control and suppress. However, a gypsum board assembly with an air gap can provide significant absorption; even though gypsum board itself is very reflective for higher frequencies and unless treated, can cause overwhelming reverberance.

Bottom line is, NRC is a good value for quick comparisons but for accurate decision making absorption coefficients at various frequency bands should be individually examined. *As it stands currently, NRC is being replaced by the* ***Sound Absorption Average (SAA)*** *value. Instead of sampling 4 frequency bands, SAA is the average of the absorption values from 12 frequency bands between 200Hz to 2500Hz.* SAA may provide slightly more accuracy, however, it is still a single averaged number.

Vid.03/09 Video on sound reflectivity of untreated gypsum board.

Sound transmission is the leftover sound after reflection and absorption passing through the length of one medium to the surrounding next one, whether it is a solid material or air. ***Sound Transmission Class (STC)*** *is a single-number rating that specifies how effectively a building component blocks the transmission of airborne sound between two spaces,* an averaged attenuation at various octave bands, similar to noise reduction coefficient (NRC). ***Sound attenuation*** *is the progressive reduction of sound intensity as it travels through a medium.* A higher STC rating means more acoustic separation of environments. However, it does not guarantee an efficient separation at all frequency bands, as blocking the lower frequency content is espe-

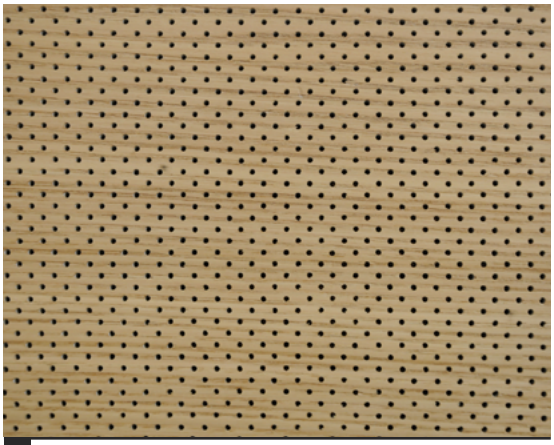

Fig.03/21 Wood can be perforated to achieve acoustic semi-transparency. Without perforations it can only reflect sound waves.

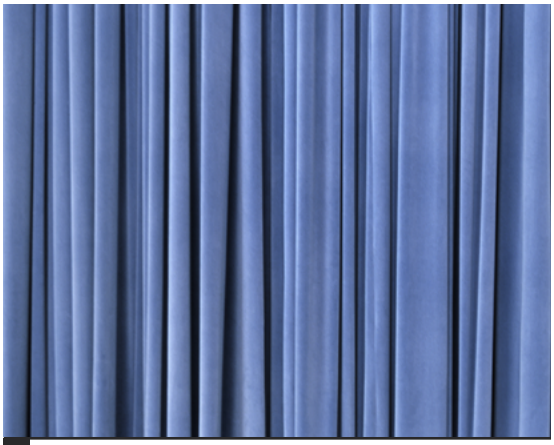

Fig.03/22 A thick velour curtain with deep pleats can provide some acoustic absorption, mostly at the high end of the sonic spectrum.

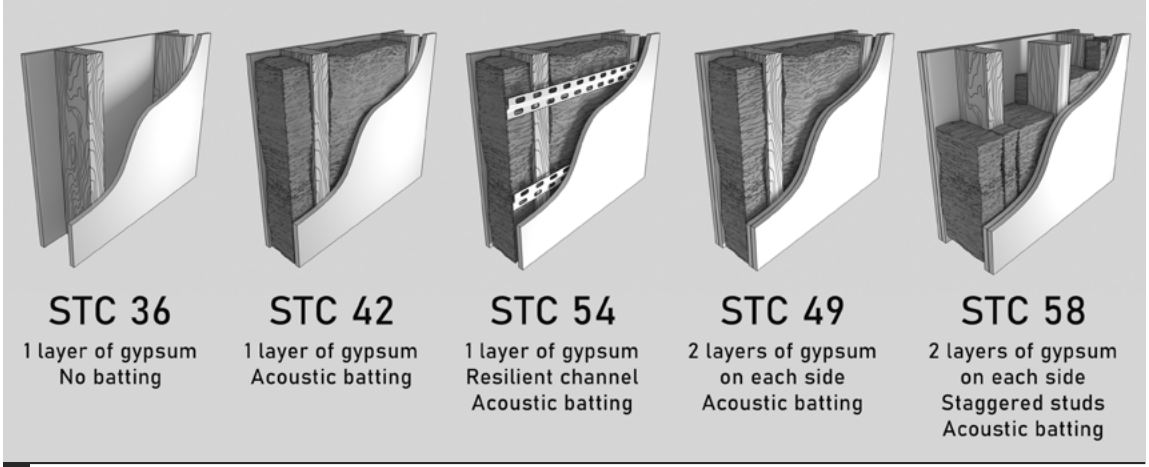

Fig.03/23 Sound transmission class (STC) for various gypsum board assemblies.

cially difficult since it can travel easily and far. ***Apparent Sound Transmission Class (ASTC)*** *is a relatively more recent and accurate representation of sound transmission between adjacent environments, based on occupant perception.*

The solid members of a continuous structural system, such as a reinforced concrete floor slab or even a wood joist spanning across two rooms, can carry vibrations between separate acoustic environments, especially the lower frequency content. This phenomenon, sound being transmitted through the building via the structure, is referred to as structure-borne noise. *The* ***Impact Insulation Class (IIC)*** *describes how well a building element or assembly can resist the transmission of impact-generated sounds.* Ceramic tiling or granite flooring has an IIC value of around 30, hardwood flooring is around 35, carpet with an underlay can be as high as 75.

A resilient finish, or underlayment, or raised flooring with resilient joints are good ways to mitigate the ***transmittance of impact sounds****. Resilience in this case refers to a material that can dampen energy through elastic deformation, such as rubber or neoprene.*

Sound can also leak through the smallest of seams, cracks, and openings, oftentimes negating the isolation attained with a partition or a divider. *This phenomenon is referred to as* ***flanking transmission,*** *where unwanted sound travels or rather bleeds through a supposed separator between two acoustic environments,* often due to bad partition design including, any uncaulked cracks, seams, or gaps, openings between rooms in the plenum (the area between

Fig.03/24 Resilient pads and coils are used to minimize transfer of equipment vibrations to the building.

suspended ceiling and ceiling), unsealed openings and penetrations, unstaggered and unsealed outlets, lack of using furring strips or dampening connections with resilient brackets, poor duct, conduit, and plumbing design, poor grill/register placement niches on walls, exposed plumbing, poorly caulked floor-wall and ceiling-wall seams, a lack of absorptive batting in the partition airspace. *Latex **acoustical sealant** is a good option for sealing seams as it can maintain its flexibility for a long time, does not harden or crack, and does not lose sound attenuation capability over time.*

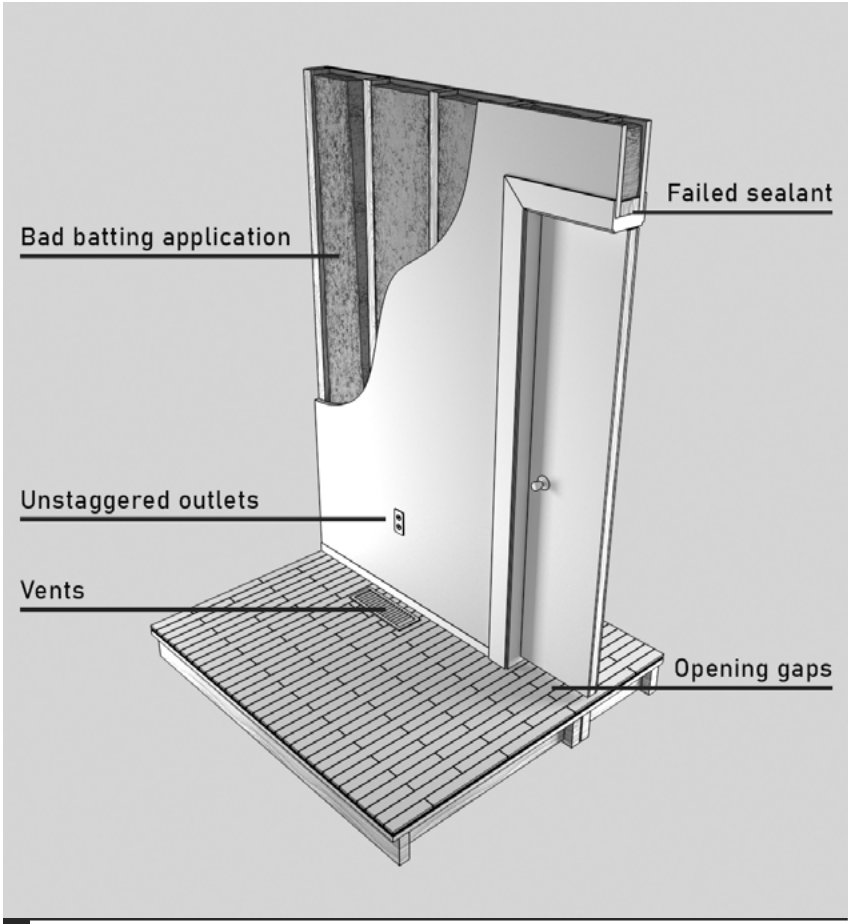

Fig.03/25 Illustration of common flanking points in a residential partition.

*An assembly's acoustical transmission performance will only be **as good as its weakest point**. It is always better to address bigger problems like a sound leak through a crack than setting up expensive resilient channels or using high-performance acoustic ceiling tiles.*

*Unless a partition is fully separating two rooms, in other words, **if air can freely flow** in between, these two rooms are referred to as a common acoustic environment.* In classrooms and conference halls speech intelligibility is important to achieve, however, in an open plan bank office, private conversations of customers might require limiting speech intelligibility, therefore achieving speech privacy. Open-plans, movable dividers, or separators between cubicles contribute little to speech privacy. ***Articulation index (AI)** is defined as the measurement of speech privacy in spaces with an open plan.* AI value below 0.05 indicates confidentiality, and above 0.2 indicates minimal or no speech privacy. Another metric is the *Privacy Index (PI) which is the inverse of AI in percentage form.* A PI value of 100% - 95% indicates confidentiality.

*If speech privacy is required, the direct sound should be blocked and absorbed, especially at the **1KHz to 4KHz range**.*

Another way to ensure speech privacy is increasing the background noise, ambient sound, or music. ***Sound loses intensity with distance**, this means the speech in close proximity will be clearly audible, whereas at distance it would be non-intelligible*.

04

SUSTAINABILITY

- *Sustainable thinking and design*
- *Carbon footprint*
- *Embodied energy and recycling.*
- *Life cycle assessment (LCA)*
- *Green building certification*
- *Eco-labels*
- *Green cleaning practices*

Since the 1950s, the connection between global warming and significant loss of ecosystems, declining biodiversity, exacerbating pollution, and the overuse of limited natural resources has increasingly alarmed the global community. *The **environmental movement** started taking shape in the 1960s and became a precursor to today's sustainable design mindset.*

Sometimes referred to as "green design", ***sustainable design** is a philosophy aiming to ensure that today's design needs are met without compromising future generations' ability to meet their own design needs*; a definition made by the Brundtland Commission of the United Nations back in 1987. It strives to minimize and potentially reverse negative environmental impact through conscious and efficient design practices. *Understanding and practicing sustainable design is crucial for any interior architect and designer due to the fact that the construction industry, they are a part of, **consumes 40% of the extracted raw materi-***

Fig.04/01 View of the Spiral Jetty, a land-art designed by Robert Smithson, contrasting man-made with nature.

als and contributes to 11% of the greenhouse gas emissions**, globally.* Since the impact is so enormous, any step taken in the right direction is bound to have a significant positive impact. The designer should think and scrutinize the necessity of any form of consumptive decision and refrain from deterioration, depleting, and diminishing. ***"Reduce, reuse, and recycle" is a maxim that encapsulates the sustainable design mindset. The sustainable design mindset urges the designer to consider *extraction, manufacturing, packaging, human rights, labor standards issues, transportation, maintenance, life-cycle, toxicity & off-gassing, water footprint, biodegradability, closed-loop manufacturing, green labels and certifications, end-of-life options* for any material to understand its impact on the environment in short and long term.

Successful sustainable design can only be achieved with a holistic approach, meaning, instead of focusing on discrete decisions based on recyclability, embodied energy, or toxicity, *assessing the overall benefits and impact with careful consideration of* ***life-cycle assessment*** *is often more appropriate*. ASTM E2129 outlines a good framework for thinking about sustainable products: ❶environmental impact, ❷manufacturing processes, ❸performance of the installed product, ❹indoor air quality, and ❺manufacturer's commitment to sustainability through corporate policy.

Environmental impact *would comprise the effects of the extraction of the raw materials, disturbing the local ecosystem, including deforestation or release of chemicals to the environment, as well as the fossil fuels spent in extraction.* Toxic emissions are a significant concern for most raw material extraction and purification processes, and often pose a threat to the local environment as well as the people involved in the manufacturing process. Consequently, sustainability issues are intertwined with economic and social issues. But the designer should also consider that local materials are often a better option as they don't impact the local economy negatively while minimizing CO_2 output due to fossil fuel consumption for transportation. ***Local doesn't immediately mean completely sustainable***. A local silver mine can still leak cyanide if managed improperly, or a local marble quarry will still destroy habitats.

Chemical runoff from some industrial processes can contaminate the soil. Especially the chemicals that are water-soluble can move through the soil reaching underground and surface waterways, aquifers, or move to water bodies and start accumulating on surrounding flora and fauna. ***Bioaccumulation*** *is the gradual and persistent accretion of chemicals and toxins in an organism; and being part of a larger habitat these organisms can be consumed by others,*

Fig.04/02 Being at the top of the food chain, bald eagles are often tested to assess bioaccumulation.

Vid.04/01 Video on bioaccumulation and biomagnification.

*which results in **biomagnification**, the gradual accretion of chemicals and toxins throughout a food chain.* Bioaccumulative chemicals will ultimately impact the local human population's health and wellbeing.

***Rapidly renewable** is a term that refers to resources that, after being harvested, replenish within the span of ten years.* A very popular example is bamboo, which can be used in many ways, such as plywood core, or veneers, or for extracting textile fibers. Cork, linoleum, and wool are other well-known rapidly renewable material sources. Biodegradable Polylactic acid (PLA) and starch plastic are produced mainly from renewable plant sources, but the associated environmental impact can be extensive, including deforestation, depletion of groundwater, agricultural runoff, incentivizing highly genetically modified species, fossil fuel consumption for farming, displacing local food production, etc.

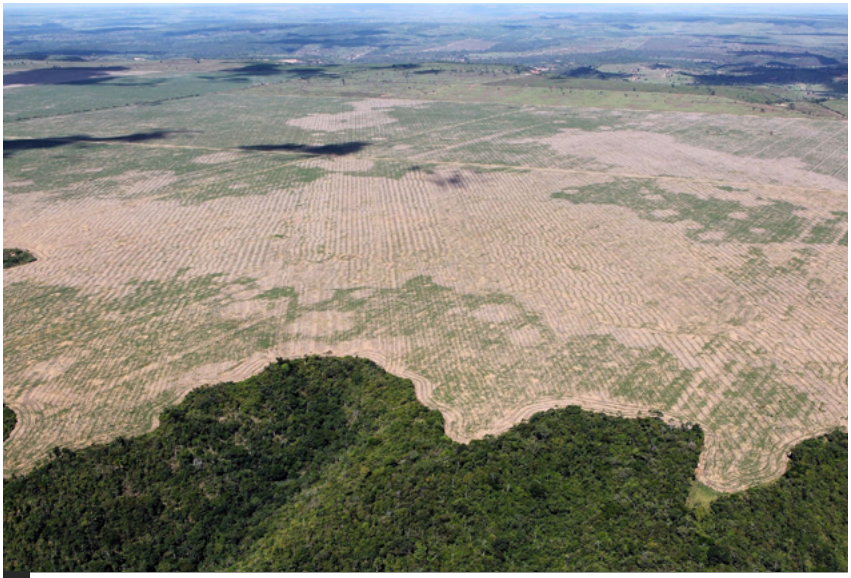

Fig.04/03 Excessive agricultural demand results in deforestation to create farmland.

> *Ultimately **when there's an environmental advantage there are also disadvantages**. How the designer balances the total harm and benefit a material throughout its useful life, considers its overall positive impact for society, and how it can be safely disposed of are exceedingly important.*

For instance, titanium utilized in aircraft manufacturing is very energy-intensive to manufacture and process, however, by making aircraft lighter, thanks to its high strength-to-weight ratio, it contributes to reducing the release of CO_2. Furthermore, it is highly recyclable and due to its high-value, recycling is actually feasible and widely practiced.

Tab.04/01 Questions for assessing environmental impact of various materials and finishes.

(1) Are the extraction and manufacturing processes non-destructive and non-toxic? Is the main resource renewable? What is the ratio of recycled to virgin content?
(2) Are the extraction and manufacturing processes humane, fair, and beneficial to the local community?
(3) Are the resources extracted, or materials manufactured locally, within a 500 mile radius? Are the packaging requirements modest?
(4) Is the manufacturer committed to environmental and social sustainability? Does the manufacturer offset resulting carbon emissions?
(5) Is the material fully or highly recyclable? Is the recycling process feasible? Is the recycled content of high or lesser quality? Can the material be reclaimed or repurposed?
(6) Does the material or finish feature established and widely recognized green labels or certifications? Does the material or finish supply credits towards green building certifications?
(7) What is the life expectancy of the product? Does the material emit any VOCs? Are cleaning and maintenance practices feature non-toxic and biodegradable products?
(8) What are the end-of-life procedures of the product? How much of the material is expected to contribute to landfills? Is the material readily biodegradable or compostable?

Fig.04/04 Cork is a rapidly renewable material, majority of which have to be transported from Europe.

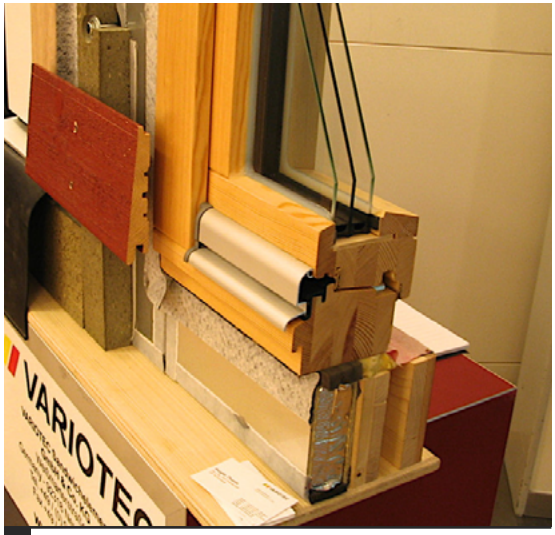

Fig.04/05 Meeting the passive house standard requires a multi-layered and complex insulation solution.

CARBON FOOTPRINT

Carbon footprint *is the total amount of greenhouse gases generated by any process, either directly or indicrectly. These greenhouse gases include carbon dioxide (CO_2), but also methane (NH_4), nitrous oxide (N_2O), and fluorinated gases.* Carbon footprint is not limited to the emissions during a product is being used, but also the emissions during manufacturing, transportation, construction, and disposal.

> *The carbon-neutral design mindset suggests* ***smaller is better****, in other words less manufacturing and less building results in less carbon emission.*

Carbon-Neutral Design (CND) *refers to a net zero carbon footprint associated with all processes from the extraction of raw materials to occupant behavior.* Since building construction and operation requires a significant amount of energy, sometimes the carbon released needs to be balanced by reducing or sequestering CO_2 somewhere else, through some other process. This is called ***carbon offsetting****, it is essentially compensating for carbon emissions outside of the manufacturing or use processes, such as funding renewable energy, sustainable agriculture, reforestation, or simply purchasing carbon credits.*

Net-zero building *refers to a building that is so energy efficient that it generates as much energy as it uses, through highly efficient insulation, solar energy panels, geothermal heating and cooling, integrated wind turbines, or various other means.* Some Passive House Standard compliant buildings are examples of net-zero residential design. The interior is sealed so well from the exterior that in theory no heating/cooling is necessary, thus the label ‘passive’.

Biomimicry *involves using forms, processes,*

Vid.04/02 Video on carbon offsetting and how it works.

Vid.04/03 Video on the experience of living in a passive house.

functions, and systems found in nature as a source of inspiration for the design and development of products that are more efficient, durable, and sustainable. A direct translation of the term would be "emulating life". Studying the chemistry of light generation in a firefly to invent a source of illumination, or studying the peregrine falcon to optimize the aerodynamics of an aircraft, or using ant colonies as a jumping-off point to develop dwelling complexes can be considered biomimicry examples. If achieving sustainability is the ultimate goal, where waste, resource depletion, and overall negative environmental impact are aimed to be eliminated, it is only logical to look at and understand a source that has established a balance within itself and with its surroundings.

Fig.04/06 The burrs of the burdock plant were the natural inspiration behind Velcro.

RECYCLING

The ***embodied energy*** *of a material or product is the total energy consumed during the entire production process.* This includes extraction of raw materials, refinement, processing, manufacturing, packaging, as well as transportation, shipping, and delivery procedures. For instance, wood is among the materials with the lowest embodied energy, especially when compared to other construction materials like steel, concrete, or various plastics. Wood is simply felled, cut, dried, and processed without significant requirement for refinement, heat, pressure, transportation, etc. On the other hand, Aluminum's embodied energy is very high due to the very energy-intensive refinement process, but after being created, the material can be recycled indefinitely and with high efficiency. Meanwhile, in addition to its high embodied energy, PVC is notoriously hard to separate from waste streams and recycle. The embodied energy of aluminum is justified in the long run through a lifetime of energy savings, whereas the same cannot be said about PVC.

Recycling *refers to collecting, separating, reprocessing, and reusing waste materials.* The recycled material content can be of high quality and highly feasible, equal to the virgin material such as in titanium. Or, it can be slightly lesser quality, so that it can be mixed with virgin material at various percentages to keep the resulting material quality at a certain level. For instance, up to around 30% of re-melted glass, also known as cullet, can be mixed with virgin glass to make clear float glass. Or the quality of the recycled material can be low and it can only be used for lesser products. Recycled PVC can have so many impurities due to the numerous additives used, mixing it with virgin PVC drastically reduces material quality and predictability. Low-quality recycled output coupled with low virgin material costs result in limited recycling. For PVC, recycled

Fig.04/07 Even the separated PET waste features multiple contaminations.

content is around 3% of all that is manufactured, the rest goes into a landfill. ***Cross-contamination*** *is another issue for recycling; the material itself can be highly recyclable, however, it might be combined with other products that would require further processing, increasing recycling costs, sometimes exceed virgin material production costs.* For instance, PET bottles are highly recyclable but they are often contaminated with a wrap-around label that is manufactured from a different plastic and an adhesive from yet another plastic, in addition to the residue from the liquid carried inside. The separation and cleaning processes increase costs to a level that only around 30% of PET bottles are recycled.

Even though providing the manufacturer an aura of credibility, the labels "recycled" and "recyclable" can be ***inaccurate and misleading*** *without knowing the exact percentages, which can potentially result in carefree consumer behavior.*

There are 4 important terms regarding recycling. ***Pre-consumer*** *recycled content, or post-industrial recycled content, refers to the material that is recovered from the waste stream of another manufaturing process.* Fly-ash, which is burnt coal ash, is one such example. *On the other hand,* ***post-consumer*** *recycled content refers to used and disposed materials that are reclaimed and reprocessed.* For example, recycling newspapers or water bottles. ***Downcycling*** *produces materials that are of lower performance and degraded quality.* Most plastics are recycled this way. After several cycles material becomes waste. Oppositely, ***upcycling*** *produces materials of higher quality and usefulness.* Homasote® panels and Richlite® are two examples of this process, which are recycled common paper products manufactured to be robust building products.

Biodegradability and compostability have been important terms associated with environmentally friendly material manufacturing. ***Biodegradable*** *essentially means disintegration by living things; that a material can be broken down into* CO_2*, water, and base building blocks through natural processes, including exposure to sunlight, elements, bacteria, fungi, algae, etc.* This label can be misleading, as the length of the process is not clearly defined; so, a material that degrades over decades can still be labeled biodegradable. If material is biodegrading slowly, over a decade, it will disintegrate into smaller particles, such as microplastics, and have ample opportunity to contaminate water resources or move up the food chain. Furthermore, when a biodegradable plastic is buried under mountains of trash with no access to oxygen and sunlight, it may not degrade at all. Also, specific species of bacteria may be needed to be present to carry out the decomposition. ***Compostable***

Vid.04/04 Video on the intricacies of aluminum recycling.

Vid.04/05 Video on Richlite®, an upcycled panel product.

Fig.04/08 Compost mounds need to be frequently aerated, otherwise buried waste won't break down.

Fig.04/09 Reclaimed wood imbues any design with a unique visual character.

means that the material undergoes a biological degradation process leaving no toxic residue. Compostability is clearly defined and regulated better than biodegradability. *In order to label a material compostable, 90% of the material must be converted to CO_2, water, and biomass* ***within 90 days.*** There are various types of composting such as vermicomposting involving worms, or windrow composting involving periodic aeration. A "compostable" label does not guarantee that the product will break down through domestic composting processes.

Reclaimed and repurposed materials have significant importance in sustainable thinking. *Many materials can be* ***reporpused and reused****, discarded brick, lumber, tires, etc.; cheaper and faster than recycling*. Reclaimed materials and products can be creatively refinished, repurposed, and utilized in a different context and for different use. The "Rover Chair" by Ron Arad is a famous example where a used car seat was taken out of context and with minimal additions transformed into living room furniture. The options are limitless as long as there's an open eye to see the potential. ***Design for disassembly*** *is another important concept related to sustainability, which leverages flexibility, partibility, and convertibility, suggesting that new components can be added and subtracted to meet changing needs of the user.* This concept also applies to inter-changing the parts that are worn or damaged. It is better to change a carpet tile worn under the use of chair casters rather than changing the carpet of the whole office, or changing a warped wood shelving instead of throwing away the whole cabinetry. The design for disassembly mindset favors mechanical fasteners against adhesive use, or simplicity over complexity and embellishment.

Life Cycle Assessment (LCA) *is a systematic analysis method used to evaluate the environmental impacts associated with all stages of a*

Vid.04/06 Video on life cycle assessment (LCA).

Fig.04/10 The KSU College of Architecture, Planning and Design is housed in the LEED Silver certified Seaton Hall.

product's life. It encompasses environmental and technical data from raw material extraction through manufacturing, use, and disposal or recycling. Life cycle assessment is probably the most important way to look at sustainability over the long term. A product might have minimal embodied energy, cheap to produce, but if it deteriorates quickly and cannot be recycled as it is hard to identify and separate, it goes to contribute to a landfill. Therefore, contrary to the information on paper, it may not be sustainable at all. PVC is one such material. Due to the extensive diversity of additives it is very hard to separate from waste streams and recycle. ***Life Cycle Thinking*** *is considering the full range of environmental, social, and economic impacts of a product or service from cradle to grave.*

GREEN BUILDING CERTIFICATION

The term ***green building certification*** *refers to processes that evaluate, recogize sustainable design and construction efforts based on cretieria related to energy efficiency, water usage, materials, indoor environmental quality, and site development.* There are multiple organizations throughout the world granting green building certification. ASTM International, has developed hundreds of standards to ensure the design and construction of sustainable buildings, which form a foundation for codes such as the International Green Construction Code (IgCC) and building sustainability rating systems such as Leadership in Energy and Environmental Design (LEED).

> *LEED is the* ***most prevalent green building certification program*** *across the globe. This program created a systematic framework to evaluate building's as well as neighborhood's sustainability performance, ultimately helping clients, investors, designers, contractors to make environmentally conscious decisions.*

Each decision, starting from building site to maintenance and operation is awarded points

according to the *LEED framework, and projects are awarded one of the following ratings: LEED certified, silver, gold, and platinum.* LEED certification displays a commitment to sustainability, environmental stewardship, and responsible building practices. It demonstrates a dedication to reducing carbon emissions, enhancing energy efficiency, conserving water, improving indoor air quality, and utilizing sustainable materials. LEED certification also signifies a commitment to the well-being of building occupants and the broader community, promoting healthier, more sustainable living and working environments.

LEED has multiple branches of evaluations, the ***LEED Interior Design + Construction (ID+C)*** program focuses on certifying various types of interior spaces and contains the following seven categories, each of which are separately evaluated: (1) location and transportation, (2) sustainable sites, (3) water efficiency, (4) energy and atmosphere, (5) materials and resources, (6) indoor air quality, (7) innovation.

Even though LEED has immense popularity in the US and prominence across the globe, there are other formidable environmental sustainability certifications. the ***Building Research Establishment Environmental Assessment Method (BREEAM)*** *is another popular certification program, that is more popular in the United Kingdom, that has a different set of criteria and evaluation process that is claimed to be more rigorous and quantitative.*

Living Building Challenge is another comprehensive sustainability standard. *Instead of only focusing on minimizing the negative environmental impact, this certification aims to improve the wellbeing of occupants, community, and the local environment of a building,* ***aiming to be regenerative****.* One important aspect of the Living Building Challenge is, it promotes a Red List that include but not limited to vinyl derivatives, BPA, phthalates, paraffins, formaldehyde, halogenated flame retardants, toxic heavy metals such as arsenic, mercury, cadmium, and lead, asbestos, etc. It also introduces the Declare label for materials and expects products in the Declare Database to be used to the outlined extent. *Living Building Challenge is putting a strong emphasis on salvaged and reclaimed materials, and diversion and integration of waste.*

Another program relevant for interior spaces is the ***Well Building Standard****, which is developed to create health and wellbeing-focused environments with some unique standard categories such as nourishment, movement, sound, and mind among others: air, water, light, thermal comfort, materials, and community.* In terms of material specifications, the Well Building Standard is primarily concerned with the materials and the chemical byproducts that can threaten the wellbeing of individuals during the construction, remodeling, furnishing, and operation of a building. There's a requirement for transparency in materials, achieved through labels of independent organizations such as: the declare label, mentioned above, Health Product Declaration, Cradle-to-Cradle, or Greenguard. *The materials listed in the Living Building Challenge Red List, mentioned above, and the Cradle-to-Cradle Restricted Substance List are expected to be* ***completely omitted****.*

ECO-LABELS

In the context of materials and finishes, ***eco-labels*** *are identifiers that describe a product's ability to meet various health, safety, and sustainability standards.* The Environmental Protection Agency (EPA) defines eco-labels as identifying marks, owned or managed either by

Vid.04/07 Video on the Living Building Challenge.

government agencies, non-profit organizations, or private sector entities, associated with products that indicate an ability to meet or exceed a single or a group of environmental performance criteria. *Eco-labels are awarded based on an* ***independent evaluation*** *of products, or* ***self-reporting*** *by manufacturers.*

With the growing interest in environmental protection and sustainability, *a consciously vague or misleading language and marketing strategy on product information, advertisement, promos, and sales pitches created the issue known as* ***greenwashing.*** The various manufacturer claims might not be all-out misinformation, but could be hiding negative impact and trade-offs. Biodegradable, single-use plastics or starch plastics are one example of greenwashing. There are certain conditions to be met for the breakdown to happen, such as the presence of certain species of bacteria or continuous air and sun exposure. Most landfills cannot meet these criteria and the readily disposed of plastic stays pretty much intact.

> *The bigger problem is that the biodegradability claim influences the end-user to quickly* ***dispose of products without much thinking****, causing more unseparated trash, whereas minimizing waste by more durable multiple-use products would have been more environmentally friendly.*

When trying to assess if a product meets health, safety, and sustainability standards, instead of relying on manufacturers' claims, it is better to focus on eco-labels that are either backed by established non-profit organizations such as the Environmental Protection Agency (EPA), or the Underwriters Laboratories (UL), or labels that are widely accepted throughout the industry such as Green Seal or Declare. Some of the most relevant eco-labels are explored below.

GREEN SEAL ● This is a non-profit certification program, extablished in 1989, developing standards for products and services to promote sustainability, reduce waste, and improve health and environmental performance. The certification covers a broad gamut of products and services, aside from construction materials, cleaning products, food packaging and preparation services, hospitality services, paper, and paper products. Green Seal is integrated into the LEED evaluation process and LEED points can be accumulated with certified products.

GREENGUARD ● Published by UL, products carrying this particular label meet low emission standards contributing to minimizing indoor air pollution. Products carrying the Greenguard Gold Certification meet even stringent VOC emission standards and are claimed to be safer for children

PRODUCT LENS CERTIFICATION ● Also published by UL, aims to provide clear and meaningful communication of risks and hazards associated with various products, ensuring overall transparency based on actual usage of the product. Like Green Seal, certified products can also generate LEED points.

ENERGY STAR ● *Established by the EPA and the US Department of Energy*, is a mark of energy efficiency, providing a concise and comparative picture of the energy usage of products. The evaluation processes are carried out by independent agencies. With its yellow and black graphics, it is easily and immediately identifiable. This certification is provided for appliances, HVAC equipment, computers, and even entire buildings and manufacturing plants.

DECLARE ● Published by Living Future Accreditation and recognized by the Living Building Challenge and LEED, this label documents a product's story, contents, composition, life expectancy, and end-of-life options. The online database lists all Declare products, some with Red List Free mark. ***Red List*** *includes ingredients that are known to*

Link 04/01 *Link to the Transparency Database Precautionary List.*

be harmful to human health and the ecosystem.

HEALTH PRODUCT DECLARATION (HPD) ● *Developed by GreenCE*, is a standardized product content report that outlines ingredients that can be considered environmental health hazards. HPD is self-reported, unlike the other eco-labels. HPDs are also a way to accumulate LEED points. Currently, third-party verification is not required.

CRADLE TO CRADLE (C2C) ● This certification evaluates brands based on their commitment to five sustainability categories: material health, material reuse, renewable energy and carbon management, water stewardship, and social fairness. Five achievement levels are assigned to independently evaluated products signifying the manufacturer's dedication to sustainability.

TRANSPARENCY ● This is a database established by Perkins + Will, that informs designers and the public about the health impact of end-user materials as well as manufacturing chemicals and ingredients. *The* ***Precautionary List*** *is similar to the Red List but detailed information is provided for each item.* The website also features a stream of news on the health impact of building materials and the industry.

GREEN CLEANING PRACTICES

In order to maintain the spatial conditions, as well as occupant health and standard of living, regular cleaning practices are a necessity. Using the correct cleaning product on every surface is important in terms of minimizing user exposure and increasing the useful life of surfaces. However, *many cleaning agents and products used to maintain the materials and components in living and working environments contain toxic chemicals such as harsh acids, and solvents contributing to the VOC content of the environment,* ***degrading air quality****.* At the very basic level, the cleaning products can act as an irritant and cause immediate harmful effects on the eye, skin, or the respiratory system and provoke allergies, not just for the occupants but also for cleaning crews as well.

The biodegradability of cleaning products is another crucial consideration, especially their ability to degrade and disintegrate after being flushed down the drain. However, there are different types of water and different drains within a building. ***Potable water*** *refers to drinkable water,* ***grey water*** *refers to wastewater without any contamination, and* ***black water*** *refers to contaminated water.* The contamination in question includes excrement and chemicals. The used water from sinks, showers, and baths are considered greywater and may only be subject to light treatment, unlike black water from toilets that has to be treated at sewage treatment plants.

Fig.04/11 The strict cleaning procedures introduced after COVID-19 exposed the occupants to higher levels of VOCs.

*This means that the **non-biodegradable cleaning products** mixed with greywater streams can affect garden soil, water systems, plant, and aquatic life and they can persist for longer periods, possibly moving up the food chain.*

*It is possible to develop a **green cleaning strategy** to ensure that environmental impact is minimized.* Product packaging and shipment efficiency, safety, and recyclability, as well as cleaning procedures that minimize exposure and allow for efficient application are important. *EPA manages the **Safer Choice Program** which identifies certified cleaning products that are safe for human health and the environment.* LEED points can be accumulated when green cleaning policies are in place, *the products and equipment have a low environmental impact, and are **properly stored in designated locations**, such as housekeeping closets.* Furthermore, the designer should be conscious of the cleaning requirements for the materials being specified, as to minimize the need for frequent cleaning with harsh cleaning products.

05

PAINT & WALLCOVERING

- *Typical paint components*
- *Paint history and types*
- *Gypsum and plaster*
- *Paint application and disposal*
- *Wallcovering history and types*
- *Wallcovering application*

Paint is a liquid surface coating that forms a protective film upon evaporation. It often contains pigments and various additives for visual effect. Cave paintings are the earliest applications of paint, some dating 40 to 50 thousand years ago. The application of paint with the specific intention to visually enhance a space came from the ancient Egyptians, known to be brilliant paint manufacturers and artists. Some of their wall applications still possess their brilliancy today. Ready-mixed, or prepared paint, became widely available towards the end of the 19th century, enabled by the industrial revolution, transforming the look of interiors as well as products. Today, paint is the most inexpensive method to protect and visually enhance a surface.

*Paint is a mixture of **4 fundamental components**: ❶pigments to give color to the coating, ❷additives to enhance the performance, ❸binders to hold the particles together, ❹solvent to enable transfer and spread to a surface.* The

Fig.05/01 Dating back to 13000 years ago, the Cave of Hands is located in Santa Cruz, Argentina.

amount, balance, and quality of each one of these will affect the quality of the paint job. Lower-grade content would be cheap but the result won't be satisfactory. Higher-grade content may be easier to work with and suitable for DIY situations but might not be justified in all scenarios due to budget limitations. Trained professionals can achieve good results with relatively lesser quality paint, that is why contractor-grade paint is cheaper than retail-grade paint.

Pigments *are powdered chemical compounds, such as copper phthalocyanine or titanium dioxide, that impart color to and enhance brightness of the mixture.* There are two types of pigments; prime pigments that introduce the color, and extender pigments that enhance coloring properties. Higher pigment concentration, or pigment load, provides a coating with better saturation, coverage, and hiding power, however, it is relatively expensive. On the other hand, lower pigment concentration looks more desaturated, less brilliant and intense; appearing somewhat dull and transparent. Depending on the resin content, paint can appear relatively glossier. Too much pigment in a paint mixture can be detrimental to the application, causing gaps to form between particles. The application surface becomes textured, matte, permeable, and less resistant to abrasion. It is the overall balance and appropriateness for the purpose that determines the performance of the paint. ***Extender pigments*** *are colorless and inert chemicals such as calcium carbonate, calcium sulfate, silica, clay, talc, etc. These are added to adjust or improve the paint's properties such as glossiness, consistency of the application, and enhance durability and abrasion resistance.* Extender pigments are typically low cost compared to prime pigments; they give the paint body and bulk. Typically, higher quality paint has a higher prime-to-extender pigment ratio. Even though it functions similar to extender pigments, ***titanium dioxide****,* TiO_2*, is an important prime pigment that has a bright white color and it is*

Fig.05/02 Titanium Dioxide (TiO_2) is a pure white pigment with highly useful properties.

Fig.05/03 In order to mitigate the tiny craters, defoaming agents should be mixed in the paint formula.

widely used to introduce brightness, opacity, and hiding power to paint. It is relatively expensive.

Recently TiO_2 has been classified as a suspected carcinogen by the International Agency for Research on Cancer (IARC). It is much less toxic than lead, but it might ultimately share a similar fate.

***Additives** are special-purpose ingredients that improve or fine-tune the performance of the coating.* There's a large selection of additives available such as thickeners that improve the consistency of the paint; dispersing additives that are used to eliminate flocculation, which is forming of small loose aggregations within the mixture; wetting agents that improve the liquid absorption capabilities of the powdered paint components; antisettling agents that increase the viscosity of the mixture delaying the drying and settling processes both during application and storage; defoamers that eliminate foaming which causes coating defects during application; coalescents that facilitate continuous film formation during application; UV stabilizers that prevent UV degradation; biocides that inhibit mold and mildew growth; fire-retardants that establish fire resistance, achieving up to ASTM E-84 Class A rating depending on the amount of additive mixed in. It is also possible to add various additives to introduce texture, such as sand texture, smooth texture, or coarse texture additives.

*Designers should be careful as paint additives, even though they are highly useful, can significantly **impact toxicity levels and VOC emissions**.*

***Binders** hold the contents of the paint together and enable the film coating to adhere to the application surface.* Gum Arabic is a natural secretion by acacia trees, primarily used as a binder since 3000 BCE in the Middle East and Africa. Binder directly determines paint's performance in terms of abrasion resistance, scrubbability, color and gloss retention, etc. *Typically, binders have very **high density and limited flow**, they need to be mixed with a solvent to make paint application possible.* Common binders include acrylic, alkyd, epoxy, latex, and polyurethane; binder type needs to match solvent type.

Fig.05/04 Acacia tree sap, or gum arabic, has been used as a natural paint binder for thousands of years.

Fig.05/05 An eggshell paint finish produces a smooth gradient when interacting with light.

The ratio of the binder determines the sheen level of a paint application. ***Lower sheen*** *levels feature lower binder ratios,* they are harder to maintain, however, they also conceal imperfections, are easy to touch up, and produce no glare. On the other end of the spectrum, ***high gloss*** *finishes feature higher binder ratios*. They are easier to clean and maintain, however, they highlight imperfections and require extensive substrate preparation. The lowest sheen levels are best for ceilings where substrate prep is more expensive and almost no traffic will be received, and the highest sheen levels are appropriate for conditions where ensuring hygiene or maximizing daylighting is an important factor. Typically, manufacturers assign a name for each sheen level based on the percentage of reflectivity; some common ones are flat (up to 10% reflectance), eggshell (10% to 20%), satin (20% to 35%), semi-gloss (35% to 65%), and high-gloss (65% and up).

Solvents, *or thinners, facilitate the transfer of paint components to the application surface*, sometimes referred to as "vehicle". They increase flow, enable a uniform spread, and allow the penetration of the application surface. Solvents are not part of the cured application; they evaporate leaving a consistent film coating

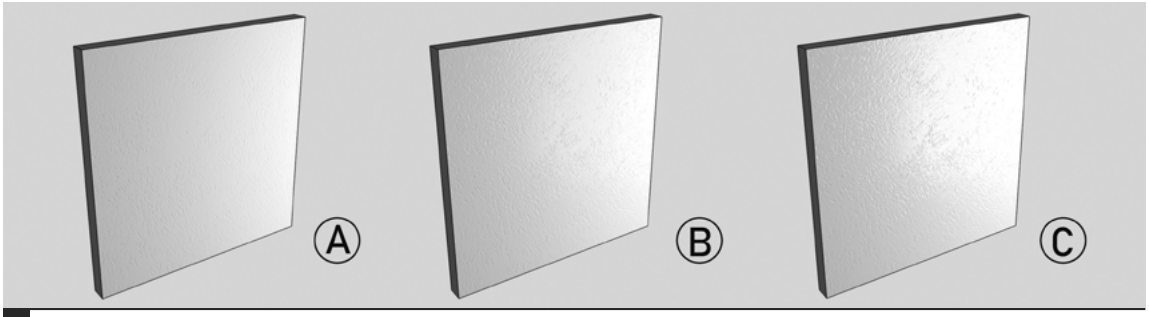

Fig.05/06 Different levels of sheen in paint applications: eggshell (A), satin (B), and gloss (C).

of the other three of the components of the paint. *The amount of solvent negatively affects* ***coverage and hiding power*** *of paint, cheaper paints feature proportionally more solvent.* Spraying applications might necessitate higher solvent content to increase flow and minimize clogging. One gallon of paint typically covers 300 to 400 square feet of wall surface. However, the number of coatings ultimately impacts how much paint is needed. For repainting over the same color, one or two coats would be sufficient, for darker, deeper, or lively and saturated colors multiple coats would be needed. Absorbency of the substrate might affect the number of coats, if not primed properly gypsum board or plaster can soak a significant amount of paint. *The* ***complete curing*** *of paint can take up to 2 months and some manufacturers suggest refraining from wiping or washing the application for around two weeks.*

There are two major paint categories based on the solvent utilized: water-based and oil-based. ***Water-based paints*** *use water as the solvent, which are further categorized based on binders as latex paint, acrylic paint, or acrylic latex.* Some advantages include fast curing times and significantly low VOC emissions, convenient cleanability with soap and water. Latex paints feature better elasticity, they are resistant to cracking and retain color well. They are breathable, allow moisture through, rather than causing it to build up in the substrate, which may end up resulting in mold and mildew growth.

> *The latex paints currently available in the market* ***can match oil-based paint performance*** *and some even exceed it. There are extremely durable water-based paints in the market, up to 25000 scrubs in accordance with ASTM D2486.*

Also referred to as alkyd-based, ***oil-based paints*** *feature alcohol, mineral spirits, or paint thinners as the solvent. Oil-based paints are known to be durable, ideal for trim, woodwork, and cabinetry applications, especially moving or sliding parts; they can resist wear and impact exceptionally well.* They provide higher washability and scrubbability, do not allow moisture penetration, hence commonly found in wet spaces. They also have higher coverage, a smoother look, more forgiving to substrate imperfections; longer drying times helps to conceal brushwork. Despite their advantages, oil-based paints have some significant disadvantages. They are relatively costly; require hazardous chemical solvents for cleanup; release a significant amount of VOCs when drying, to an extent that their use is restricted in some states, such as New York, Pennsylvania and Virginia. Water-based paint cannot be painted over with oil-based paint.

Fig.05/07 Oil-based paint is appropriate where moisture exposure or scuffing is expected.

> *The VOC emission levels for architectural paint are* ***regulated by EPA under the Clean Air Act (CAA)****, however, designers should consider that this act mainly targets ambient air quality and does not guarantee low toxicity in indoor environments. Some states apply further restrict ions to VOC emission levels.*

In addition to water-based and oil-based paint, there are many other types of paint that feature

different formulations. ***Clear coatings,*** *such as clear epoxy and polyurethane, does not contain pigments and primarily applied to provide protection or enhance appearance.* ***Stains*** *have a high concentration of solvent and low concentration of pigment and binder, intended to penetrate the application surface and provide a transparent tint.* Paint can also have very specific functionality. ***Intumescent paint*** *is a fire-resistive film coating that foams and expands when exposed to heat above around 200°F creating an insulating barrier, mainly used on steel or wood structural elements.* The number of coatings gives 30- to 120-minute fire protection; though an excessive number of coats might result in sagging. It is possible to apply a compatible topcoat in any color.

GYPSUM & PLASTER

Gypsum and plaster are the two most common substrates for paint as well as wallcovering applications, therefore a fundamental understanding of general properties and construction is imperative.

Gypsum board, also known as drywall or gyp-board, is a very common wall and ceiling substrate. Gypsum is the name given to a naturally occurring and highly common mineral, calcium sulfate dihydrate (CaSO4.2H2O). *It is a non-hazardous, non-toxic chemical, though in powder form, that is commonly encountered on construction sites, can* ***irritate eyes, skin, and respiratory system****.* The mineral is first heated into an intermediary product known as calcined plaster, which is later mixed with water and sandwiched between paper facers. Evolved from a product called plasterboard, the first gypsum boards manufactured in 1916 featured paper-felt facers, in the next two decades the construction of the board improved and transformed into the version with paper facers widely in use today. It has been a consistently popular construction material since the 1940s.

Aside from the high energy cost of the baking process, ***gypsum requires quarrying*** *which results in deforestation and habitat loss.* However, gypsum is also fully and infinitely recyclable. The paper facers on both sides are removed along with screws and nails, which are also fully recyclable. The downside is, the amount of contamination reduces the quality of recycled material. Therefore older boards from demolition waste require extra processing, and only so much recycled gypsum is allowed in newly manufactured boards. But, ground gypsum has many uses other than being recycled into gypsum

Vid.05/01 Video on gypsum board manufacturing and use.

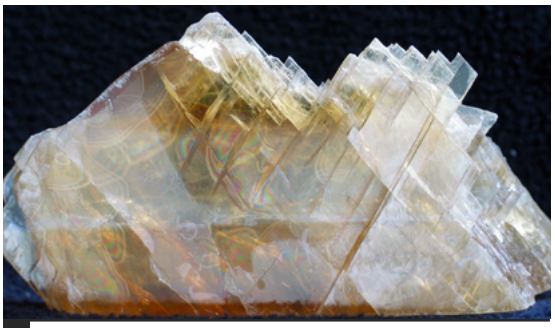

Fig.05/08 Gypsum crystal before processing.

Fig.05/09 An abandoned gypsum mine.

boards, it can be used to amend the soil, as an additive for other construction materials such as plaster, for water treatment, etc. However, if gypsum ends up in landfills, untreated, there's a possibility of producing toxic gases due to bacterial activity.

There is a wide selection of gypsum board types, aside from the regular product. Gypsum is inherently fire-resistive, but it starts to crumble after 30-minutes of exposure. *Fire resistive gypsum boards are called* ***type-X boards***, these feature glass fibers as well as other core additives to achieve 1-hour fire resistance per each 5/8" thick board and 45 minutes for 1/2" thick board. Multiple boards can be layered to meet exact building code requirements. There is a type-C version available with improved performance.

If some form of impact, piercing, or sustained application of force is expected, ***abuse-resistant or impact-resistant gypsum panels*** *may be a good option.* These panels uniquely feature a fiberglass mesh between the core and the backing. *A* ***glass-reinforced gypsum board*** *is a lightweight and high-strength alternative to the regular gypsum board.* It is somewhat water and mold-resistant.

Moisture-resistant gypsum board*, or green board, features a green-colored moisture-resistant backing. It provides resistance against humidity, however, it is not completely water-resistant.* There's a higher performance ***foil-backed*** *version, where the moisture-resistant backing is substituted with a vapor retarder aluminum foil.* For both types, the rest of the gypsum board is standard. Gypsum, when allowed to get wet, it can sag and facilitate mold and mildew growth. There's a ***sag-resistant gypsum board*** available; these are used as ceiling boards. The core is strengthened with additives or reinforced with glass fibers; they are lighter weight than regular drywall boards.

The standard 1/2" drywall can be bent at a radius of 10ft and 1/4" drywall can be bent at

Fig.05/10 Green-board is appropriate where some moisture exposure is expected.

a 5ft radius. A ***flexible gypsum board*** is a 1/4" thick board that can be curved around a 1ft radius without warps, bows, crumbling, or cracking. No wetting facers or scoring/kerfing for very tight curves is needed.

Prefinished gypsum boards *save installing costs and time, eliminating dust and debris.* There are benefits such as high washability, low maintenance, and fire resistance. They can feature vinyl or textile surfaces with various colors or textures.

In the ***standard GA-214****, the Gypsum Association defines 6* ***levels of gypsum board finish****, that are commonly referenced in modern construction projects.* Each level of finish outlines criteria to achieve incrementally higher finish quality and smoothness, based on how much visual exposure and scrutiny the surface will be subject to. The lowest level, Level 0 is appropriate for temporary construction, is a completely unfinished application featuring no taping, sanding, patching of any kind. Level 1 is

Vid.05/02 Video on curved drywall application.

appropriate for areas where the surface will be concealed and away from public view, features seams treated with taping and joint compound, tool marks, and ridges are tolerable. On top of Level 1 recommendations, Level 2 features covered and coated fasteners as well as a thin coating of joint compound on all seams; it is appropriate for use as a tile substrate, or in areas with low aesthetic priority such as storage rooms or garages. Level 3 features an additional coat of joint compound on fastener heads and accessories, all joint compound is expected to be smooth and free of any tool marks or ridges; appropriate as a substrate for textured wallcovering or paint applications. Level 4 is appropriate for smooth paint and thick profile backed wallcovering applications, and level 5 recommended for high sheen smooth paints, especially if side lighting or grazing lighting is expected, and thin profile wallcovering applications. Both levels feature a smooth surface, level 5 featuring an extra thin skim coat of joint compound. The ***standard ASTM C840*** can also be referenced for this process. It defines a stricter specification for the application and finishing of gypsum boards.

Plaster *is a thick viscous material, a mixture of gypsum, water, and sand that hardens as it dries and becomes rigid and brittle.* The mixture can be referred to as mud. ***Gypsum plaster****, also known as plaster of Paris, uses gypsum as a binder; it is comparatively more common.* This type of plaster is targeted towards interior applications. Too much moisture exposure can cause mold and mildew. It is commonly reinforced with glass fiber for enhanced performance. Joint compound is a specific mixture of gypsum plaster. Gypsum can be substituted with cement or lime to achieve different types of plaster. ***Cement plaster,*** *also referred to as stucco, uses Portland cement as a binder. It is relatively more durable, can be used on exterior walls.* It is possible to mix in glass fiber and vermiculite for added strength. ***Lime plaster*** *is permeable and inhibits mold and mildew growth. It is less brittle than gypsum and cement plaster and less prone to cracking.*

Fig.05/11 Plaster application over cross wood lath can still be found in some older housing.

Around the 1940s, before gypsum wallboard became a widely used material, wood lath and plaster was the dominant wall construction method. The application was expensive and

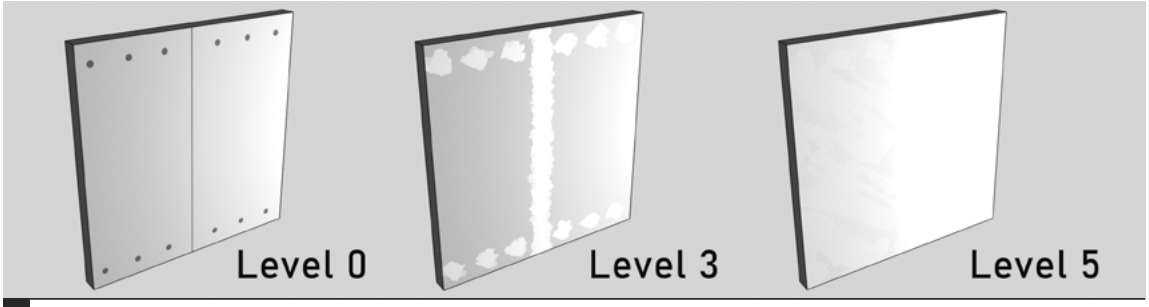

Fig.05/12 Three distinct levels of gypsum board application according to GA-214.

time-consuming. There are lath and plaster walls and ceilings still present in houses built before the 1940s. They can be harder to repair than drywalls, and might require relatively costly replacement.

Compared to gypsum board, plaster is a slightly more durable application and it provides a relatively tighter seal and good acoustic separation. Vermiculite can be introduced to the mixture for improved fire resistance. ***Plaster*** *is brittle after it is completely dried, building movement may introduce cracks to the material, therefore it needs routine maintenance.* Drying times are shorter than drywall skim coating and application is relatively quick, however, it requires skill to install, therefore it is costly.

Contemporary applications feature one of the many types of metal or fiberglass lath. Lathes are typically slightly furred, meaning spaced from the attached substrate, providing support for the plaster. Diamond wire lath is a simple wire mesh. Paperback wire lath is attached to a backing paper for easier installation. ***Expanded metal lath*** *features some inherent depth to hold onto multiple layers of plaster application. Ribbed lath features even deeper ribs for more robust plastering, much more dimensionally stable than other options, and suitable for ceiling applications.* Exterior applications require an exterior grade galvanized metal lath, as plaster tends to soak up moisture and can cause corrosion.

Typically, plaster is applied in three coats – ❶***scratch coat*** is applied first to create a combed surface for the second coat, commonly referred to as ❷***brown coat*** to attach. This layer is left rough and open for the application of the smooth ❸***finish coat***, third and last. Each coat is applied after the previous coat has dried. A two-coat or thick single coat application is possible but they provide less durability and protection.

Plaster, has ***excellent moldability and retains intricate detail.*** Glass fiber reinforced plaster is highly appropriate and widely used for molded decorative applications, such as crown moldings, cove moldings, chair rails, or wainscoting.

PAINT APPLICATION

For any common paint application, surface preparation is the most important procedure to ensure a ***well-performing and aesthetically pleasing finish.*** Since paint is essentially a very thin film, often 3 to 5 mils, any irregularity or imperfection on the substrate is directly telegraphed to the surface. *A* ***mil*** *is a thousandth of*

Fig.05/13 Laborious to install, a furred diamond wire lath provides good basis for plaster to hold on.

Fig.05/14 With silicone molds, plaster trims can feature highly intricate detail at a reasonable cost.

an inch, equals to 25.4 microns. New substrates are more predictable, on the other hand, older substrates are full of surprises. They can feature corrosion, decay, soaked chemicals, moisture build-up, or even feature hidden fungal growth; all of which can possibly bleed into the finish coat, causing adherence problems, deformation, and staining.

After confirming that the substrate is healthy, ***Surface preparation*** *typically involves removing previous application residues and mending defects, such as patching cracks, dents, and other surface irregularities.* For drywall preparation, depending on level of application, seams and fasteners are coated. *Typically,* ***joint compound*** *is used for patching and filling, spackle is a different product and used for small patching jobs.* ***Skim coating*** *is a way to create a consistently flat and smooth foundation for paint application.* It is achieved by applying a layer of joint compound and smoothening with a skimming blade. If the substrate features an undesired texture, substantial flaws, or it belongs to a wall that is expected to receive grazing lighting, skim coating is a necessity. After the filling compounds are cured, the surface should be sanded with increasingly finer grit abraders to achieve a smooth application surface. For some applications, the surface is expected to be coarser for the paint to adhere, for others, maximum smoothness is expected to achieve the best finish with a thin coat. *For* ***wood surface preparation****, moisture content must be balanced with the target environment, cracks, holes and gaps should be treated with wood filler, then surface is sanded.* Wood should never be sanded across the grain, this might create highly visible scratches. *For metal surface preparation, the first step is cleaning rust and residue from the previous application.* Sandblasting is an alternative to manual sanding.

The typical paint application features three layers: ❶primer or basecoat, ❷undercoat, and ❸topcoat or finish coat. ***Primer*** *is the foundation for the subsequent coats, the first layer applied after substrate preparation is complete.* There are self-priming finish coats available that negate a primer, but most professional applications would require one. For pale colors white primers can be used; for darker and brighter colors tinted primers are more appropriate, to reduce number of coats and achive depth.

Fig.05/15 Skim coating involves a continuous layer of joint compound over finished drywall application.

> *When ordering materials for a paint job, the designer should consider that primers can cover between 200 to 300 square feet surface per gallon,* ***around 30% less*** *than the same amount of paint.*

Fresh drywall soaks in liquid and moisture and *primers* ***minimize substrate absorption****, enabling efficient use of paint. It creates a surface for better paint adhesion ensuring consistency of color and sheen.* Specialty primers can inhibit mold, rust, and staining, as well as promote adhesion. Oil-based based primers are better at blocking the chemical bleeding from the substrate, which can be a problem for old construction. Primer should always match the paint solvent type. *An* ***undercoat*** *can prevent moisture and stain seepage from the substrate, may provide extra protection for denting, and creates a tinted foundation for darker colors.*

Paint can be applied via brush, roller, or spray. ***Brushing*** *gives better control, results in a consistent, uniform finish, however, application process is relatively slow.* ***Rollers*** *can quickly cover large areas, though the details have to be sorted with a brush.* It is easier to reach higher areas. The required skill ceiling is relatively low. ***Spraying*** *is another tool to cover large areas, however, skill and experience are a requirement to achieve a consistent application.* Spraying does not leave any brush marks, however, coats might be thinner due to the lighter consistency required for spraying, more coats therefore more paint is needed. An inconsistent application might cause drips and globs to occur. *In all applications,* ***masking*** *wall details is mandatory to prevent brush slip-ups or overspraying.* ***Textured paints****, sometimes referred to as novelty or faux finishes, boasts visual intricacy achieved by the use of stencils, sponges, special rollers, rags, etc.* Such applications require tools, skill, experience, but also a keen sense of composition, rhythm, and visual balance. Considering the time commitment required, novelty and faux finishes can be fairly costly to implement.

Paint is classified as ***household hazardous waste*** *and the transportation, removal, and disposal are regulated at the government level as outlined by EPA.* Planning is required when ordering paint. How much paint is required should be carefully calculated and leftovers should be expected. Any leftover paint should either be donated or disposed of through hazardous waste collection as well as take back and recycling programs. Additional guidance can be sought from local public works department, waste management centers, and paint retailers. ***Paint should never be poured into sinks or toilets*** as it will block the plumbing and create water treatment complications, illegal in some states. Painting tools such as rollers, brushes, etc. used to handle water-based paint can be washed into the drainage, though not advisable.

Fig.05/16 Painting is a messy process, and masking is a requirement for even the smallest job.

Fig.05/17 Textured paints are often applied with specialized or unusual tools, requiring a lot of skill.

Vid.05/03 Video on appropriate paint disposal process.

Vid.05/04 Video on lead paint identification and abatement.

Lead was a hugely popular paint additive from 1900 to 1960. In 1978 it was banned from use after the negative health impact was better understood. ***Lead-based paint*** *was present in three-quarters of U.S. homes built before 1978, and even today many of these houses might feature lead paint.* The reason behind lead use was to stabilize the paint, increase durability, and resist moisture. Lead paint cracks, peels, and chalks over time, released to the immediate environment, which can be ingested or inhaled. Lead is a known carcinogen, a poisonous neurotoxin, and an endocrine disruptor. It is extremely harmful especially during child development.

It is critical that lead paint is ***identified and removed by experts****, or sealed in an approved manner. Any demolition process, or even sanding down a substrate can disturb the present lead and release lead dust, so utmost care and attention is required.*

Fig.05/18 Flocked wallpaper is often associated with the Victorian era patterns and aesthetic.

WALLCOVERINGS

Wallcoverings *are continuous sheet materials that are intended to be cut into strips, aligned, and adhered to wall surfaces.* ***Wallpaper*** *refers to a single type of wallcovering product; the two terms are not interchangeable.* In the past the material was just decorative paper whereas today's wallcoverings can be vinyl, foil, cotton, or various veneers. Even though there is evidence of rice paper wall applications by the Chinese as early asw 200 BCE. Evidence dates the first use of wallpapers in Europe to 16th century, though wallpapers start to rise in prominance in the 17th century France, thanks to emerging printmaking techniques and formation of guilds. After the industrial revolution, wallpaper became available to people of more moderate means, William Morris's paisley pattern designs garnered public interest. Also popular in this period, ***flocked paper*** *features a raised velvety texture achieved through sprinkling silk and wool particles to an adhesive coated surface.* The adhesive is

Vid.05/05 Video of a 1963 documentary on wallpaper.

Fig.05/19 Paisley designs were popularized by William Morris, from the Arts & Crafts movement.

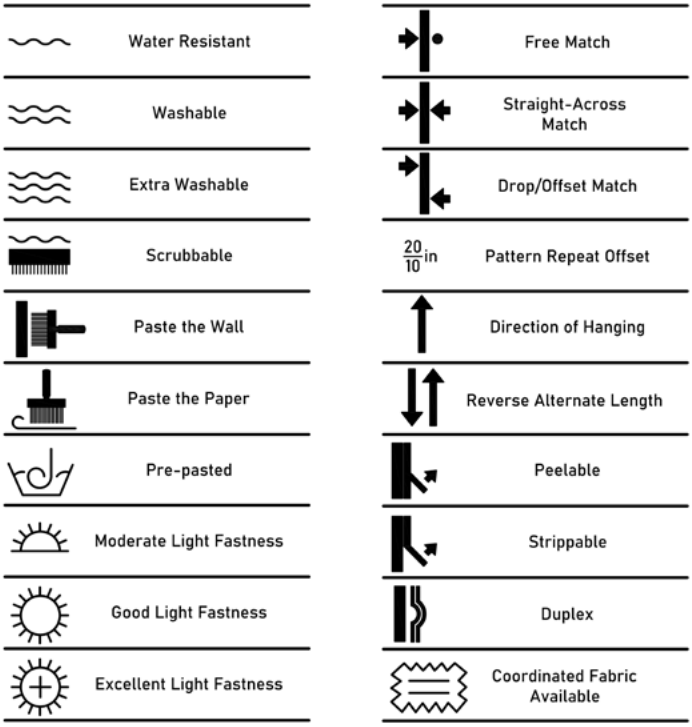

Fig.05/20 Most commonly used international wallcovering symbols.

applied according to the desired pattern.

Accurate specification of wallcovering products requires an understanding of characteristic properties, which are as follows: ***washability*** determines the resistance against light cleaning with damp cloth or sponge; ***scrubbability***, measured in cycles, determines the resistance against vigorous cleaning with detergents; ***abrasion resistance***, is also measured in cycles, determines the wallcoverings ability to withstand rubbing, scraping, and erosion; ***stain resistance*** determines the material's ability to endure staining from a variety of reagents; ***colorfastness*** determines the ability to maintain color and resist fading against chemical and mechanical abrasion as well as UV exposure; ***blocking resistance*** is the material's ability to avoid unwanted adhesion; ***strippability*** refers to the ability of the wallcovering to be separated from the substrate as a single piece, without leaving any residue; slightly different, ***peelability*** refers to a feature where when separated from the substrate, the wallcovering leaves a liner layer behind to be used for new application or can be cleaned with warm water.

*The **breathability**, or permeability of a wallcovering is an important concern that determines the possibility of fungal growth on the substrate.* Similar to oil-alkyd paints, the trapped moisture might facilitate hidden mold and mildew growth behind the wallcovering. This is especially problematic on the interior surface of exterior walls that are not well insulated. Cold spots due to thermal bridges eventuate condensation points that are much more susceptible to growth. ***Microventing*** *enables breathability for otherwise impermeable non-woven products.* It is normally invisible, visible only when held before a light source. *Woven or breathable wallcoverings are **susceptible to bleed**, where moisture, stains, or adhesives from the backside can bleed towards the front facing of the product.* A sealer on the substrate, as well as a backcoating is required to prevent this phenomenon. Applying wallcovering without cleaning up the previous layers of paint or wallcovering might impede breathability and create problems, even when the new wallcovering is breathable.

> *The designer should consider that **organic fibers** are food source for micro-organisms and insects. Moreover, they might not be able to sustain dimensional stability with moisture changes. Polymer-based or fiberglass wallcoverings are less susceptible to this problem.*

A typical wallcovering product features three layers: decorative layer, intermediary layer, and backing layer. [1] *The **decorative layer** features the pattern and relief determining the visual quality; it can feature a transparent wear layer*

Fig.05/21 Close-up detail of grasscloth wallcovering.

for improved abrasion resistance. Decorative layer can feature various materials such as paper, fabric, vinyl, leather, metallic foil, wood or cork veneer, or grasscloth. There are several printing methods for applying patterns and textures on wallcoverings – ***screen printing*** involves several screens with different colors and patterns assigned to them, which are sequentially pressed for a combined impression. ***Block printing*** is a more traditional technique that involves pressing paint via carved blocks onto the wallcovering. ***Rotogravure***, or cylinder printing, involves the wallcovering running through engraved cylinders fed with colored ink. Digital printing provides flexibility, enables previously highly expensive murals at a reasonable price, or custom patterns in short-runs. [2] *The* ***intermediary layer*** *supports the decorative layer both structurally and visually.* Lastly, [3] the ***backing layer*** *that is adhered to the wall surface determining the mechanical performance of the product.* The backing layer can belong to one of the three categories: ***Paper backing*** is more appropriate for light traffic applications. ***Woven backing***, often involves a cotton polyester blend for better performance and increased flexibility. Woven scrim backing is lightweight, and Osnaburg backing is medium-weight. Drill refers to a heavy-duty backing used for high traffic situations. ***Nonwoven backing*** allows higher dimensional stability, can be fused with the decorative layer.

Acoustic wallcovering *solutions are available with a noise reduction coefficient (NRC) ranging between 0.2 to 0.9 depending on the mounting configuration.* Lacking physical depth, wallcoverings are very ineffective in attenuating lower frequencies and they are not intended as standalone acoustical solutions by themselves.

According to the standard ***ASTM F793****, wallcoverings are classified into 6 categories based primarily on use characteristics, with increasingly higher performance requirements, .* ***Category I*** is decorative applications only. ***Category II*** covers decorative and medium serviceability applications; some colorfastness, washability, and flame resistance requirements are present. ***Category III*** covers decorative and high serviceability applications; with some scrubbability requirements, good crocking resistance, and stain resistance against a variety of reagents. ***Category IV***, also referred to as Type I, is for commercial serviceability, with higher scrubbability, abrasion, and tear resistance requirements. ***Category V*** or Type II is also for commercial serviceability, involves higher performance requirements and significantly higher blocking resistance and stain resistance. ***Category VI*** or Type III is for commercial serviceability as well, with significantly higher performance requirements. For instance, 1000 cycles abrasion resistance vs. 300 for Category V or 500 cycles scrubbability resistance vs. 300 for Category V.

Vid.05/06 Video on screen printing custom wallcovering designs.

Between multiple manufacturers, wallcoverings feature a massive selection of patterns. Wallcoverings can also feature tactile patterns, engravings, or metallic effects, etc. ***Murals*** *are large-scale continuous artworks produced and applied as a series of panels.* They can depict literal scenes or abstract graphics. For instance, Chinoiserie murals feature patterns that reflect the heavy interest developed towards eastern artwork in the 18th century Europe. *Almost every wallcovering manufacturer has a* ***custom pattern service*** *with detailed submission requirements.* Custom projects can be costly with increased lead times. Besides a litany of colors and patterns, wallcoverings also provide functionality such as magnetic, dry erase, or whiteboard surfaces.

Fig.05/22 Drop matching involves every other strip to be offset a certain amount.

Pattern matching is a very important concept in wallcovering applications. The major types of pattern matching are straight-across match, random match, and drop match. In ***straight-across match****, the pattern matches accross the width of each strip as they are aligned throughout a single reference line, typically the ceiling.* In ***random match****, the pattern does not require any alignment as continuity is not expected.* However, achieving a good sense of randomness and balance requires experience and skill on the wallpaper hanger's part. It is possible to rotate and reverse strips to counter visual impact of color and shading discrepancies.

In ***drop-match,*** *the pattern aligns only when one strip is dropped per pattern repetition.* Typically the length of the pattern repeat is 18" or 36". Instead of the horizontal axis, a diagonal axis is emphasized. Drop-match results in the most wastage, each vertical strip needs to be continuous. There are two types available: half-drop match and multiple-drop match. ***Half-drop match*** *involves dropping every other strip by half of the pattern length;* so for a 36" pattern repeat the drop is 18". ***Multiple-drop match*** *is more complex, involving at least 4 drops before the strip aligns with the first strip.* This means for a 36" pattern height stretching 4 strips, each strip should be dropped 9" before the pattern repeats itself on the horizontal axis. Wallcovering should be carefully cut, laid down, and numbered before adhesive application. ***Dye-lot number*** *indicates if a series of wallcovering rolls are printed in sequence or not.* This is important to make sure that the colors will exactly match between strips from different rolls, minimizing visual inconsistency.

Wallcovering rolls are priced as a single unit but sold as continuous double units (double roll),