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 are mandatory minimum standards for practice. 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 indepen-
dent organizations, culminating in labels that facilitate informed design decisions. **Guidelines** outline best practices for specific aspects of a design product.

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 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

![Restaurant kitchens are considered risky environments in terms of fire safety.](image)

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

**Video on the International Building Code.**
other end of the spectrum, unprotected wood 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, ability to be cleaned or sanitized, ease of use (particularly in panic situations), visibility, 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 classifications, describe procedures, and define various conditions to be met, which are administrated by independent organizations, usually indicated by marks of approval presented on a label or data sheet. The Underwriters Laboratories (UL) tests building materials, finishes, and upholstered furniture and publishes the materials’ test 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 have no independent legal standing they are typically referenced by codes using the standard organization’s acronym and standard number, with the year of the publication edition at the end, for example ASTM E119-20.

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) creates methods for defining and developing standards. American Society for Testing and Materials (ASTM International) publishes over 12,000 standards in 15 categories including construction and textiles. National Fire Protection Association (NFPA) creates and publishes over 300 standards, including testing requirements for textiles and means of egress design. National Sanitation Foundation (NSF International) creates and publishes plumbing and sustainability standards. 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 from a burning material is the most frequent cause of death during a fire. 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.
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
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.

**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
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. ADA guidelines do not vary with jurisdiction; the same requirements apply across the nation. 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 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*.

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

| (1) Flooring materials must be level and flush with the surrounding surface |
| (2) Slip resistance must meet a coefficient of friction greater than 0.6 (0.8 for exterior surfaces and ramps and slopes) |
| (3) Changes in height ¼ inch or less require no transition, but changes up to ½ inch require a beveled transition, and changes greater than ½ inch require a ramp |
| (4) Carpet may have a maximum pile height of ½ inch and must be fastened along the edges. |
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 broader spectrum of human sizes, shapes, and capabilities, including the children, elderly, pregnant women, people with temporary disabilities, etc. should always be considered. Universal design, more comprehensive than accessible design, aims to ensure that design is inclusive of all people with respect to human factors issues. 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.

**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.
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...
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.

Almost every material interacts with their surrounding environment either by emitting or absorbing and then emitting contaminants; 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 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 the correct use and proper maintenance requirements and cleaning procedures, periodic treatments and ventilation requirements. Even though a material considered safe with regular ventilation of the environment, 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.
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 of toxic vapors produced by off-gassing from the materials, and the effect can be exacerbated by poor HVAC. 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.

The toxic vapors and air contaminants that evaporate at room temperature under normal atmospheric pressure are commonly referred to as **Volatile Organic Compounds (VOCs)**. VOCs contain at least one carbon atom, thus the identifier “organic”. Some VOCs can have sharp odors while others can only be detected by sensitive equipment. **Undetectable smell does not equate to harmlessness.** VOCs commonly evaporate from plywood, plastics, fibers, varnishes, and coatings; from cleaning chemicals, solvents, paints, waxes, petroleum fuels, etc.

**The most critical period for VOC exposure is immediately after the finishing of the interior. Occupancy should be delayed to allow for off-gassing** during this period and the space should be properly venti-

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 penetrate fibers or absorptive materials such as carpeting, ceiling tiles, drapery, and upholstered furnishings. 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 to deteriorate indoor air quality significantly.
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. Asbestos fibers may still be found in existing construction, 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.
These may not be as risky but in time fibers can get loose and airborne due to weathering.

**In order to eliminate asbestos exposure, be cautious when drilling holes, causing abrasion, or unplanned removal in buildings constructed before and during the 1980s.**

Asbestos must be carefully dealt with during renovation or demolition. The Asbestos Hazard Emergency Response Act (AHERA) of 1986 outlines the inspection, identification, and removal processes. The Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) regulates the removal of asbestos, as well as other materials related to occupant health and safety issues. 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, it 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. It is critical that the old paint must be identified and removed by specialized professionals, or sealed in an approved manner. Old lead pipes and solder should also be replaced as soon as possible. The EPA has established a Lead Renovation, Repair, and Painting Rule (RRP) requiring the contractors that might disturb lead-based paint

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

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

**vid.03/06** Video on asbestos removal.
in homes, 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, since December 12, 2016 the EPA has been regulating the emission levels of certain wood products. Phenol-Formaldehyde is taking over urea-formaldehyde use in some industries due to significantly lower emissions.

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. PVC also has an exceptionally high toxic potency during combustion, it releases HCl and Chlorine if sprayed with water and foam while burning.

Specifying non-chlorinated vinyl alternatives 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 released into the surrounding environment.

**Health problems** include delayed development in infants and children, immune system, and thyroid function disruption. They are persistent.
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 is the manner in which sound energy is spread in a given 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
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.

In technical terms, **reverberation is the length of time required for sound to decay 60 decibels from its initial amplitude level.** 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.

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
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 and converted to heat energy and lost. The **ability of a material to absorb sound** is dependent upon the porosity, 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 dwell around the 125Hz band are 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.

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 well 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 refers to the gradual loss of energy or amplitude as sound 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-
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. 

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

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**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.

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**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.

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.