OET016
Construction Methods and Materials

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Chapter 1
Introduction and Built Environment

Historians have established that humankind has been manipulating the environment for millions of years. We built shelters for living and later for commerce, converted forest to tillable land, constructed roads, and generally shaped the world to serve our own desires and expansion. We have built and built and built. Our constructions have been destroyed by nature, strife, and even by ourselves to serve our further growth and development. As our structures are destroyed we build new ones, often larger, stronger, and more advanced than those they replace. All of these efforts combine to form the built environment.

As we examine our impact on the built environment we often frame our comments in respect to our footprint. Our footprint takes into account all of the environmental impacts of a particular activity, structure or person. For example, you could calculate your personal carbon footprint on an annual basis. Several free online calculators are available to help you estimate your annual footprint based on what kind of car you drive, how many miles you drive, how your home is heated, how often you travel, etc. The calculators estimate the total impact on the environment of your lifestyle in terms of CO₂ emissions. This is known as your carbon footprint. Carbon footprints are most prevalent due to the belief that CO₂ has a direct impact on our environment.

During the eighteenth and nineteenth centuries, Europe and North America experienced the Industrial Revolution. This rapid development and deployment of new and innovative technologies changed the way we impact our environment. As manufacturing and distribution processes developed, they increased the impact on the environment. Manufacturing technologies, especially those driven by the burning of fossil fuels, drove humankind’s footprint on the environment to dramatically increase. However, there was little or no realization of the importance of this increased footprint until many years later.

In considering the patterns of global industrial development, it is common to examine those of Europe and North America. However, it should be acknowledged that the cultures of Asia, Africa, and South America had been developing for millennia, and while they may not have been caught up in the Industrial Revolution, they should not be considered lacking or inferior. To the contrary, these cultures made many important contributions to philosophy, art, and science. Perhaps embarking on the road to industrialization later in the twentieth century will allow these cultures to learn from the West and avoid some of the same pitfalls of modernization.

Everything that humans touch and manipulate is considered part of the built environment, even if it is not a building as we may imagine. (For an interesting comparison, investigate how European and North American attitudes on use of “virgin” land differ.) The general categories for built environment include:

Buildings

One of the most common changes we make to the built environment is to construct a building. Each year we build millions of square feet of homes, schools, offices, retail stores, factories, and more. Each time we build or renovate a building we impact the environment, changing our footprint.
A construction project often begins with a piece of blank ground devoid of improvements. During the course of construction we manipulate the ground to accommodate the foundations of the building, removing the soft topsoil and finding support adequate to carry the weight of the building. Later in this text we explore soil bearing capacity and the concept that the earth will support our structures, but only to a certain weight. Different soil types have different bearing capacities, so we sometimes must keep digging to find a firmer base for our construction.

In addition to the actual building footprint, construction efforts also will touch much of the rest of the property, as we provide parking space for construction workers, staging areas for materials storage, temporary office spaces, and temporary utilities, such as toilets, power, water, etc. On a large suburban or rural site we can usually accommodate these activities, though at some cost to the environment. In urban settings we need to accommodate the same activities, but with a much different footprint. This often requires a tremendous coordination effort.

**Demolition and Brownfields**

When you examine the progression of development in the United States you will notice that during the height of the Industrial Revolution we developed dense urban centers, often with multistory buildings for offices, apartments, retail, and more. We left some land for park or green space. With the development of transportation we began to move away from the urban core. Suburbanization began, first using a system of trolleys or inter-urban railways, then with the mass production of the automobile. The American dream changed to include a single-family home away from the city. New neighborhoods developed in what was formerly the country, or farmland. As these neighborhoods grew they were served by roads, highways, retail establishments, and more. Our footprint grew.

But as we progressed from urban to suburban, population growth did not follow hand-in-hand. There were not enough people to fill the empty urban areas left by the middle class migration outward. Many urban areas changed in character, leaving mostly business functions that occurred during the day. The vibrant activity of families living the city disappeared. Urban residential buildings were relegated to those who could not afford to move to the suburbs. Urban flight began late in the nineteenth century and continued through the 1960s and 1970s.

A thorough study of the suburbanization of the United States should include an examination of the role of class, race and socioeconomic status with regard to the desire or ability to move from urban to suburban America. Ohio provides many good case studies of this pattern in its cities. For example, the development of German Village on the south side of downtown Columbus can be traced to the Industrial Revolution and before. The vast majority of the structures in the Village were working class family homes, with the ethnic German laborers providing a workforce to the neighboring breweries. The brewing businesses expanded and thrived, with several prosperous breweries in the neighborhood at the turn of the twentieth century. However, as modernization of brewing methods occurred and rigorous competition forced consolidations and closings, the brewery business changed. Following World War II many families left German Village, and the decline began in earnest. Investment in the neighborhood waned, and the most affluent inhabitants left the Village. However, a strong effort began in the early 1980s to revitalize the neighborhood. Many saw this as an affordable opportunity to live close to downtown. Investment increased and the neighborhood was revitalized.

With urban flight, many structures fell into disrepair and eventually were abandoned. This was true of all types of urban construction, from office buildings to residential buildings to manufacturing
complexes. Buildings were abandoned without consideration of the footprint they left on the urban landscape. Manufacturing and transportation sites often included hazardous chemical contamination which owners simply left behind, sometimes unaware of the consequences. Massive amounts of concrete, steel and other building materials filled the abandoned cityscape, only to be addressed as redevelopment occurred. In this way the footprint of current urban development can be seen as even larger than development on “virgin” soil. The environmental impact of removing or altering existing structures must be combined with the construction and occupation activities of new development to create an accurate footprint for new construction.

As urban manufacturing facilities were abandoned they were termed brownfields. These areas require cleanup of chemical wastes, building materials, and more to allow for safe redevelopment. Many government agencies have become involved in the redevelopment of brownfields by providing tax incentives, low interest loans, and grants to promote development. (OhioLink, the online service that provides cataloging and information management for numerous college and public sources, has videos showing brownfield development.)

Construction

During the construction of any built environment project, from roads to buildings to landscape, we often impact more than just the actual site of the construction. We incorporate a variety of materials into our designs, most of which must be brought to the site for inclusion in the construction. The transportation of these materials increases the footprint of our project dramatically. In essence we are responsible for the energy devoted to the product from its initial manufacture to its installation at our site. The raw materials and their transportation, manufacturing process, transport of the finished product, and finally delivery to the site all need to be considered when selecting materials. Many of the systems which rate our construction for environmental responsibility include criteria for selecting materials from within a reasonable radius of the building site.

During the construction process there is impact on the site in many ways which are broader or larger than the actual building footprint. Construction workers must be accommodated, from parking vehicles to accepting deliveries to providing offices and temporary utilities. Most of these activities will take place outside of the building footprint. We must therefore carefully consider the how we undertake these activities, controlling the long term negative impacts as well as controlling the effect we have on neighboring sites. For example, we will need to control trash collection and removal, recycling activities on site, water runoff, etc. The United States Green Build Council (USGBC)’s Leadership in Environmental and Energy Design (LEED) criteria include many measures for evaluating and minimizing the footprint of the construction process. Some of the specific areas of concern include:

- Air quality on the jobsite
- Parking
- Temporary offices and facilities
- Storage of materials
- Water runoff control
• Temporary utility usage and efficiency
• Recycling of jobsite waste
• Recycling of construction materials

LEED is discussed more fully in a following section.

Occupancy and Operation

Many of our resources are dedicated to the operation and maintenance of our built environment. Heating, cooling, ventilating, lighting, and operating buildings accounts for approximately 42% of the energy generated in the United States. For this reason, building designers, contractors and owners must work diligently to assure the most efficient construction is undertaken.

When combining construction activities with operation and maintenance requirements, the built environment consumes approximately 50% of the energy generated in the United States. Given the recent crises facing our energy supply, it is easy to assume that we must address this single most significant demand on our resources. There are two ways of approaching the issue: create more energy to continue supporting the built environment, or create a more efficient built environment that requires less energy.

As the purpose of our study in this text is to address the construction of the built environment, we will adopt the philosophy that to be responsible designers, contractors, and owners, we will devise methods to consume less energy. Perhaps in a course on energy generation design it would be appropriate to explore ways of generating additional energy, perhaps from renewable sources like wind or solar collection; however, we will focus on building efficient buildings, minimizing their demand for energy, and making the built environment a responsible component of the world energy picture.

Civil Engineering Projects

It is easy to imagine buildings as part of the built environment, but in reality it is much broader than occupiable buildings. These are often civil engineering projects.

Transportation is a very large portion of our built environment, and includes roads, highways, airports, railways, and more. These facilities and arteries require space in their final manifestation as well as a typically larger space during construction. Since the Industrial Revolution and the linking of the east and west coasts of the United States by railroad, we have been manipulating the environment, flattening hills, crossing rivers, shaping drainage, altering courses of rivers and streams, and more. We have taken the attitude that the ease of our transportation needs outweigh the existing environment, and therefore we can manipulate and alter that environment to fit our desires.

In addition to the first environmental cost of transportation projects, the impact of the continual maintenance and repair required for these types of construction must also be considered. Simply observe the amount of road reconstruction and repair that occurs each summer. We are continually altering, fixing, and widening our transportation arteries. Our impact as we make these manipulations includes the demolition activity as well as the new construction activity. It may also include the
temporary facilities or routes to accommodate traffic during construction. All of this combines to form a large footprint.

In addition to transportation there are many other civil engineering projects which add to the built environment. These include utilities, landscape projects, parks, and other support areas. Utility transmission is one of the invisible aspects of the built environment, with water supply lines, storm and sanitary sewer lines, and gas lines being buried underground. We seldom consider the environmental impact of placing these various service lines throughout the city or country. Electrical supply and communication lines can be more obvious as some are not underground. It is easier to see the impact these lines have on our built environment.

LEED

Responsibility for protecting our environment is extremely important in our society today. The design, construction, and maintenance of a building and its site can have a significant effect on the world around it. The United States Green Build Council (USGBC) recognizes this and strongly advocates environmentally friendly sites. The USGBC has established the Leadership in Environmental and Energy Design (LEED) certification system, which sets standards for buildings and sites. LEED has instituted a rating system for buildings and sites, and meeting these rigorous standards earns a prestigious award. Many of the points to be earned toward certification are directly attributable to the site selection. This further reinforces that close attention should be paid to the many aspects of a building site. The designer and construction leader should refer to the LEED standards on the USGBC website: www.usgbc.org.
Chapter 2

Project Team, Design, and Construction Processes

This chapter covers a variety of topics, all collected here to give you background regarding the design or construction process you are studying. We will progress from the history of architecture to styles of architecture to actually getting a building constructed. The outline is:

1. Architectural Styles
   a. A Brief History of Architecture
   b. The Industrial Revolution
   c. Modern Architectural Styles

2. The Project Team
   a. Owner
   b. Design Options
   c. Design Professionals
   d. Contractor
   e. Financing
   f. Code Enforcement

3. Project Delivery Systems

4. Awarding a Contract
   a. Liability
   b. Owner’s Administration
   c. Schedule of Values
   d. Notice of Commencement
   e. Notice of Furnishing
   f. Mechanics’ Liens
   g. Affidavit of Mechanics’ Lien

5. Project Life Phases

6. Selecting a Contractor
a. Construction Management  
b. Design-Build  
c. Bidding and Negotiation  
d. Public Works  

7. Contract formats  
   a. AIA  
   b. AGC  

8. Construction  
   a. Job Meetings  
   b. Interpretations and Clarifications  
   c. Certificate of Payment and Retainage  
   d. Waivers of Lien
2.1 Architectural Styles

2.1a A Brief History of Architecture

The history of architecture is really the history of the world. Humans have consistently worked to create spaces where they can live, conduct trade, manufacture items and more. In the beginning of our time on earth this started as a basic effort to protect ourselves from the elements, whether heat, cold, wind, rain, snow, etc. But as various populations developed into societies around the world, the values and beliefs of the society began to be manifested in its architecture. While the focus of this text is building materials, it may help to be able to place these materials in a context of time and style.

It is important to recognize that architectural styles develop for a variety of reasons. Some styles are born of necessity, such as simple shelters or basic manufacturing facilities. People often try to cover the most space possible with a durable material to protect them from the weather. They work with the materials at hand, whether it is wood, stone, steel, glass, or brick. Other styles develop as a manifestation of a system of beliefs. For example, many Christian churches have floor plans in the shape of a cross, emblematic of the crucifixion of Christ. Still others are developed as an abstraction of an idea or guiding principle. Modern architecture is an example of that, with its clean, stark lines representing the movement of society away from the clutter and ornamentation of Victorian times.

Many architectural historians start tracking the development of architectural styles with ancient Egypt with its iconic pyramids and sphinxes. We still marvel at the ability of a society to construct these enormous tributes to their leaders with manual labor and basic tools. Meanwhile other societies were developing their architectural manifestations of their beliefs and priorities. In Asia, temples were developed to express the Tao, Hindu, and Shinto traditions. These societies were developing their architecture as long as 3,500 years ago.

As populations developed in the Mediterranean, they developed what would become Western architecture. Starting with Greece in approximately 600 BC, people began to make buildings that were abstractions of their primitive structures. Perhaps earlier shelters had been a series of sticks or logs, erected as posts and then covered with a roof of additional sticks or logs. Perhaps they found a way to support the roof with larger logs that became beams. Examine the Greek temple structures and you will find these are abstractions of those simple log structures. The columns can be seen as trees, with the fluting resembling bark. Corinthian columns are even topped with carved leaves, reinforcing the abstraction of nature. The triglyphs and metopes that form the rhythm of the entablature can be seen as the exposed ends of logs laying across the roof, supporting a thatch of grasses to keep out the elements.

An in-depth study of the history of architecture is beyond the scope of this text. However, we can follow the development of architectural styles through history. We can start with the earliest records we have, from Asian temples to Egyptian pyramids, and we can see how we design with similar elements and shapes through the ages.

In general terms, western architecture progressed in these styles:

<table>
<thead>
<tr>
<th>Style</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancient World</td>
<td>???–500 BC</td>
</tr>
<tr>
<td>Greek</td>
<td>700 BC–100 BC</td>
</tr>
<tr>
<td>Roman</td>
<td>300 BC–500–1500</td>
</tr>
</tbody>
</table>
Each of these eras in history brings with it an evolution of architectural designs. But it is possible to trace styles through the ages. For example, conduct a quick online image search for these buildings:

<table>
<thead>
<tr>
<th>Building</th>
<th>Location</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parthenon</td>
<td>Athens, Greece</td>
<td>400 BC</td>
</tr>
<tr>
<td>Church of the Invalides</td>
<td>Paris, France</td>
<td>1680</td>
</tr>
<tr>
<td>Old Dayton Courthouse</td>
<td>Dayton, Ohio</td>
<td>1850</td>
</tr>
<tr>
<td>Province of Ontario Building</td>
<td>Barrie, Ontario, Canada</td>
<td>1985</td>
</tr>
</tbody>
</table>

As you are looking at these buildings, notice the use of columns on the front of the building. The columns are the tall, round structural elements that hold up the attic space and roof above. Notice the similarity of these architectural elements over the millennia. For over 2000 years we have used elements that have remained mostly unchanged. Why? Hasn’t someone come up with other structural systems that eliminate the need for columns? Of course the answer is yes. Most every house we build in Ohio includes a series of bearing walls to support the attic and roof above. So we can build without classic columns: why don’t we?

There are several reasons, ranging from personal taste to corporate standards to evoking longevity. This is really the essence of architectural styles. Why do we design buildings to look a particular way? Because we want to use the language that has been established by those who came before us to continue a story, even if it is to set the story on edge and explore different interpretations.

The Greeks used columns to replicate the strength and substance of the trees that had originally supported their roofs. These columns became central features of Greek design, especially public buildings which came to embody the republic. Temples, gathering spaces, markets and other important buildings used a colonnade around their perimeter, allowing easy, even democratic, access for all. The philosophy of the politics of the Greek world became embodied in their buildings. You can see the columns in the photo you found of the Parthenon, the crown jewel of the Acropolis in Athens.
During the Renaissance architects used the column to evoke the history the Greeks had created. The Church of the Invalides and countless other Renaissance and Baroque buildings employed columns to help people envision the buildings, and therefore those associated with the buildings, as possessing longevity, stability, strength and significance. The manufactured history added a layer of legitimacy.

As the United States expanded from east to west, you can see the construction of many important buildings, including the 1850 courthouse in Dayton, was influenced by the language and images of the classics. Our newly formed government sought to use architecture as those before had, lending a sense of longevity and legitimacy to the new republic.

2.1b Industrial Revolution

In the late eighteenth century advances in science and arts were happening with amazing frequency. The method of scientific experimentation had taken hold, leaving the ideas of medieval alchemy behind. Scientists worked to form hypotheses, test their notions, control variables and repeat the tests until they had discovered a scientific truth. Inventors and scientists were anxious to make advances in the realm of building design and construction. Perhaps the most important advancement that came from this time is modern steel making.

In general terms, steel is manufactured by heating iron ore, a naturally occurring mixture of minerals that can be mined in many areas of the world, to a liquid state. A variety of impurities are poured off of the molten iron ore. The remaining material, iron, is shaped and molded to make units that we can use to construct buildings. In the early days of this process we were limited by the heat we could generate the furnaces. Without extremely high heat it was impossible to remove as many impurities as we might like from the iron ore.

The earliest of these metals manufactured from iron ore was cast iron. The name comes from the method of placing the molten iron into sand casts, providing a shape for the piece as it cooled and hardened. Cast iron tended to be brittle, due to the remaining impurities, and had limited applicability in construction. It was discovered that if cast iron were hammered, some of the fibers would align, creating a stronger structural piece. This type of material is wrought iron. However, this metal, too, was limited in its applicability in construction.

Henry Bessamer developed a method of injecting oxygen into the furnace used to melt the iron ore and remove the impurities. This added oxygen resulted in higher heat in the furnace, finally allowing the removal of even more impurities. This blast furnace process made possible modern steel. The impurities were diminished dramatically, and the possibility of modern skyscrapers was born.

2.1c Modern Architectural Styles

The Industrial Revolution brought advances in many materials, the methods we used to manufacture them, the transportation to move them and finally the labor to install them. During this revolution, many architectural styles developed. Some styles were based on images from history, as we discussed above (Neo Classical, Georgian, Empire). Others were the manifestation of the efficiency of the machine age (Modern, Art Deco, de Stijl). Still more styles were direct reactions against the machine age, emphasizing manual labor and the dignity of the craftsman (Craftsman, Stick, Art Nouveau).

A quick online search will bring images of the major styles of modern architecture. Search for:
• Victorian  
• Queen Ann  
• Stick  
• Shingle  
• Art Nouveau  
• Art Deco  
• De Stigl  
• Modern  
• Cubist  
• Post Modern

Several online databases provide extensive collections of photos and information on styles and specific architects. A good place to start is www.greatbuildings.com. Additionally, Architectural Record is a leading magazine in the built environment, and hosts wide ranging collections of articles on modern architects and projects on their website, www.archrecord.construction.com. Most schools in Ohio are members of OhioLINK, the online service that provides cataloging and information management for numerous college and public sources. Use your institution’s membership in the service to search for books, articles and videos of significant architects, buildings, and styles.

2.2 Project Team

The construction of a built environment project, whether residential, commercial, or institutional, requires the input of many parties. For example, there is always a project owner, a designer, a source of financing, a code enforcement official and a contractor. We will examine several options for each of these team members and the contractual relationships that guide their interaction.

2.2a Owner

The vast majority of money spent on construction is from commercial or governmental sources. The United States federal government and all its associated departments spend billions of taxpayer dollars on construction projects, as do each of the 50 states. The total of government spending on construction in 2009 was more than 316 billion dollars of which the federal government spent more than 27 billion. Private industry spent more than 367 billion dollars on construction, of which 77 billion was for energy related projects. The housing industry for single, multifamily, and residential improvements comprised more than 251 billion of the nation’s economy. Altogether in 2009 the United States erected almost a trillion dollars in construction projects, according to the US Census Bureau. Current totals can be obtained from the U. S. Census Bureau at http://www.census.gov/const/www/totpage.html.

The project owner is the source of financing for any project. When the financing involves tax dollars, there are rules as to what the government agency must do to guarantee that all industry stakeholders have an equal opportunity to bid on and secure public works. These restrictions in the writing of specifications and bidding will be discussed later. Due to the public demand for services, spending on the infrastructure never ceases, which makes government a constant source of revenue for the construction industry. Probably the biggest frustration that contractors face in dealing with the government is the ubiquitous bureaucracy and determining who in that system has the authority to bind the government to a contract. When dealing with political bodies, the contractor should find out who exactly has legal capacity to bind the commission, department, or agency to an agreement.
When the owner is a private entity that is devoid of public funding, that entity may spend its construction dollars in any way it sees fit. Regardless of whether an organization is nonprofit or for profit, as long as tax money is not involved, they do not need to assure that all contractors have the opportunity to bid their work. Private construction funds are not regulated by law, as long as they are obtained and spent in a lawful manner. What a contractor needs to be cautious of is the authority of the person signing documents for the entity. If the owner is an organization run by a board of trustees or a board of directors, then an officer of the corporation is likely to be the person having capacity to bind the entity to an agreement. Usually this will be the Chief Executive Officer (CEO), the Chief Operating Officer (COO), or the Chief Financial Officer (CFO). There may be elements of the organization’s charter that allow for purchasing agents to sign for low cost items, but this would rarely include major construction.

If the organization is privately held, then the owner would likely be the partner with the largest investment. Privately held businesses may give written authority to one of their officers, but it should not be assumed. A careful check of authority might save a contractor great grief in the future. It is always prudent to talk with the majority owner of an entity to check on legal capacity. One should not be shy about this. Many a work order for extra work was found to be nonbinding by the courts because the person who approved the work did not have the legal capacity to bind the owner to the work order.

Developers are a special classification of owner. They rarely intend to use the construction themselves and are building on speculation that the finished project can be sold. At times, the financial backing behind a developer may be tentative, and progress on the job may be dependent on that financing. A contractor has the right to ask for, and receive, written confirmation that the owner has the financing to complete the work contracted.

Finally, there is the individual, such as a homeowner, who intends to occupy the project and use it for a lengthy period of time. The individual likely has to obtain financing through a bank or savings and loan. In the case of custom built housing, the contractor often must apply directly to the bank for progress payments. Again, it is prudent for any contractor to obtain assurance of financing and be aware of the conditions thereof, regardless of the type of structure that the individual has in mind.

2.2b Design Options

Every project requires a design to guide the construction or installation. The size and nature of the project and the sophistication of the owner influence the design process. For example, a small residential project could be designed and executed by a homeowner. For a large commercial project, the owner will probably employ an architect who will team with a series of engineers and consultants to complete the design work. Let’s investigate some of these options further.

2.2c Design Professionals

Construction is generally categorized in two types: residential and commercial/industrial. Residential construction is further defined by whether it is one, two, and three family dwellings or multifamily dwellings. For code purposes, one, two, and three family dwellings are referred to as residential and all other buildings are referred to a commercial/industrial. Residential projects in Ohio are regulated under the Residential Code of Ohio (RCO) which became the law of the land in 2006. Under this code, anyone may design a one, two, or three family dwelling as long as they meet the prescriptive criteria of the code and submit plans and specifications as spelled out in the code to the applicable building authority.
Commercial and industrial buildings are regulated under the Ohio Building Code (OBC). Only registered architects and professional engineers may design buildings under this code. The State of Ohio has a seal law, which requires architects and engineers to seal their work and take legal responsibility for it. Accordingly, the OBC tends to be performance oriented, allowing for the design professional to meet performance criteria by whatever means they see fit, within broad limits. The Ohio Revised Code defines who may call themselves an architect or engineer and hold themselves out to the public as such. Generally, architects design buildings and hire engineers to design the building service systems such as the plumbing, electrical, and heating and air conditioning. Where infrastructure projects are undertaken, a professional engineer will have the lead and may hire the architect to handle the enclosure for the project.

Many times the architect or engineer may hire a specialist in any given field. For example, in the design of a theatre, a specialist in acoustics may be employed, or a lighting specialist may be brought on board. For a surgery center, the architect might employ a consultant who has vast experience with the requirements of the health department and similar licensing boards. The design of any project is complex and the larger the project the more minds are required to achieve an acceptable result.

Typically the relationship between the owner and design team is as follows:

![Diagram showing the relationship between owner, architect, engineers, and specialized consultants]

2.2d Contractor

The word contractor is universally accepted as the individual or organization who takes responsibility for the construction of the building. Its use is derived from the fact that the owner will enter into an agreement (contract) for construction and the builder assumes the responsibility to complete the building.

It is likely the prime contractor will enter into agreement with others for various phases or specialties such as plumbing or electricity. Sometimes the prime contractor is referred to as the general contractor. The general contractor may choose to subcontract portions of the project work to subcontractors or trade contractors. These portions of the contract remain the responsibility of the general contractor. The subcontractors may possess skills the general contractor does not, or may have additional
workforce available which the general contractor does not. There are many variations to the scenario, as well as motivating factors the contractors and owners.

2.2e Project Financing

When a project owner makes the decision to construct a built environment project they are also making a decision to invest resources into the project. These resources include the time of their employees, the productivity they may be sacrificing to focus their efforts on the project and their monetary investment. For a commercial owner, all of these decisions must be made in the framework of their overall business plan. The investment must support the goals of the business.

For a residential owner the decision to build or renovate is often guided by their desires, as well as their requirements for their home. Again, the cost of the project must be considered by the owner and the decision that the benefits outweigh the costs will guide their actions.

Whether commercial or residential, every project requires owners to invest dollars to achieve the goals of the project. More often than not, the owner will require the assistance of a financial institution to back their project. To simply pay cash for a new home or building is out of the realm of possibility for most homeowners or businesses. So the owner uses their creditworthiness, along with a down payment as a sign of good faith, to secure a loan from a financial institution to cover the cost of a project. This is referred to as project financing. In return, the bank charges interest on the loan which provides their income.

The process of financing a project is similar for residential and commercial projects. Once the creditworthiness of the owner is established, the next step is to evaluate the feasibility of financing the project. Often this means an appraisal of the project must be completed by a professional appraiser. This process includes finding similar properties that have recently been sold. The goal is to establish a baseline price, or appraisal value, for the work. The appraiser will use the design of the new building to evaluate and establish a market value.

The appraisal value will be used as a deciding factor for the bank if they provide project financing or not. If the value of the project supports the value of the project, the bank will most likely move forward with the project. If the appraised value is less than that which the project is worth on the open market, then the bank may decline the project. In essence, the bank is looking to make sure it is financing a project which is not above the current market value of similar projects. The bank needs to be assured the value of the project will be commensurate with the value of the loan; the owner will not be “upside down.”

The financial downturn of the late 2000’s was driven by the failure of several aspects of the mortgage investment market, including this idea of appraisal value and current market value as drivers of mortgage acceptance by banks.

If the bank accepts the value and appraisal of the project, it will enter into a construction loan. This loan is typically a short term note, limited to 12 months for residential or a couple of years for commercial. This note will cover the construction period, and the owner will pay interest to the lender as they draw funds from the loan. These draws correspond to the work being completed, with milestones established at regular intervals, either by calendar days or completeness of work. For example, a draw may be made when foundation work is completed or the rough inspections are passed. Each construction note will have its own definition of when draws are made and the appropriate milestones.
2.2f Code Enforcement

The Ohio Board of Building Standards establishes the building codes, both commercial and residential, for the State of Ohio. When a building or renovation is proposed the owner is responsible for obtaining a building permit. The building permit is the sole responsibility of the property owner, despite the fact that the act of obtaining the permit is often delegated to the contractor. Most owners are oblivious of the fact the permit is theirs, and will be attached to the property only.

A plans examiner will review the documents as submitted by the property owner. The documents for the construction process will be prepared by an architect or engineer in the case of a commercial project. For residential construction, these documents may be prepared by anyone capable, according to the Residential Code of Ohio. These documents describe all aspects of the project, from foundations to roofing. They include descriptions of all materials, while the actual building process (means and methods) are left to the devices of the contractors. The role of the plans examiner is to confirm that these documents comply with current building code. However, it is not required that the documents describe the best possible construction means and methods; rather the code requires the minimum effort possible to comply with code. In other words, the code describes the least amount of effort required to comply with the law.

Once a building permit is obtained, the authority having jurisdiction will perform a series of inspections of the work. Usually these inspections are of the structure, the electrical, plumbing, mechanical and life protection systems, such as fire protection. The permit fee paid by the property owner actually pays for the plan review and inspection process. The typical series of inspections includes:

- Foundation/footing
- Rough electric
- Rough plumbing
- Rough mechanical
- Framing
- Insulation/drywall
- Elevator (commercial)
- Structural connections (commercial)
- Finish electric
- Finish plumbing
- Finish mechanical
- Final building

The actual series of inspections may vary, and is dictated by the authority having jurisdiction (AHJ). The AHJ may request special inspections of specific aspects of the construction, such as mechanical connections, excavation conditions, etc. These inspections will be requested as the building permit is
2.3 Delivery Systems

There are several ways in which a building goes from an initial idea to a finished product. The first step is the idea generated by an individual or group, which is the owner. An owner might create a simple sketch of an idea for the basic building design including layout and amenities, or make a list of features they wish to have in the new building. From this first idea the building process begins to take shape. The owner must now decide how to go about relating that information to a finished building.

Several options exist for the owner and the level of involvement they wish to have in the building process, including three specific systems known as owner-architect-contractor; project or construction manager; and design-build.

In the owner-architect-contractor delivery system, the owner works closely with both an architect and a contractor to see that the building they wish to have comes to fruition. In the beginning the owner selects and works with an architect to come up with detailed plans of the building. These plans are used throughout the building process to dictate the materials, style, and layout of the building. Once the blueprints are finished and approved for construction, the owner finds a suitable contractor to perform the work. In this arrangement, the architect and contractor have little involvement with each other, most likely only to clarify information on the plans or specifications. In this arrangement, the owner has greater involvement in the day to day process of the project, including being responsible for finding a suitable architect and contractor.

The second delivery system uses a project or construction manager as a liaison among the owner, architect, and contractor. This manager relates the needs and wants of the owner to the architect and then to the contractor. This allows the owner to have minimal time invested in the building process with the manager correlating between all of the involved parties. The fees for a project manager may range from a fixed rate to a percentage of the overall project cost.

The third delivery system is referred to as design-build. Design-build is a one stop shop for the owner. The owner goes to the design-build firm with his or her ideas and everything from the blueprints to the construction is done in house. The design-build firm houses architects, engineers, and construction personnel. Typically the owner can coordinate with the assigned project manager, and the manager will in turn coordinate in house with the involved parties. One advantage of this arrangement is that the owner does not have to shop for an architect and a contractor, since everything is under one roof. Questions that may arise during the building process may be answered more quickly because the architect and contractor work for the same firm. Some firms may offer a discount if they can both design and build the building.

There are nearly infinite ways these three delivery systems can be arranged. Regardless of the arrangement, it is imperative that each party thoroughly understand their respective roles in the process.

2.4 Awarding a Contract
2.4a Liability Issues

In the design and construction of building projects, all members of the project team are exposed to legal liability in one way or another. The mere act of entering into a contract of any kind requires each party to perform according to the agreement, which can trigger liability if one does not perform. When considering the team of the owner, design professionals, and the constructor (contractor), each has a certain amount of assumed risk, which is liability.

The owner has the least amount of legal liability for the project, but the greatest amount of assumed financial risk. The owner of a project has obligations to those that invest in the project or loan money to build. To these investors, the owner has a legal liability for the amount of their investment, according to the terms of their contracts. The owner also has the potential to reap large rewards from the project in that the finished result should be, at least, worth the capital invested and, usually, much more.

The design team is employed to use their best professional judgment and expertise in the design of the project. Performance is generally based on the concept of usual and reasonable professional care. If a member of the design team does not meet these standards, he or she will be liable for any damages that may result from his or her performance. There is a base set of duties that any design professional is expected to provide, and a minimum of care that must be expended when carrying out those duties. Design flaws, incomplete documentation of design intent, and outright negligence are likely to expose an architect or engineer to legal action.

The owner and the architect or engineer enter into a contract that denotes the scope of services to be provided by the professional. The chief professional then enters into subcontracts with other professionals to provide services. The contract is only between those who are signatories and no one else. Accordingly, if the owner entered into a contract with the architect, the owner cannot bring legal action against the engineer. The owner can only sue the architect, who must then bring action against the engineer. This is referred to as “privity of contract” and is generally upheld at law.

The constructor, or contractor, is the entity that physically builds the project. In many cases, there is a general contractor who subcontracts the physical work out to others and acts as a facilitator of the work. When a general contractor is awarded a building contract, he or she enters into a written agreement with the owner that incorporates the construction documents into it. The general contractor is responsible to provide a final product that is in accordance with the construction documents. It is up to the general contractor to organize the subcontractors and direct the means and methods of construction. These means and methods are solely the responsibility of the contractor unless otherwise specified in the construction documents. Accordingly, if a contractor bids on a project, it is assumed that the contractor has the means and methods to build it. The question of how to do it is not one for the designers.

The contractor generally assumes the majority of risk in a project and expects compensation according to that risk. A major point of contention between contractors and designers is the shifting of risk from one to the other. With risk comes legal liability, and all parties to the building process seek to minimize their risk and maximize their profit. As with the owner and designer, there is privity of contract between the owner and the contractor, and the owner may not bring action against a subcontractor.

During the construction phase of the project, the design professional often becomes the owner’s agent. Some courts have allowed the contractor to bring action against the architect or engineer, especially if their performance as an administrator causes financial damage. This may be the case where an architect has delayed the progress of the work unreasonably. This situation is, however, exceptional and
the owner is usually held liable for the actions of his agent.

2.4b Owner’s Administration of Contract

During construction, the owner must assure that the contractor is performing in accordance with the contract documents. For most owners, their personal time and knowledge is not sufficient to perform this task. Often the owner will hire an expert to observe the construction and administer the contract. The designer of the project, be it an architect or engineer, is often the ideal candidate for the administrator’s position. Occasionally, the owner will hire a construction manager (CM) to administer the project due to this person’s knowledge of construction processes and procedures. For a CM to be effective, he or she should be involved with the project from the design phase in order to understand the owner’s and architect’s intent.

Regardless of who acts as the owner’s representative and administrator on the work, that person should perform numerous activities throughout the project. The administrator must observe the work to determine its compliance with the contract. The administrator cannot direct the work since that would be taking on the job of the contractor. The administrator is just an observer who reports to the owner or takes action for the owner to protect the owner’s interest.

The administrator should keep complete records of all observations made. To this end, a log book is quite helpful. Each day the administrator should record who is working on the site, what the weather is, any conversations with contractors stating who, what, where, and why, and arrival and departure times for contractors and materials. As a complement to this job log, the administrator should keep a log of all phone calls engaged in, again with all pertinent information. These logs can be the difference between winning and losing a legal action. Usually, the one with the best records wins.

2.4c Schedule of Values

Commonly on a large job that utilizes a general contractor or a contractor that performs numerous divisions of the work, the contract will ask the contractor to break out his bid into the various sections of the work. Accordingly, the contractor will devise a table that will assign monetary values to each division or specification section of the work. The following link shows an example of a schedule of values for a project:

[http://www.fpm.iastate.edu/planning/contractors/data/Sample%20Schedule%20of%20Values.pdf](http://www.fpm.iastate.edu/planning/contractors/data/Sample%20Schedule%20of%20Values.pdf)

The work can be broken into quite small pieces, and the contract documents will specify how the owner wants the work to be scheduled. The schedule allows the entity whose job it is to check how much is paid and to determine what the value of the work is. For example, if one of the sections of the schedule shows $5,000 for tile, the person checking quantities will examine the construction documents to determine how many square feet of tile are required. Then the examiner will visit the job site and determine how many square feet of tile have been installed. From this the examiner will be able to determine the percentage of the tile work that has been performed and determine how much money is due on account of that work. If 20% of the tile is in place upon examination, the contractor is due $1,000 of the $5,000 total.

Often, it is to the advantage of a general contractor to assign high costs to the work that will be performed early in the project and discount the price of work to be performed late. This allows the
contractor to bill for a large amount of money early, which is to his benefit. This practice is called “front loading” the project and although it is not necessarily illegal, it is considered unethical.

2.4d Notice of Commencement

According to the Ohio Revised Code, any owner or lessee of property on which they intend to contract for improvements must file with the county recorder a Notice of Commencement that provides, in affidavit form, all the information that is listed in section 1311.04. This document should be posted on the site and must be supplied by the owner to subcontractors and material vendors on request. The purpose of the notice is to inform all those who are supplying improvements to the property what the legal description of the property is, who has the legal authority to enter into a contract, and who are the “Original Contractors” (prime contractors).

2.4e Notice of Furnishing

When a Notice of Commencement has been filed, each subcontractor and material supplier that provides labor or materials to a construction project must file a Notice of Furnishing with the original contractor and the owner if the subcontractor is to preserve his lien rights. Section 1311.05 of the Ohio Revised Code states the exact information required on this notice and shows the exact form in which it is to be written. There are time limitations on this notice. It must be given within 21 days of the first work on the property. If filed after this period, the lien rights of the subcontractor extend only to work performed 21 days prior to the notice.

2.4f Mechanics’ Liens in Construction

“Mechanics’ lien rights” refers to the concept that when a person or a group works to improve property, be it real property or chattel, there is the right to fair remuneration for the work performed and the materials supplied. If there is a contract that states the remuneration in currency, then the contractor has an ownership right to the property improved until the debt is paid and the contract met. In construction, a contractor has these rights against the property that he or she has improved. However, there is a legal process that the contractor must follow to establish lien rights. Once this process has been followed, the lien holder has financial interest in the property, and the owner cannot change the financial position of the property without the lien holder’s consent. The property may change hands, but liens will accompany it.

2.4g Affidavit for Mechanics’ Lien

To claim lien rights, a contractor must file within 60 days of the last substantial work on the property an affidavit, or statement that is sworn to before witnesses and a notary public, attesting to the true value of the work not reimbursed. Section 1311.06 of the Ohio Revised Code states the form that the affidavit must take, and subsequent sections define the procedure for filing and satisfying the lien. The lien is filed with the county recorder and must be given to the owner or lessee of the property. The Ohio Revised Code Chapter 1311, which deals with lien law, can be found at http://codes.ohio.gov/orc/1311.

2.5 Five Major Phases in the Building Process:
- Predesign
- Design and documents
- Preconstruction and bidding
- Construction
- Post-construction and closeout

**Predesign**

In this phase, the designer must determine exactly what the owner wants and what the owner can afford. This is no small task. Generally the predesign phase includes:

- Site selection and analysis—looking at the site in terms of suitability of the landscape, transportation, utilities, climate and legal restrictions.
- Budgetary considerations—what can they *really* afford?
- Writing a “program”—a statement of the requirements that the client has for the project including: square footages, special equipment, materials of construction, and any other considerations.
- Selection of the design team members

**Design and Documents**

- Schematic or preliminary design—“pretty pictures” are produced and the designer uses the greatest amount of creativity as to how the project will look and how the rooms will relate to one another.
- Design development—the designer works with the engineers and consultants to determine the details of how the building will fit together and how the systems for the electrical, HVAC, plumbing, etc., will be coordinated with the overall plan.
- Construction documents—the designer and consultants refine their ideas on computers and produce working documents. Currently, these would consist of the drawings that are a two dimensional representation of the work, and the specifications that are a written description of the material and labor requirements for the work.

*Note:* Most specifications are written in accordance with the 49 division CSI MasterFormat. This format is a standard of which all in the construction industry need to be aware.

**Preconstruction and Bidding**

- After the construction documents have been completed and agreed on by the owner and designer, the project can go out to bid. In the bid phase, contractors examine the construction documents and develop a price for the total job.
• In all public work and some private work, any qualified bidder may submit a price for the job. The bid request is published in a public format and the lowest qualified bidder is chosen (a must if the work is public). The bidder generally must follow the bid form and be responsive to the rules set forth for the bid process.

• Invitational bidding is a closed process where only chosen contractors are invited to bid on the project. Invitational bidding may not be used in public work.

• Negotiated contracts circumvent the bidding process. A preferred contractor is chosen and the costs are worked out between the owner and contractor.

• Often the work is broken into a number of bid packages and each contractor that successfully bids on a package will have a contract with the owner. Any contractor that has a direct agreement with the owner is a “prime” contractor, and if there is more than one, it can be referred to as multiple prime contracts. This is often used for the “fast track” method of construction.

Each of the above methods has advantages and disadvantages.

Construction

Often during the construction phase, the designer becomes the representative for the owner and may act as the conduit between the parties to the contract (owner and contractor). The contractor must prove that the materials and assemblies that will be used in the construction meet the requirements of the contract documents. Accordingly, prior to construction, the contractor may be required to produce:

• Shop drawings—drawings that describe assemblies that will be used and show how they will fit into the project.

• Mock-ups—sample assemblies that are site built and show the quality and aesthetics of what will be used. These generally remain on the site and the actual construction is judged according to conformance with the mock-up.

• Cut sheets—manufacturer’s data sheets.

• Other submittals as required.

All of the documents above must be approved by the project architect or engineer. Other duties of the architect or engineer include construction contract administration:

• Observation of construction—the designer observes the progress of the work and reports to the owner concerning its conformance with the construction documents. The work may be stopped if it does not conform, but it is usually a bad idea to stop the work.

• The designer is not “inspecting” the work in progress or directing it.

• Actual inspection of the work comes only at the end when the contractor claims that work has been completed to the extent that the owner can take possession (substantial completion), and when the work is fully complete.
• During construction, the designer is charged with deciding if the payments claimed by the contractor on Certificates for Payment are justified by the amount of work properly installed in the project.

• The designer is also charged with deciding the validity of and processing the paperwork for any changes that may be ordered in the construction. This is done via a written “change order,” which may apply to time as well as cost.

Post-construction and Closeout

• “Substantial completion” is the date on which the contractor turns possession of the project over to the owner. The time for all warranties begins to run, an inspection is made, and a “punch list” is written showing all deficiencies in the work. The contractor then has a limited amount of time to complete the work and correct problems.

• A certificate of final completion is issued when the deficiencies have been corrected.

2.6 Selecting Contractors

The process to select an architect or contractor may seem like an overwhelming task for the owner that knows little about the construction process. There are some steps that an owner can take to help make this construction selection process easier. Most of the time construction services will be performed by an individual or organization within the local geographic area. The major factors that an owner should consider include price, quality, and timeliness. One of the best ways to consider these factors is to talk with previous customers of the architect and contractor and take a look at previous work by the contractor. It is common in the building industry for firms to give referrals.

2.6a Construction Management Method

In addition to the architect, the owner hires a consultant who is an expert in building construction, methods, and cost control to help contain the cost of the project. This entity, the Construction Manager (CM), should ideally be brought in during the design process to work with the designer on decisions that would affect costs. After the design is complete, the CM runs the project and schedules the construction. These functions traditionally belonged to the general contractor (GC), so the introduction of the CM usually cut the GC out of the picture. Needless to say, the GCs were not amused, so many of them began marketing themselves as CMs.

Although the original concept was to make all the subcontractors “prime,” owners found that there was no incentive for the CM to save them a substantial amount. Accordingly, a CM “at risk” method was developed where the CM is paid for consulting during the design phase and then acts as a GC during the construction phase.

2.6b Design Build

In a design build project, the contractor and designer are one entity. The owner deals with the same entity in the design phase as in the construction phase. Usually, the design build entity is a joint venture of a design firm and GC.
2.6c Bidding and Negotiation

Once the blueprints are completed the bidding process to actually construct the building can begin. It is advisable that a new owner gather bids from several different contractors and subcontractors to help obtain the best price. If an owner knows the contractor he or she wishes to use already, that will most likely cost a premium for requesting their services, but will give a better idea of the quality and workmanship the contractor provides.

An owner should be cautioned that the lowest price does not always equal the best choice. Like the old adage says, you get what you pay for. Any bids that are drastically out of range of the other bids should raise a red flag. For example, if five separate bids are obtained with three bids hovering around $1.2 million and one bid is $800,000.00 and another bid is $2 million, the lowest and highest bids are probably ones the owner should consider cautiously. For the $800,000.00 bid, there could perhaps be missing data, poor quality materials, and/or poor workmanship. The $2 million bid may use materials in excess of the requirements of the project or the bidder may be wishing to make a large profit.

It should be noted that contractors are in the business to make money. Just as when you or I go to the grocery store, we understand that the store will make a profit from our purchase. However, organizations that wish to make a profit outside of the general industry average should be avoided.

If the owner chooses the delivery system of owner-architect-contractor, the owner may wish to take upon him or herself a majority of the manager’s role in the construction of the building. This will require the owner to seek bids from multiple disciplines. For example: the owner may need to obtain a bid from a general contractor, electrician, plumber, roofer, and tile setter. If the owner wishes to use a project manager delivery system, the project manager would then decide from whom to get bids and then, with counsel from the owner, select the companies that would actually be awarded the work. In the design-build arrangement, all bidding and subcontractor selection would happen in house.

Many times an owner (or jurisdiction in the case of public works), will specify the minimum requirements for the contractor to be able to submit a bid. These might include previous construction, insurance policy limits and bond requirements, and previous experience matching the type of construction that is being bid on. For example, a firm that specializes in residential construction would probably not be a good candidate to build a multistory commercial complex.

After bids are received, the owner then has the task of selecting the contractor. Based on price, quality of workmanship, material choices, and reviewing previous work, the owner will narrow down which bids to consider. The owner may then contract the qualifying companies for more detailed clarification or for negotiations. Once an agreement is accepted and signed by both parties, the owner and contractor are legally bound to the terms of the agreement. It is important for the owner and contractor to understand the terms because they are both responsible able to perform. The contractor will, understandably, carry most of the weight of the contract. The owner is typically responsible for the financial aspects of the project and the contractor is responsible for building the building.

2.6c Public Works

To bid on public works projects with city, state, or federal governments, certain laws and regulations must be followed to give appropriate opportunity to those that wish to bid. There is typically a minimum timeframe required for the invitation to bid be posted. Posting can be online or in a newspaper, or
both. Bids are submitted sealed (no one else sees them until they are opened). After selection, the winning bid is then made public.

2.7 Contract Formats

2.7a AIA

The American Institute of Architects (AIA), based in Washington, D.C., is a national association for registered architects and design partners. The purpose of the AIA is to be a resource for architects, including helping them maintain their license and helping to set standards within the profession. The AIA also has established a code of ethics to help its members maintain a high level of professionalism. The AIA has a series of standardized documents that architects can use as agreements between various parties, including change orders and general terms and conditions between architects and owners.

2.7b AGC

The Arlington, Virginia based Associated General Contractors of America (AGC) is an organization set up to help promote skill sets and integrity in the area of building construction. It also helps support safety on the job, and the use of technology to strengthen communication between owners and contractors. The organization offers training to its members, as well as acts as a voice of the construction industry in local and national policies. Like the AIA, the AGC has a series of standardized legal documents and construction forms that can be used as agreements among contractors, owners, and architects.

2.8a Job Meetings

Periodically, all the members of the construction team should meet to review the work done, resolve problems, and plan for the work still to be performed. The job meetings must include the job administrator, the prime contractors, architects and engineers as required, and any other persons whose input will have a positive influence on matters to be discussed. The project administrator should schedule these meetings at least every two weeks, if not weekly. Prior to the meeting, the minutes of the last meeting should be sent to all attendees with an agenda for the upcoming meeting. Minutes should include:

- Time and date of the call to order
- Attendees
- Old business that was discussed as indicated on the agenda
- New business
- A list of follow-up items stating who agreed to do what before the next meeting
- Date, time, and place of the next meeting
- Time of adjournment
2.8b Interpretations and Clarifications

During the course of construction, a contractor may require more information than is supplied in the construction documents. Accordingly, the contractor should submit a Request for Information or Request for Interpretation (RFI) to the entity in charge of administration of their contract. A subcontractor should submit to the general contractor, and a prime contractor should submit to the owner’s representative. There are many standard forms for this purpose and the contractor should check with the administrator concerning the format for the request. This request is the first step in a process that might lead to a change in the work.

On the following page is an example of a Request for Interpretation form from the Ohio Administrative Services. Note that its path through the administrative system goes from the contractor, where the question is asked, to the architect, who answers the question, and back to the contractor who then must decide if the answer will cause a change in the time or the cost of construction. A subcontractor would send an RFI to the GC, who would then follow the chain of command to the administrator.

2.8c Certificate of Payment and Retainage

The certificate of payment is a form used by the contractor to apply for periodic payments. There are a number of standard forms developed by various organizations. Certificates state how much work has been performed by the contractor related to the contractor’s schedule of values. The most common of these is the American Institute of Architects forms G702 and G703 and forms from the Engineers Joint Document Committee:

www.civildesignassoc.com/images/G702703.doc

Note that there is a line item in the certificates linked to above called retainage. Retainage is a percentage of money earned by the contractor that is retained in the owner’s account. The theory behind this is that the owner can guarantee full completion of the work by retaining funds due the contractor until the final completion. The concept of retainage has always been a point of contention between owners and contractors, especially when the owner requires a performance bond. With a performance bond in effect, the contractors maintain that retainage is a double guarantee of performance. The owners maintain that the performance bond requires a lawsuit to take effect before payment can be obtained, and that retainage is much more immediate and effective in encouraging prompt performance.

2.8d Waivers of Lien

Before an owner pays a contractor, he or she usually requires a waiver of lien for all funds to be paid on account. The waivers state that the contractor and his subcontractors or material suppliers will not file a lien against the owner’s property on account of the bill funds if they are paid. This is a conditional waiver and release of lien. The waiver is dependent on the submission of payment. After payment has been received and the check has cleared, the contractor may be required to submit an unconditional waiver for the amount of the payment.

At completion of the work, the contractor will send to the owner a full conditional waiver and, upon the transfer of funds, a full waiver for the complete amount of the contract.
Chapter 3
Construction Documents

The design work completed by the architects, engineers, and other designers is collected in a series of drawings and descriptions that make up the construction documents. This collection of work comprises the whole of the design effort. It is imperative the documents, in total, describe the entire work to be done on the project. This responsibility falls upon the design professionals to assure completeness of content and design. However, since the construction process varies with each project, no set of documents is perfect or complete. The built environment industry has accepted the fact that construction documents are not complete or perfect, but the responsible designer supplies documents of the highest quality possible. Designers are often held to a standard of care which requires them to do what any other architect would do in a similar situation and with similar resources.

It is also important to recognize the design process as an iterative one. As we learned in Chapter Two, the design progresses through a series of refinements, from schematic, to design development, to construction documents. At each stage of the design input is gathered from the various designers, as well as the owner regarding the work.

There three major parts of construction contract documents are:

- drawings
- contract or project manual
- written agreement or contract

After the owner hires the contractor(s), these are the only basis on which performance under the contract is judged. Contained within the contract manual are numerous separate documents that define the bidding process and the general terms of the agreement.

We will examine the various pieces of the contract documents and their role in the project.

Drawings

The most familiar of the documents is the set of drawings. These are graphic representations of the horizontal and vertical location of components of the building and the manner in which elements of the construction are to be connected. The drawings seldom address the particulars of the manufacture, quality, or methods of construction. The drawings generally show the design of the project from the largest overview of the total project site and then gradually become more specific as to what they describe. There are three basic categories of drawings:

- **Plans** are drawn as if the roof was lifted off the building and it was viewed from above. (Actually, it is more accurate to view the building having been sliced through, at 48” above the floor line. This is repeated for each level of the building.)

- **Elevations** view the building as if standing on the ground or a floor in the building. They can be interior or exterior views. They are prepared without the aid of perspective. This method of drawing a “straight on” view of the building is referred to as orthogonal.)
• **Sections** show a vertical cut though the building and look at the place where the cut was made. The view will extend into the building, showing detail and materials.

From the plans of the site and building, which designate horizontal locations, the designer develops elevations which show the exterior and interior walls and vertical locations of floors and materials. Generally the next design drawings are building sections that show a vertical cutaway of the building showing interior spaces and the location of interior elements in the vertical plane. The detail of the components within the walls and floors will be drawn in the building sections, with additional detail added in wall sections or enlarged “detail” drawings. A typical drawing index, or table of contents, might look like this:

**Civil engineering design work:**
- Site plans for excavation, drainage, paving, utilities, etc.

**Architectural design work:**
- Floor plans (of all floors, including basement)
- Elevations (exterior and interior)
- Building sections
- Wall sections
- Details
- Schedules

**Structural engineering work:**
- Floor plans (of all floors, including basement)
- Elevations (exterior and interior)
- Building sections
- Wall sections
- Details
- Schedules

**Plumbing, mechanical and electrical work:**
- Floor plans (of all floors, including basement)
- Elevations (exterior and interior)
- Building sections
- Wall sections
- Details
- Schedules

**Consultant’s work:**
- Floor plans (of all floors, including basement)
- Elevations (exterior and interior)
- Building sections
- Wall sections
Plan drawings, sections, and elevations are produced in orthographic projection, which shows only two dimensions; therefore, there is no perspective to them. From these drawings more specific ones are developed that show wall construction and details of connections. The detail drawings are occasionally three dimensional (isometric) to give a good visual rendering of the design concept.

Drawings are produced by the architect and each of the engineers that comprise the design team. Each design specialty has standard drawing configurations and symbols that encompass their unique drawing “language.” An architect’s drawings establish the base from which the engineers work. Therefore, architectural plans and engineering plans all start with the same drawing and then each specialty adds their own design and details according to what part of the building system they are designing.

As Building Information Modeling (BIM) is increasingly used in the development and documentation of projects, the model provides the base for all of the consultants to develop their work. It is possible to maintain a central model on a server, allowing access and frequent updating by the various designers.

Project Manual

The project manual is a written document produced by the architect and all of the consulting engineers and designers. The purpose of the document is to provide information that is not conveyed on the drawings. Information regarding the bidding process, contract language, calendars and much more, while critical to the success of the project, should not be placed on the drawings. Instead these documents are assembled into a book that accompanies the drawings. This book, when combined with the drawings, comprises the sum total of the project documentation.

The project manual is divided into two parts: the front end and the specifications. The front end includes many of the instructions for bidders, as well as project-specific information for the eventual contractors, owner, and designers to use to guide the construction process. A typical project manual table of contents could include these front end items:

- Notification to bidders
- Prevailing wage statements (typical for public work)
- Project schedule
- General conditions
- Project estimate
- Schedule of allowances
- Request for information form
- Bid form
- Surety requirements (bid bond, performance bond)

The conditions, both general and specific, state how the contract will be carried out and administered. They define the legal relationship between the owner and the contractor and define any legal relationship that others, such as the architect, construction manager, or commissioning agent may have to the contract. Generally, only the owner and the contractor are bound by the contract, and secondary players act as agents of the signatories.
Specifications

This is the second part of the project manual book. The technical specifications describe the materials and components of construction that are to be used. They are, as the name indicates, the specifics, in writing, of components. Each section of the specifications refers to one part of the construction of one material, such as rough carpentry or masonry. The intent of the specification is to convey detail about the materials or assembly that cannot be placed on the drawings.

Each specification section is generally broken into three major parts: general, products, and execution. Under each major part are separate sub-elements.

General:

- Summary of products included or related to the specification subject
- System requirements, including design and performance requirements
- Submittals of product data, drawings, mock-ups, reports and similar material that must be submitted prior to installation of the subject of the specification
- Quality assurance documents and samples
- Delivery, storage, and handling instructions
- Project and site conditions required for installation
- Sequence and scheduling requirements
- Maintenance manuals and extra material requirements

Products:

- Allowable manufacturers
- Materials by performance criteria
- Manufactured units
- Equipment
- Components
- Mixes
- Accessories
- Fabrication requirements
- Source quality control

Execution:

- Examination of conditions for proper installation
- Preparation of any substrates
- Erection
- Installation
- Field quality control
- Adjusting
- Cleaning
- Protection

CSI Format

The architect and each of the consulting engineers or experts are responsible for writing his or her own specification section. Usually the architect or head engineer will set the standard for the specifications so that they will all be similar in format. The Construction Specifications Institute (CSI) publishes standards known as CSI formatting that most architects and engineers follow, and which can be found at www.csinet.org. This allows each job to have a format that is familiar to the contractors and avoids confusion about where the specifications for an item are located in the project manual.

The construction of a building is a very complex undertaking. There are innumerable different systems that make up the various parts and pieces of the structure. The site of the building is one of these important systems and good designers and contractors will pay close attention to the many aspects of a site. If this is not done, a very beautiful and functional building may not meet the owner’s intended purpose.
Chapter 4
Permits

Government agencies have passed laws to control the use of land and the minimum standards to be used in building construction. The documents that establish the specifications are codified, and thus called “codes.” Codes are established with regard to where certain types of buildings can be built, how they can be constructed and how they are to be used.

As you examine existing zoning and building conditions, you will find many uses that may seem to fall outside of the rules. This may be a result of “grandfathering.” In these instances a building is allowed to remain in place even if the zoning use changes. You can find lone houses in the midst of industry, or a school in a warehouse district.

Some of the typical Ohio codes include:

Zoning

A zoning code is a law that regulates and controls the use of private property. The purpose of a zoning code is to regulate land use, prevent land-use conflict, and allow growth to occur in a rational manner. While there is criticism of zoning laws, arguing that they impinge on the right of an individual to use property as they want, the concept of zoning has been at the highest levels. The constitutionality of zoning ordinances was upheld by the US Supreme Court in the 1926 case Village of Euclid, Ohio v. Ambler Realty Co. Zoning law is usually use-based (regulating the uses to which land may be put), and characteristics-based (building height, building setback, parking numbers and location, etc.). An excellent explanation of zoning in Ohio is found at http://ohioline.osu.edu/cd-fact/1265.html.

When an owner or agent (architect, etc.) applies for a building permit, the person must also apply for a zoning permit. The zoning administrator will review the application to be assured that the proposed use and any structures to be constructed meet the zoning code. Inspections are made during the construction process, as well as when work is complete, and when the project meets the zoning laws, a final zoning certificate is issued.

Zoning codes also include an appeal process which usually includes a Board of Zoning Appeals and a Planning Commission. These entities have the right to make decisions on zoning matters and can approve “variances,” which are exceptions allowing uses or property characteristics that do not meet the exact code requirements. These decisions are appealable to the courts.

Zoning codes are established, usually by local authorities, as a tool to help plan how a town or city will develop. For example, code may dictate that residences may not be built in an industrial or factory area. In making this decision, the zoning authorities are using geography to keep the residential area cleaner and quieter. It will also allow the industrial users to operate three shifts, or have delivery vehicles making noise at any hour without disturbing residents.

Zoning is usually done at a local level, allowing town leaders to establish their own vision of how the town will develop. The town may have developed a long term vision of the expansion they plan,
perhaps with additional roads, highway access, etc. These basic transportation plans will help planners decide where commercial and industrial uses will be allowed. This will then influence residential, school and office placement. Parks, hospitals, schools and other services are appropriately distributed. Schools are located close to neighborhoods where children will live.

While the concept of zoning is clear, making the most functional and attractive arrangement of property uses, the application of the concepts in an older, established city may be difficult. Existing uses may not fit with the plans of the zoning board.

**Building**

States have the authority to establish codes for the health safety and welfare of the public. In Ohio the governor-appointed Ohio Board of Building Standards adopts model codes and then makes changes to assure they are appropriate for Ohio. The model codes are developed by the International Code Council. These revised codes are then issued as the Ohio Building Code (commercial) and the Residential Code of Ohio (residential). These codes are referenced as part of the Revised Code of Ohio, the law of the land.

A variety of codes combine to guide the construction of a building. The umbrella code is the Ohio Building Code (OBC), and many codes are included by reference. Applicable building codes in Ohio are:

- Ohio Building Code (OBC)
- Residential Code of Ohio (RCO)
- National Electric Code (NEC)
- Ohio Mechanical Code (OMC)

Many of the worst disasters in buildings have been as a result of fire. The birth of modern building codes can be traced to the great Chicago fire of 1871, in which a great portion of the city was destroyed. Following the fire, insurance companies developed codes to protect their interests. If a customer wanted to have their structure insured, they now needed to comply with the company’s standards. Therefore codes are especially designed to protect against fire and assure people can exit safely in the event a fire should develop. We will see how fire code influences both commercial and residential codes.

The Ohio Building Code (OBC) is the law established by the state containing the minimum standards that must be met in the construction of all buildings that will be used for purposes other than one, two or three family dwellings. Examples include commercial establishments, places of assembly, schools, industrial plants, etc. These standards are established for buildings in these categories because they will be occupied by the public and they need to be properly protected. Emphasis is on safety associated with fire and safe exit in the event of fire. This code is known as a “performance” code, which means that the designer must put together a proposed building that meets the intent of the code. For example, depending on the intended use and size, the code will require safe exiting doors for a certain number of people. It is then the responsibility of the designer to provide the exits.

The Residential Building Code of Ohio (RCO) sets the standards for structures that will be used for one, two or three family occupancy. These are separated from the others because family use is not as complex as public use. The code is “prescriptive,” which means that it establishes exact standards that
must be met. For example, it demands that at least one exterior door be 36 inches wide. This is not dependent on the number of occupants.

The National Electric Code (NEC) has been developed by the National Fire Protection Agency and has been adopted by the State of Ohio. It contains all the requirements for proper installation of electrical facilities. A detailed description of the purpose of the code can be found on the “document scope” link at [http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70&cookie%5Ftest=1](http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70&cookie%5Ftest=1).

The Ohio Mechanical Code (OMC) is based on the International Mechanical Code. It provides minimum regulations for mechanical systems using both prescriptive and performance-related provisions. The topics covered by the code include ventilation, exhaust systems, chimneys and vents, duct systems, refrigeration, combustion air, etc.

### Permitting Process

All building codes are administered by a building official who is empowered by the appropriate government agency to be certain that the buildings are designed and constructed in accordance with the codes.

Before construction begins, permits must be obtained. Permits are issued by the local jurisdiction such as county or city. The purpose of a permit is to help ensure compliance with the local, regional, or national building codes. Pulling a permit, as it is generally called, is usually done by the general contractor or subcontractor performing the actual task such as plumbing. However, the ultimate responsibility for assuring a permit is obtained for any work falls to the property owner.

The process begins by the owner (or agent) presenting plans that have been developed for the intended use. These are reviewed by the building official to guarantee that the intent of the codes is met. Once this is ascertained, a permit is issued which allows construction to begin. The building official (or an agent) makes periodic inspections of the work in progress to verify that plans are being followed and codes met. Upon completion of the building, the building inspectors make a final inspection, and when all codes are met an Occupancy Permit is issued by the building official that allows the building to be occupied for the intended use established at the time of permit application.

A list of what needs to be inspected is usually included with the permit, but is determined by the authority having jurisdiction with the guidance of the appropriate code. For example, in residential construction there might be a dozen or more inspections throughout the building process. These will range from a foundation inspection to a framing inspection to an electrical inspection. Failure to comply with the building codes may bring a fine or stoppage of work. Before a building can be considered finished and usable, a certificate of occupancy is granted by the local jurisdiction after all inspections are completed and approved.

### Appeals

Since codes are written in such a way that they may be open for a certain amount of interpretation, disputes may arise. Each government agency has an appeal process in place which may include a board of local people to review an appeal from an applicant. In Ohio, The Board of Building Standards has been
formed under State law and is the highest appeal agency. Their decisions may be appealed to the courts if someone continues to believe their cause is correct.
Chapter 5
Most Commonly Used Building Materials

Building Materials

The built environment has been constructed from many different materials and our society continues to create new and exciting materials to make our world a better place. However, there are four primary materials that are mainstays. This section gives details of these four building materials: concrete, steel, masonry, and wood. Some or all of these are used in buildings in multiple ways.

Concrete

This section covers the manufacture, mixing, placing, and curing of concrete, including:

- Short history of concrete
- General nature of concrete
- Types of Portland cement
- Water
- Aggregate
- Admixtures and binders
- Water to cement ratios
- Tests for concrete consistency and quality
- Reinforcing of concrete
- Form work for concrete
- Placing of concrete
- Curing of concrete
- Precast concrete

Materials Selection and Team Coordination

The major decisions about the concrete are made by the structural engineer. The contractor has to follow the instructions of the engineer very precisely if the concrete on the job is to be of the quality
required. The concrete contractor has to coordinate carefully the delivery times of the material with the ready mix plant.

Environmental Issues

The cement used in concrete requires a great deal of energy to produce. It is also considered caustic and may result in chemical burns to the skin. After concrete has set, it is benign and offers no threat to the environment.

Building Code Applications

The Ohio Building Code covers concrete in Chapter 19. In Chapter 17, Structural Tests and Special Inspections, there are numerous requirements for concrete construction. The residential code has requirements for concrete construction throughout the document.

History of Concrete

No one knows where or when concrete became a material of construction. It is known that ancient cultures used lime as a binder and mixed with it with sand and other minerals. Concrete, as a material that resembles today’s concrete, was first used by the Romans in about 300 BC. The Romans found that the volcanic ash in Pozzouli, Italy, produced by the eruption of Mount Vesuvius, could be mixed with lime and water to form a plastic material that could be placed in forms and hardened over time. This cement came to be known as Roman cement. Unfortunately, the fall of the Roman Empire resulted in the loss of Roman concrete technology and the use of hydrated lime again became the standard for binding masonry materials together. The techniques used to build the Pantheon of light weight concrete had disappeared. More on this topic can be found at http://www.greatbuildings.com/buildings/Pantheon.html.

It was not until 1824 that any similar material appeared again. In that year, a mason, Joseph Aspdin, ground limestone and clay and heated them on his kitchen stove to form the first hydraulic cement, one that hardens after the addition of water. He patented the mixture and named it after the gray rock quarried on the Isle of Portland; hence, Portland cement.

Modern Portland cement is made from a carefully blended combination of calcium, silicon, aluminum, and iron. The process involves grinding the materials, mostly locally mined, and burning them in kilns, which causes them to fuse together at high heat levels to produce pebble sized spheres called clinkers. These are combined with gypsum and ground into a fine powder, which is the cement. More information can be found at www.cement.org/basics/concretebasics_history.asp.

Modern Concrete

Concrete is the only building material that can arrive at the site in a plastic form and be molded to whatever shape the designer pleases. This unique attribute of the material has been exploited by
architects and engineers to cast shapes that could never be found in nature or could never have been produced with any other material.

Modern concrete is comprised of Portland cement, aggregate, water, and occasionally admixtures. When the water and cement are mixed together, a chemical reaction takes place called hydration. Hydration begins the process of setting in which the hydrated molecules of cement begin to bond together and harden. The reaction is exothermic; in other words, it produces heat.

There is a direct correlation between the heat produced in the concrete and the rate at which it sets. Concrete that produces a high heat or is placed under hot conditions will have a faster setting time and will tend to shrink more than cooler concrete. Accordingly, the temperature at which the concrete is discharged from the truck may be closely monitored.

Concrete takes time to set and gain strength. It initially has a dormant period where chemical reactions are taking place, but the material has not started to set, or harden. This allows for it to remain plastic during transport and placement. When it has first been placed, it hardens, but remains soft for a few days (save high early strength) and slowly gains strength over time. Its compressive strength increases with time and, theoretically under proper conditions, could continue to strengthen indefinitely. Concrete’s tensile strength is quite low, so low in fact, that it is considered negligible. Therefore, where tensile strength is required, steel is used in conjunction with the concrete. Fortunately, these two materials are quite compatible, having similar coefficients of thermal expansion and little if any chemical reaction to one another.

The chemical bonding of the cement particles can be thought of as spherical bonds, much like the gravity field around a planet. As the hydration process proceeds, these bond spheres expand in radius and overlap with an increasing number of other bonding spheres. Accordingly, the longer the time allowed for hydration, the more particles of cement will become bonded together.

The cement that binds the concrete together is susceptible to some elements and chemicals. Sulfates are a major detriment to the durability of concrete, and Types II and V cement have been developed to minimize the effect of sulfates. There are other compounds that, when added to concrete in its initial hydration, will denigrate the bonding ability of the cement and cause it to develop a weak final product. One should always be cautious when adding any product to plastic concrete.

**Portland Cement Types**

*Type I – Standard*

This is the standard grey Portland cement that is considered the benchmark against which all other types are compared.

*Type II – Modified*

Modified Portland cement has a slight sulfate resistance and has a slightly lower heat of hydration than standard. This cement is a good choice for footings that are to be placed in contact with a high sulfur content soil, such as soils in southeastern Ohio.

*Type III – High Early Strength*
High early strength cement has been ground into a finer powder than Type I. Its chemical composition is no different, but being finer, it forms bonds between the cement particles more quickly and produces a higher heat of hydration in the process.

*Type IV – Low Heat*

Low heat cement sets more slowly than standard cement and produces less heat of hydration. Accordingly, it is usually used for massive pours, such as dams, where a build-up of heat in the concrete would cause cracking and excessive shrinking upon setting.

*Type V – Sulfate Resistant*

This type of cement is specially formulated to resist the ravages of sulfur and its derivative compounds. Type V might be useful in the construction of concrete chimneys for power plants that burn high sulfur coal producing sulfurous gasses or in sewage treatment plants with high levels of sulfur hydroxide.

Types I, II, and III are produced with the air entraining chemicals in the cement. These types are labeled Type IA, Type IIA, and Type III A.

**Aggregate**

Up to 75% of the volume of concrete is aggregate. It is essentially a filler material that allows concrete to be the affordable building material that it is. Aggregate is stone and sand, and since it comprises such a large part of the mix, its physical qualities have to be in line with what one would expect from the final product. More information on aggregate is found at [www.cement.org/basics/concretebasics_concretebasics.asp](http://www.cement.org/basics/concretebasics_concretebasics.asp).

The aggregate used in structural concrete must be strong, abrasion resistant, be able to withstand freezing and thawing, and be chemically neutral with the other products used. For example, there is brown sandstone that is common to Ohio. Some of this stone can be crushed by hand and does not make a quality aggregate for concrete. In most of Ohio, the aggregate is crushed limestone; a perfect material to be used with cement made primarily of lime.

The cleanliness of the aggregate is of importance. Mud and other contaminants have a deleterious effect on the binding power of the cement. Aggregate must be washed to assure that unwanted materials are not transferred to the mix. Crushed stone can be advantageous in comparison with rounded, smooth river run gravel. First, the chemical composition and types of stone are much more uniform in crushed aggregate. Second, the crushed stone has a non-uniform surface that allows for the cement to bond to a greater surface area than that of rounded gravel.

Where strength is not the primary concern, concrete is often made with lightweight aggregate that not only reduces the weight of the concrete, but also offers a greater insulating value than normal aggregate. This is sometimes referred to as insulating concrete. Expanded mica (vermiculite) or expanded volcanic glass (perlite) are the most common materials. Expanded shale can be used to achieve strength close to structural concrete but 20% lighter in weight (referred to as light weight structural concrete). More information can be found at [www.nrmca.org/aboutconcrete/cips/36p.pdf](http://www.nrmca.org/aboutconcrete/cips/36p.pdf).

When using normal aggregate, the sizes of aggregates must be blended together so that they occupy the majority of the volume of the concrete. This blending of sizes is called the grading of the aggregate. To
maximize the financial economy of the mix, the least expensive materials need to occupy the largest amount of space in the mix. Therefore, it is critical that the cement paste be minimized and used mainly to bind the much less expensive aggregate together.

To achieve different grades of aggregate, the material is run through a series of sieves in a process known as sieve analysis. This separates the aggregate into different sizes. The maximum size of aggregate in a mix is dependent on the smallest spacing between reinforcing bars or the thickness of the pour. Maximum diameter should be either three fourths of the clear space between bars or one third of the thickness of the pour, whichever is least. Accordingly, the concrete mix can be worked to surround all the bars and into corners of form work without producing gaps and air spaces.

Water

The water used to mix with the cement to cause hydration must generally be drinkable, or potable. Contaminants in the water can cause the cement particles to not bond correctly and weaken the final product.

Binding Additives

There are products which, when added to the concrete mix will increase the strength of the concrete and take the place of cement. One of these is fly ash, which is a byproduct of coal fired power plants. This product is quite common in Ohio and now is in fairly common in the production of ready mix concrete. Another is silica fume, a byproduct of silicon chips and silicon based metals. Blast furnace slag that is a byproduct of steel manufacturing acts as an hydraulic cement; in other words, it will directly react with water to form a cementitious compound. Other natural pozzolans that are derived from shale and clay can also be advantageous to the final product.

Admixtures

The manufacture of Portland cement based products has advanced greatly since the mid nineteenth century. Researchers have found many additives that will either transform the nature of the final concrete product or may affect the chemical reaction of the cement during its setting and curing process. Admixtures can facilitate the use of concrete under adverse conditions, but only if they are used judiciously. Therefore, admixtures should never be used without the consent and supervision of an engineer. If used improperly, these additives can have a negative effect on the final product and promote failure of the structure.

Air entraining is by far the most widely used admixture in concrete. It creates microscopic air bubbles in the concrete which allow the material to resist expansion and contraction that results from freeze/thaw cycles. Like numerous admixtures, air entraining will cause a reduction in the strength of the cured concrete. This deleterious effect, however, is offset by the air entraining’s ability to make the fluid concrete more workable. As a result, less water is needed in the mix which increases the strength of the concrete. Therefore, air entraining is not considered to weaken the final strength of the concrete.
Accelerants are the second most commonly used admixture in concrete, and possibly the most abused. Due to the link between ambient temperature of the fluid concrete and its setting time, the cold months of the year present a problem for a concrete contractor. The setting of the concrete is delayed by the low temperature and the contractor must wait to finish the concrete. The use of accelerants on the job-site has therefore become common place.

The least expensive and most common accelerator is calcium chloride, which is close in its composition to common salt. Most Ohioans are aware of the effect of salt on concrete road surfaces and, through common sense, would not mix it with concrete. Although calcium chloride is not as detrimental to concrete as common salt, it can cause the concrete to shrink excessively and can cause corrosion of imbedded steel. Therefore, its use is limited by the American Concrete Institute to a maximum of 5% by weight of the cement. Seldom does anyone in the field calculate these ratios. Further, calcium chloride is prohibited from use where there is reinforcing steel in the concrete.

A quick setting of the concrete and high heat of hydration can be achieved through the use of high early strength cement by increasing the amount of cement by weight in the concrete mix. Both these methods are expensive and therefore avoided by the contractor, as are other types of chemical admixtures. For more information, go to [www.fhwa.dot.gov/infrastructure/materialsgrp/acclerat.htm](http://www.fhwa.dot.gov/infrastructure/materialsgrp/acclerat.htm).

Water reducing admixtures can cause the final product to increase in strength. They allow for less water to be used in the mix, thereby decreasing the water to cement ratio. These admixtures can result in a more workable fluid concrete however many of them have been known to increase the setting time of the mix. For more information, go to [www.fhwa.dot.gov/infrastructure/materialsgrp/water.htm](http://www.fhwa.dot.gov/infrastructure/materialsgrp/water.htm).

Superplasticizers (high range water reducers) are one of the newer admixtures on the market. They reduce the amount of water required to achieve a workable and pumpable mix. The greatest drawback to their use is that their effectiveness is limited in time, and so they often have to be added to the mix at the job site, which can pose quality control problems. For more information, go to [www.fhwa.dot.gov/infrastructure/materialsgrp/suprplz.htm](http://www.fhwa.dot.gov/infrastructure/materialsgrp/suprplz.htm).

There are numerous other admixtures that can be used for special applications. Each one has its advantages and disadvantages and should be used only when ordered by an engineer. For more information, go to [www.concrete.org/general/FE4-03.pdf](http://www.concrete.org/general/FE4-03.pdf) and [www.basf-admixtures.com/EN/Pages/default.aspx](http://www.basf-admixtures.com/EN/Pages/default.aspx).

**Concrete Mixture**

As previously noted, concrete is a base mixture of Portland cement, water, and aggregate. The key to the strength of the final product is in the design of the mix. The scientific formula for mix design is beyond the scope of this text; however, some basic principles of quality mix design discussed below.

The ratio of the water by weight to the cement is critical to the strength of the concrete. Enough water must be added to the mix to completely hydrate the cement. This amount of water is so small that the mix would be unworkable and would be barely fluid. Accordingly, more water is added to the mix to achieve workability for the concrete masons. Unfortunately, water that is added above the level of hydration causes the final concrete product to lose strength. So a balance between the strength of the concrete and its workability must be struck. This is referred to as the water to cement ratio, and it represents the weight of the water divided by the weight of the cement.
To completely hydrate the cement, about one pound of water needs to be used for every four pounds of cement, which comes out to a ratio of .25. Concrete this stiff will not flow and cannot be worked with. Therefore, water to cement ratios of .35 to .40 are typically used. These ratios are set at the ready mix plant and should not be varied in the field by the addition of water to the mix at the job site.

The amount of cement in the overall mix is quite important to its strength. Generally, the more cement in the mix, the stronger the product will be. A well engineered mix will specify, by weight, the amount of cement, water, fine aggregate, and coarse aggregate. The overall weight will be approximately 2000 pounds per cubic yard of fluid concrete. Often a ready mix supplier will specify a mix according to only the amount of cement in the mix, with other proportions being dependent on the cement. In this case, the mix may be specified as a “sack” mix with the number of 94 pound bags of cement per cubic yard being called out (for example, a “four sack mix”).

As mentioned in the discussion of the aggregate, its grading is important to the concrete’s economy. Careful blending of the fine and coarse aggregate will not only affect the cost of the mix, but also it will have an effect on its strength in accordance with the quality of the aggregate.

**Major Tests for the Workability and Strength of Concrete**

It is critical that the concrete be workable yet strong when it is fully cured. Tests have been devised that will measure the workability of fluid concrete and its strength after curing. The slump test measures the workability and, in the absence of admixtures, the water to cement ratio of fluid concrete. This test is performed in the field with concrete directly from the delivery vehicle as follows:

1. Dampen the slump test mold and place it on a flat, moist, nonabsorbent, rigid surface, such as steel plate
2. Fill the mold 1/3 full by volume (about 2½ inches) and rod the bottom layer with 25 evenly spaced strokes
3. Fill the mold 2/3 full (about 6 inches) and rod the top layer with 25 strokes penetrating the top of the bottom layer
4. Heap the concrete on top of the mold, and rod the top layer with 25 strokes penetrating the top and second layer
5. Strike off the top surface of the concrete even to the top of the mold
6. Remove the mold carefully in the vertical direction (take about five seconds)
7. Immediately place the mold beside the slumped concrete and place the rod horizontally across the mold, and measure the slump in inches, to the nearest 1/4 inch.

The slump test should take approximately 2½ minutes.

More information can be found at www.civil.umaine.edu/cie111/concrete/printable%20concrete%20procedures.doc and www.youtube.com/watch?v=M_JHleYDXMs.

Another major field test is for the temperature of the concrete. Temperatures may be specified for the concrete according to the ambient temperature at which the concrete is placed. Different temperatures of concrete often call for different slumps, therefore the temperature of the mix at the time of placing may be critical.
Where air entrained concrete is called for, field testing air content in the fluid concrete is often required. There are a number of tests for this as noted at this site: www.durhamgeo.com/testing/concrete/air-entrainment.html

The actual strength of the final concrete product can be measure in the lab through the use of the concrete cylinder test. In this test, a 6 inch round by 12 inch high cylinder is filled with fluid concrete by the same method used in the slump cone test. The test cylinders are allowed to set-up on the site in a controlled environment curing box, and then are transported after 24 hours to a lab. In the lab, the cylinder mold is stripped away from the hardening concrete and the cylinders are cured under controlled temperature and humidity.

In 28 days, the concrete is said to have achieved its design strength and the cylinders are crushed in a machine to determine the laboratory strength of the concrete. The major problem with the use of test cylinders is that the strength of the concrete is not actually known until it has been in place for a month. If the concrete is in the footings of the building, a great deal of construction based on those footings would have already occurred.

Fortunately, at three days the strength of a test cylinder will be approximately 30% of design strength and 70% at seven days. Accordingly, if five cylinders are taken out of each truck, one can be tested at three days, one at seven days, and the remaining three cylinders can be tested at 28 days to determine the average design strength. The early testing of the concrete will indicate if the mix is significantly weak and may allow for compensatory actions to be taken.

More information can be found at www.youtube.com/watch?v=gM7C5IoajlU and www.youtube.com/watch?v=XF07-zG3tCk&feature=related. In the second of these videos, note that the concrete test cylinder failed quite rapidly, almost exploding. This is quite typical of the behavior of concrete when it fails in compression. Accordingly, in actual use, it is preferable that the tensile steel would fail before the concrete so that the steel would begin to stretch rather than the concrete explode. Lives would be saved if there were some notification of structural failure.

There are other methods of testing for the compressive strength of concrete. One of these utilizes the rebound of a weighted hammer to gage the strength of the product, though it is not a particularly accurate method. Cores can also be drilled from the actual construction site and crushed in a manner similar to the cylinder test. The problem with core drilling is that it is a destructive test and could weaken the structure.

Reinforcing

As noted previously, concrete does not have much tensile strength to speak of. It is a brittle material and has almost no ductility. Therefore, where tensile strength is required in a concrete construction, steel is used. Fortunately, steel and concrete have very similar coefficients of thermal expansion and are chemically inert when put in contact with one another. Accordingly, they work very well together.

Steel for reinforcing bar is made in three strengths: 75,000 ksi tensile strength (grade 75); 60,000 ksi tensile strength (grade 60); and 40,000 ksi (grade 40). Generally the reinforcing bars are round and have surface deformations embedded into the steel to allow the concrete to grip it. The diameters of the bars are given in 1/8 inch increments from a #3 (3/8”) to a #8 (1”). Larger bars do not necessarily conform to the 1/8 inch incremental rule. For more information see www.sizes.com/materls/rebar.htm.
Another steel product that is commonly used with concrete is welded wire fabric, also referred to as welded wire mesh (WWF or WWM). These products are comprised of steel wires that are welded perpendicular to one another to form a rectangle. They are produced in rolls for the lighter gage wire product or in mats for the heavier gage wires.

The numbering system that is used to designate WWF contains four numbers. The first number represents the spacing of the longitudinal wires and the second, the spacing of the transverse wires (for example, 6x8 would be a 6 inch spacing for the wires that run the length of the roll or mat and 8 inch spacing for the wires that run transverse). The third and fourth numbers represent the longitudinal and transverse wire areas in 100ths of a square inch (W1.4xW2.0 would indicate that the longitudinal wires have an area of .014 square inches and .02 square inches transverse). In its most common usage, WWF is installed into concrete slabs to act to control cracking and shrinkage of the pour. Heavy wire based sheets are often used for reinforcing of structural slab floors and walls.

When referring to reinforced concrete, most practitioners mean concrete that has reinforcing bars in it, or very heavy wire meshes. Accordingly, in estimating for demolition, concrete slabs that contain light welded wire mesh could be classified as unreinforced even though they have a minimal amount of steel in them.

**Cast-in-Place Concrete**

Concrete that is transported to the building site in its fluid form, or is mixed on site and placed into forms is referred to as cast-in-place concrete (CIP). This method of executing concrete construction has been, in one form or another, used for over 2000 years. Forms are constructed, any reinforcing is placed, the fluid concrete is mixed or delivered, and the concrete is placed into the forms and vibrated into place. The great advantage to this method is the freedom of shape that can be achieved. If the form can be built and the concrete made to a consistency that fills it, any shape can be cast. There are a few considerations as to what happens when the forms are removed, but the freedom is broad.

One of the drawbacks is that the forms have to be built. Often forms need to be designed by a structural engineer to resist the huge loads imparted to them by the fluid concrete. Accordingly, there is time and expense involved. On a union job, this may involve the use of carpenters or iron workers, depending on the material that is used for the forms. The drawback of the cost of form work may be added to by the time involved in its erection. CIP may not be the best choice of construction methods for a project that needs to be put in place quickly.

For concrete slabs on the ground (slabs on grade), formwork is often pre-engineered for many reuses. Its placement and bracing is simple enough that it rarely requires special design.

The forming of concrete walls requires formwork that will resist the horizontal loads that are caused by the fluid mixture inside the forms. As the wall pour gets higher, these forces increase and tend to push the forms out of place horizontally (known as “blowing out” the forms). To hold the forms in their proper vertical alignment, wire ties are run through the forms at calculated intervals and are imbedded in the concrete when the wall is placed. After the concrete sets and the forms are removed, the protruding ends of the ties are broken off (or snapped off, which results in the name of “snap ties”). The following site discusses the subject of form ties:

[http://www.tpub.com/content/engineering/14069/css/14069_262.htm](http://www.tpub.com/content/engineering/14069/css/14069_262.htm)
A problem with steel ties in a concrete wall is that they can rust and stain the surface. Numerous wall tie manufacturers supply conical inserts that will recess the ties into the wall so that it can be snapped off below the surface of the concrete. The recess in the concrete is then filled with a mortar material to match the wall surface.

Form surfaces are usually made from plywood if the form will not be subject to repeated use. Forms for repeat use are made mostly of aluminum or fiberglass. Regardless, the forms must be treated with a form release agent to negate bonding of the concrete to the forms and allow for easy removal. The following video demonstrates the use of pre-engineered forms for the construction of a column and beam structure: [www.youtube.com/watch?v=56sf-6CWaJk](http://www.youtube.com/watch?v=56sf-6CWaJk)

One of the newest and greenest concepts in CIP concrete is the use of insulating forms. These are forms made of foamed plastic into which the concrete is placed. There are quite few proprietary types. The following video demonstrates one of these: [www.youtube.com/watch?v=WYwTAfMFCmW](http://www.youtube.com/watch?v=WYwTAfMFCmW). Another video shows the setting of forms for concrete footings: [www.youtube.com/watch?v=Iks9ul821JU](http://www.youtube.com/watch?v=Iks9ul821JU).

### Placing Concrete

Once the formwork and reinforcing are in their proper locations and are sufficiently braced, the site is ready for the placement of the concrete. The CIP concrete can be mixed on site or can be transported to the site in a truck from the ready mix plant. Transported concrete will arrive and, if so specified, tested for its compliance with the specifications. In general, transport time should be no longer than 90 minutes, and the drum of the truck should revolve no more than 600 times.

Concrete trucks come equipped with a chute to discharge the mix from the drum. If the final location of the pour is within the reach of the chute, the mix will be discharged into the forms. Transportation to a site remote from the chute discharge is usually the case. On most commercial jobs, the concrete will be pumped to its final location. Pump trucks with long hoses are employed for this purpose. The pump can move the mix horizontally and vertically; however, vertical movement is limited due to the hydrostatic pressure of the mix.

On a smaller job, the concrete may be moved in motorized buggies similar to a small motor driven, four wheel dump bin. A hand wheelbarrow can be used, but workers tire of this method quickly since concrete is quite heavy.

For long vertical lifts, a crane with a bucket is used. Standard buckets can contain up to five cubic yards of concrete. The buckets are filled from the top and have a discharge door in the bottom for placing of the mix. The crane will position the bucket directly above the location of placing and the door will be opened. There are accessories for these buckets that include chutes and hoses for inaccessible areas. Horizontal transportation of a mix can be facilitated by a conveyor belt system that is usually mounted on a truck. Vertical lifting can be done within the limitations of the throw of the system.

Once the concrete has been placed in the forms, it must be consolidated to remove any air pockets and to work the concrete around the reinforcing bars and into remote corners of the forms. This is usually accomplished with a concrete vibrator, a vibrating probe that is inserted into the concrete at predetermined intervals to vibrate the concrete into place. These probes can be electrically or pneumatically driven and are most commonly used for large horizontal slabs. For small jobs, the concrete workers may use a steel bar to compact the mix into the forms.
Consolidation is critical to the quality of a CIP product. Spaces left in the pour by air pockets can cause the concrete finish to be faulty and can even cause the reinforcing bars to be exposed. Over-consolidation, however, may cause segregation of the concrete; a condition where the large and small aggregate separates, and the mix loses its homogeneous nature. Accordingly, the final product will be weakened. Other causes of segregation in fluid concrete can be over-mixing prior to placing and attempting to move large quantities of the mix horizontally.

Consolidation of columns and beams completes the work until the concrete sets. Slabs are a different matter. Once the concrete is consolidated, a slab needs to be leveled out, which is called screeding. Usually done with a straight board, the slab is leveled out, with high spots struck off the top and depressions filled and then re-screeded.

After this leveling process, the slab is floated with a magnesium instrument called a bull float. The purpose of floating is to drive the aggregate into the slab and bring excess water to the top. The process of bringing water to the top of the slab is referred to as bleeding, and is necessary for finishing. The water that is bled from the concrete will evaporate and leave behind a dusty scum called laitance. The laitance is not a problem unless concrete is place on top of it, then it will form a weak plane in the pour.

The concrete now begins the setting process in which it gives off heat and hardens. After the slab has achieved sufficient hardness that depressions will not be caused by a mason kneeling on a piece of plywood, the slab is troweled to produce a smooth, dense surface. This can be done by hand or with a trowelling machine. If there is to be a surface finish, such as the broom finishes common to drives and walks, the finish is applied immediately after the trowelling.

**Curing**

After concrete sets, it continues to harden over time. Ideally, the concrete should be kept moist for 28 days to reach its design strength. Theoretically, concrete that is maintained in a moist environment will continue to strengthen forever. The problem that is practically encountered is that it is very difficult to moist cure most concrete in the field with any quality control. The following link discusses the problem of curing concrete in the field. Note the graph showing the differences in strength gain according to the length of time that the concrete is kept moist:


Note that the earlier the concrete is allowed to dry, the weaker the final product is. Keeping the concrete moist during its first 28 days is quite important. Chemically, the water in the concrete is acting as a catalyst for the growth of the bonding crystals in the cement paste. When the water is removed, the crystals cease to grow and bond. Therefore, premature drying of the product will lessen its strength.

There are numerous methods of keeping the concrete wet during its curing period. For columns and beams, wrapping the concrete in impervious plastic will prevent the water contained in the concrete from evaporating into the air. Footings can be covered with plastic or wet sand or straw. Horizontal slabs offer a problem because of the large surface area that is exposed to evaporation. For most commercial applications, a spray-on curing compound that seals in the water is used. Slabs can also be covered with wet straw, sand, or a plastic sheet.
Precast Concrete

While CIP concrete has been used for millennia, the industrial revolution dictated that construction should find a means to use manufacturing techniques for building structures. One of these was to cast concrete in a factory and ship it to the site, in pieces, for assembly. This method of construction became very popular in the late 1950s and has continues to be used today. Panels to veneer the building can easily be cast, shipped, and fitted together on site. These pieces that are used strictly for enclosure are not required to have structural loads imposed on them and do not need to be heavily reinforced.

Structural columns, beams, and slabs are quite a different matter. If structural strength is to be imparted to the precast pieces, reinforcing must be cast into each unit in the factory. Steel reinforcing can be stretched, or tensioned, prior to being cast into the concrete, in which case, when the tension is taken off the steel, the cast piece is subjected to the pull of the shrinking steel and is compacted into a very dense unit. Pre-tensioning of steel cables is the most common method of reinforcing precast, pre-tensioned concrete pieces. However, stretching of the cables requires steel bulwarks to resist the tension and large machines to apply it; therefore, the method is relegated to a factory setting.

Structural pieces that are too large to be cast in a factory and shipped by truck, for example bridge deck sections, can be cast on the ground near the site and lifted in to place. In these cases, the concrete has post-stressing strands cast into it which can be stressed after the concrete has been set with pneumatic jacks. The Tampa Sunshine Skyway Bridge is a prime example. This post-tensioning system is used to significantly strengthen CIP concrete slabs.

The joining together of precast concrete depends on the welding of steel plates cast into the pieces, or placing concrete around the pieces in combination with reinforcing. There are many different details, but basically the system fits together somewhat like a toy plastic beam and girder set with which many budding young constructors play. The following link shows how precast concrete building elements fit together: [http://www.pci.org/files/PCI_DWP_binder_ch4.pdf](http://www.pci.org/files/PCI_DWP_binder_ch4.pdf)

Residential and Commercial Applications of Concrete

The main application of concrete in residential work is for footings and slabs on grade. That is not to say that there are not houses built with concrete structures, it is just rare. The major problem with residential concrete work is quality control. There are a large number of contractors doing it and they may not assure that the concrete is of sufficient strength. The addition of water and admixtures to the mix at the site and the lack of curing technique are common problems.

Take, for example, concrete used for footings. When it is placed, it usually is subjected to concrete block being laid on it within 24 to 48 hours; which is hardly enough time for curing. Granted, there will usually be some moisture from the ground, but not enough to promote quality curing. Accordingly, the concrete will reach only about 60% of its design strength and the builder should be certain to order a stronger mix than is required.

Slabs on grade have similar problems in residential work. They tend to be over-stressed prior to being sufficiently cured. An example of this is a driveway that is subjected to wheel loads before it has set for seven days. The solution to these problems might be a high early strength concrete, or a concrete designed with a large amount of cement in it. In either case, the expense of the concrete will rise. It is much better to convince the owner of the necessity of allowing concrete to cure prior to loading it. One
method through which this can be accomplished is letting the owner be responsible for watering the concrete to keep it damp. By doing this, the owner gets a greater sense of involvement with the quality of the work.

Commercial applications for concrete are endless. Concrete is used for deep poured foundations such as caissons, foundation walls, slabs on grade, structural walls, floor slabs, and roof systems. It can be placed on formwork that is later removed or on decking that remains in place. The total building can be cast in place or precast.

Usually, the quality control on commercial projects is much more stringent than on residential projects. The design of commercial concrete is usually specified by a professional engineer, so the quality of the mix is much more closely regulated than on a residential job. The commercial building code requires that an independent observation agency be on site to observe much of the construction and that tests be performed and reports issued.

**Supporting Organizations**

- Portland Cement Association: [www.cement.org](http://www.cement.org)
- Concrete Reinforcing Steel Institute: [www.crsi.org](http://www.crsi.org)
- American Concrete Institute: [www.concrete.org](http://www.concrete.org)
- National Precast Concrete Association: [www.precast.org/index.php](http://www.precast.org/index.php)
- National Ready Mixed Concrete Association: [www.nrmca.org/](http://www.nrmca.org/)
- Precast/Prestressed Concrete Institute: [www pci org intro cfm](http://www.pci.org/intro.cfm)
- Wire Reinforcement Institute: [www.wirereinforcementinstitute.org/](http://www.wirereinforcementinstitute.org/)

**Masonry**

This section covers the manufacture, qualities, and assembly of masonry, including:

- Short history of masonry
- Mortars
- Brick types
- Brick faces and bonds
- Mortar joints
- Concrete masonry units
- Reinfocing
• Masonry openings
• Cavity walls
• Movement control

Materials Selection and Team Coordination

The architect is the team member responsible for the selection of the materials. Most masonry is designed according to empirical design methods derived from years of experience. Tall masonry walls and those built in seismic zones must be designed by an engineer according to allowable stress methods. Masons are assumed to know the proper method of installation of the units.

Environmental Issues

The materials that are used to make brick are environmentally neutral and are in abundance. Concrete masonry has the same environmental issues as concrete. Brick can be recycled if the mortar is cleaned from it, but the process is very labor intensive. Concrete masonry is almost impossible to recycle, except if broken up for fill.

Building Code Applications

The Ohio Building Code covers masonry in Chapter 21. In Chapter 17, Structural Tests and Special Inspections, there are numerous requirements for masonry construction. The residential code has requirements for masonry throughout the document.

History of Masonry

The oldest of the major building techniques, masonry can be traced back thousands of years to a time when it used no mortar and all the units were either cut stone or baked clay. Dry laid units can still be observed at some archeological sites. It was not until about three thousand years ago that masons began to use lime as a leveling and bonding agent between units.

The rich and lengthy history of masonry construction suggests that it is one of the strongest building methods available. In actuality, compared to other materials, stone, brick, and block masonry is rather weak. Its durability, however, cannot be doubted. The student of history must remember that what one sees from ancient times are the successes. The failures of masonry have long since been claimed by the sands of time.

Up until the development of Portland cement, masonry mortars were made from lime. Weak in its bond, and susceptible to water and weathering, lime mortar joints were usually very narrow and the mortar was used as a leveler as much as it was a binder. Any practitioner of historic restoration and preservation should note that narrow joints may indicate lime mortar.
In historic brick work, bricks were usually made on or near the site, and the materials used in their manufacture were often of questionable quality. The bricks were fired in beehive-like kilns utilizing wood fires. Therefore, bricks that were fired closest to the heat source would have harder surfaces than those that were more remote from the fire. Old brick varies quite a bit in its hardness, color, and quality. Historic brick can be soft in comparison to its contemporary counterpart.

A major problem in the repair of old brick buildings is a lack of understanding on the part of the restorer about historic brick and contemporary mortars. Numerous modern mortars will develop compressive strengths in excess of the strength of the historic brick. If these mortars are used to re-point old masonry, the mason may be creating a situation where the mortar is stronger than the brick. Accordingly, if the wall system moves, as it inevitably will, the mortar will remain intact and the brick will be destroyed. Historic brick is usually impossible to replace but mortar can be re-pointed many times.

The development of Portland cement and its use in mortar caused a quantum leap in masonry technology. This high strength binder allowed masonry to be built higher with greater bearing value. In combination with highly controlled unit manufacture, scientific structural calculations could be made concerning masonry, and its use became a science rather than an art. Regardless, many engineers and builders still use empirical methods developed over years of experience and observation.

The development of concrete masonry units (CMU) was revolutionary. CMU are less expensive to produce than brick or cut stone, and are generally larger than brick units. The use of CMU allows masons to construct masonry bearing walls faster than with stone or brick, and the quality control in their manufacture is superior. The concrete block became the standard material for load bearing masonry, and its use for partitions allows for an extremely durable interior surface.

The major drawback to the use of CMU is that it has a lower compressive strength than brick, so it is generally reinforced with steel. Contemporary design now primarily uses CMU for bearing walls, and brick is relegated to a decorative facing material, often covering the CMU. Very few buildings are constructed with brick bearing walls.

In the twentieth century, masonry units were developed from glass. Glass block is used as a decorative material in the place of traditional glass. The units are quite sturdy and difficult to break. Glass block is manufactured is numerous different face patterns, colors, and degrees of translucency. There are cases of the material being used in load bearing conditions, but they are rare.

**Mortars**

Modern mortar is made from Portland cement, hydrated lime, and mason’s sand. These materials combine to form four basic types of mortar that vary in strength according to their formulation. Generally, the greater the ratio of Portland cement to lime, the stronger the mortar is. However, strength in this case comes with a price. Lime performs two functions in the mortar. First, it allows the mortar to be mixed with more water and makes it easier for the mason to use under the trowel. Second, in place and set, lime in the mortar will slowly leach out of the mortar with weathering and heal any fine cracks that develop over time. Therefore, it prevents water from penetrating into the system which prevents cracking due to freezing.
Type M mortar (2500 psi): a high strength mortar recommended for use below grade and where reinforcing is used. Its high cement content makes it a bit harder to work with than other mortars and it has poorer weathering qualities.

Type S mortar (1800 psi): considered a structural mortar with self healing properties recommended for use above grade where it is subjected to weathering. It has more flexural strength than Type M.

Type N mortar (750 psi): veneer mortar, not recommended for structural walls. Its high lime content makes it very resistant to water penetration, which is ideal for use in brick veneering.

Type O mortar (350 psi): recommended for interior use and for re-pointing of historic masonry. It has almost no load bearing values by modern standards, but will suffice for surfacing historic mortar joints.

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>Proportion by volume of Portland cement to lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>1: 1/4</td>
</tr>
<tr>
<td>S</td>
<td>1: over1/4 to 1/2</td>
</tr>
<tr>
<td>N</td>
<td>1:1</td>
</tr>
</tbody>
</table>

Basically, there are two categories of mortars: structural and veneer. Types M and S are structural and are used with concrete masonry units. Type N is used with brick veneer. As mentioned, Type O has few uses.

As with concrete, there are admixtures that can be used in mortar. Air entraining is one that allows for some movement in the mortar, but it cannot be used over a 14 % air level. When masonry is assembled in cold weather, accelerators are sometimes utilized to allow the mortar to set before it freezes. These are sometimes called anti-freeze agents and are not allowed under some contracts. Latex additives may be used to increase the bond of the mortar and reduce moisture penetration into the mortar joints. Often, the designer will require that the mortar be of a specific color. Pigments may be added to the mortar mix to achieve the requirements, or the mortar may come with pigments added by the manufacturer. The practitioner should read the specifications carefully prior to allowing the use of any admixture. More information can be found at www.masonrymagazine.com/5-06/mortar.html.

Brick Types

Bricks are made from baked clay. They are a ceramic similar to ceramic tableware, except the base clay is not as high quality and they are usually not glazed. Bricks have been made for millennia and their manufacture is a feature of the Exodus story from the Bible. Bricks are made today in Egypt much as they were in the days of Moses. The clay is mixed with a binder, such as straw, forced by hand into a mold, and baked in the sun. Once the bricks are sufficiently hard, they are fired in a kiln.

Western brick making is much the same. Molded bricks are made by forcing the clay mixture into a mold, taking the product out when hardened, and firing it in a kiln. This soft mud process produces a
common or building brick that is fairly porous and not especially consistent in its dimensions. The advantage to this molded brick is its cost is lower than face brick; its disadvantage is that it can soak up water, which can freeze and break the face off the brick.

A more modern and the predominant method of molding bricks is a stiff mud process in which a low moisture content clay is forced at high pressure through dies to extrude a very dense and dimensionally consistent rectangular strip, which is wire cut into individual bricks. These bricks are then fired in a kiln. These face bricks have a dense face which is quite resistant to water penetration. Often these units are molded with a series of holes in the body of the brick. These holes allow for even firing, weight reduction, and act to lock the bricks together when mortar is forced into them in the laying process. See the process in the following video: [www.youtube.com/watch?v=QDeEaMLNRY](https://www.youtube.com/watch?v=QDeEaMLNRY).

Face brick can be sprayed with a glazing compound prior to firing to produce a glazed brick with a pottery quality glazing. The glazed surface is impervious to water and can be any color. Glazed brick are expensive and are not commonly used.

In the early years of road building, bricks were used as a paving material. They still are today, but not as commonly as prior to the introduction of concrete. Paving bricks are very dense and impervious, and are generally larger than building bricks. The problem with paving roads in brick is that they become slick when wet, and they can be ripped out by snow plows. The labor to install them is quite extensive, so they are generally used for special projects and decorative areas.

High heat causes problems if the brick has water of air pockets in it. Accordingly, there are special firebricks, sometimes referred to as refractory bricks, which are made from special clays and are laid with a very narrow mortar joint of fireclay mortar. These bricks are typically used to line the fire boxes of a fireplace or are used to line kilns.

**Brick Sizes**

Brick sizes are not standardized throughout the country. Traditionally, the size of bricks has been determined by the local manufacturer. However, with the increased use of concrete masonry units (CMU), which is standardized in its size, brick coursings were expected to match those of the concrete masonry. Therefore, most brick has a coursing that is three bricks high to the standard concrete block. With mortar joints, bricks approach the four inch standards and have a thickness of 3 5/8″, a face length of 7 5/8″, and a face height of 2 1/4″. With standard 3/8″ mortar joints, the brick sizing will match that of the CMU. These bricks are referred to as modular.

There are a number of variations on these sizes that are given various names such as roman, jumbo, and king size. Face brick is the most consistent in its dimensions and will be rated FBS, FBX, or FBA. FBS is the standard for dimensional tolerance, chipping, and warping. FBX has the lesser requirements, and FBA is an architectural face brick that allows for large variations in size to provide a specific look.

**Brick Faces**

How a brick is presented when it is laid into a wall is designated by a name. Usually, brick is laid into a wall with its stretcher face presented. If that brick is stood on end so that its long, thin face is vertical, it is called a soldier. If the smallest face of the brick is presented horizontally it is a header, and vertically,
it is a rowlock. The broadest face of the brick in a horizontal position is a shiner, and vertically a sailor. The following link discusses these terms: http://en.wikipedia.org/wiki/Brickwork#Brick_facing.

Courses and Wythes

Brick, concrete block, glass, or stone are all called a course. The unit thickness of a wall is called a wythe. If a wall is two bricks thick, it is referred to as a two wythe wall. Seldom are two concrete masonry units used to create wall thickness, but if they are, it is a two wythe wall.

Brick Bonds

The method used to bond bricks together into a wall system is called a brick bond. The most usual of these is a stretcher or running bond, where the coursing is all made of stretcher faces and the vertical mortar joints are staggered to fall in the center of the brick below and above. This is also the predominant method of bonding concrete masonry units together. Historically, the common bond was used most often where the wall was running bond, with every 6th or 7th course being a header. The purpose of the header course was to bond multiple withes of brick together, so it was used in brick walls that had multiple wythes to allow for load bearing. Many decorative bonds have been used combining stretcher and header faces, such as the English bond and Flemish bond.

Mortar Joints

Mortar joints that are horizontal are called bed joints. The vertical joints are called head joints. The shape and tooling of these joints is critical to the performance of a system that is exposed to weathering, especially in the northern climates. Joints might be classified as exterior and interior joints, although these classifications are not official. Exterior joints, by virtue of their shape, cause water to be shed back to the environment. These joints include concave joints, weathering joints, and vee joints. Interior joints allow rain and snow to either set on a ledge and/or penetrate into the masonry system. Among these joint styles are flush, struck, and raked. Extruded joints are in a category by themselves, since the mason will use excess mortar in the joints and squeeze it out of the joint toward the exterior. The following link discusses at length masonry bonds and mortar joints: http://www.gobrick.com/BIA/technotes/t30.htm.

Weathering

Brick manufacturers rate their product according to its ability to resist weathering. Tests are run on the brick to determine its water absorption at both room temperature and in boiling water, and the strength of the bricks is determined. From these measurements brick are rated as Severe Weathering (SW), Medium Weathering (MW), or Negligible Weathering (NW). Each area of the continental United States has a recommendation for the brick weathering rating. Ohio’s rating is SW.
Concrete Masonry Units

Concrete masonry units (CMU) are made by filling molds with a zero slump concrete and mechanically compacting it. The resulting units can be immediately removed from the molds and transported to a curing room where they are exposed to a moist, warm environment for 24 hours, and then set in the yard for shipping.

CMU come in solid units, which are often referred to as concrete brick, and hollow, or cored, CMU, which are commonly called concrete block. Most block is manufactured with two hollow cores, although some may be three core. Two core blocks weigh less, allow vertical reinforcing to line up and, due to one less web acting as a thermal bridge, are less thermally conductive. The three core blocks are less likely to break and have greater strength.

Load bearing CMU are made in accordance with ASTM C90, which calls for three weights of CMU: normal weight, medium weight, and lightweight. Not only do the units have a difference in weight, but also they have a difference in load bearing capacity. Generally, normal units are the least expensive to manufacture and have the greatest density, load bearing, resistance to weathering, and durability. However, they are heavier to ship and lay than the medium and light weights.

CMU are porous and there are blocks that are specially manufactured for exterior applications. CMU that are not manufactured to resist the penetration of moisture should be coated if they are exposed to weathering. Some blocks can be porous enough that they allow the passage of air through them and may not be suited for airtight structures. Further, absorption of water into CMU in northern climates may promote block degradation due to freezing of water in the material.

The sizes of concrete block are standardized and a normal size, hollow CMU is 7 5/8” x 7 5/8” x 15 5/8” (8”x8”x16” with a 3/8” mortar joint). These are referred to as 8” block due to the thickness of the block with a mortar joint. Also commonly used are 4”, 6”, and 12” block.

There are many different configurations of concrete block, as well as numerous facing patterns. Notable among these is the lintel block, also referred to as a bond beam block. It is U shaped, and is laid in place with the opening of the U up so that reinforcing can be cast into it. Masonry, especially CMU, is weak in comparison with other building materials, and it is necessary to reinforce it with steel rebar and concrete. The bars are surrounded with a grout mixture, which is a high slump concrete made with fine aggregate, bonding to the bars and the masonry. Therefore, the reinforcing forms what could be viewed as concrete columns and beams, depending on the orientation of the bars.

The following link discusses in length concrete masonry units:
http://www.free-ed.net/sweethaven/BldgConst/Building01/default.asp?iNum=0702.

Reinforced Masonry

One method of imparting tensile strength to masonry is to fortify it with reinforcing bars that are the same as used for concrete work. A special U shaped block is manufactured to receive these bars and
then be poured full of concrete to form what is, essentially, a concrete beam. These are called bond beams, and they are commonly used as lintels and at the top of CMU walls to form a continuous tie beam all around the building. When completed, the bond beam looks exactly like the rest of the masonry and has an advantage over steel lintels in that it will not rust. At the top of the masonry wall, a bond beam can tie the top of the building together so that the top of the wall is reinforced against flexure, and they offer a bearing surface for roof and floor joists that distribute loads evenly to the masonry below.

Masonry walls are subjected to lateral forces from soil and wind. The result in long and especially tall walls is that they may overturn or fall over due to horizontal cracking. To prevent this, columns are built into the wall called pilasters. The columns are reinforces with vertical bars and poured solid with concrete. Essentially, they are a CIP concrete column. Often, they support a major beam such as might be found in the center of residential floor framing. Pilasters are commonly spaced at 20 feet on center, and since they are a major static point in the wall, expansion and control joints are often cast to one or both sides of them.

Hollow CMU shrinks over time and will exhibit cracking in the mortar joints. To minimize this cracking and to help control the effects of lateral loads, all walls should be constructed with horizontal joint reinforcing set into every other horizontal joint. This reinforcing is often referred to by the trade name Dur-O-Wall. Use of this reinforcing is not optional in hollow CMU walls. It is required by code.

The following link is to Dayton Superior, which manufactures a wide variety of masonry and concrete accessories: [www.dur-o-wall.com/DurOWal_main.html](http://www.dur-o-wall.com/DurOWal_main.html).

**Masonry Openings**

Due to a practical lack of tensile strength, masonry must utilize arching action to span openings, or be supported by materials with tensile resistance. The architecture of the ancient Egyptians shows that the column and beam construction they used depended on solid blocks of stone to act as spanning elements between vertical supports. Accordingly, the supports were placed quite close to each other because stone has very limited spanning capabilities.

The Romans perfected the concept of the arch which can span large openings and still have all its masonry units in compression. This then led to vaults and domes that could be made totally of masonry units without any tensile reinforcing. The problem with the use of arches, vaults, and domes is that their construction requires the use of bracing until the arch is complete. Accordingly, the process is labor intensive and in ancient times required a large amount of lumber. The following link explains quite completely the arch and its use in masonry: [www.brantacan.co.uk/masonryarches.htm](http://www.brantacan.co.uk/masonryarches.htm)

Lintels are defined as horizontal spanning elements that carry the load of masonry across an opening. In medieval times, stone and wood beams were used above windows and doors. A major problem with the use of a wood lintel is that the moisture content and thermal movement of wood and masonry are quite different and this differential movement caused stability problems in the masonry.
In modern construction, lintels are made of steel or reinforced, precast concrete. These materials move at much the same rate as the masonry and are quite compatible with it. Steel L shaped angles are commonly set into the masonry on each end of the opening and the masonry above the opening is laid on the steel. For large openings, wide flange steel shapes are similarly used. Precast concrete lintels are usually eight inches high and of a thickness similar to the wythes of masonry that will set on them. The following link shows lintels and bond beams spanning openings: http://www.imiweb.org/design_tools/masonry_details/details/01.030.0601.php

Brick no longer is used in multiple wythes to form bearing walls. Load bearing masonry is now primarily a function of CMU. Accordingly, brick is valued for its durability and weather resistance and is used as a veneering, or skin, material. Regardless of the structural backing material, brick must be tied to the backing wall so that it will stay in place and not peel off the building when exposed to movement in the wall. The usual materials for backing walls are wood, cast concrete, and CMU. The brick is tied to the backing wall with brick ties of various designs.

The building practitioner must be aware that the brick will not move with the backing wall. Different materials move at varying rates with exposure to heat and moisture. Examination of the movement of materials is critical in building a durable veneer wall. First one must consider brick. It is fired in a kiln; so when it is first removed from the firing process, it has very little or no moisture in it. When exposed to the air, the brick begins to draw moisture from the air and, as a result, swell. This is referred to as being hygroscopic. This swelling takes a long period and could happen over months. Accordingly, the brick wall will swell after the units are installed.

Consider the backing material starting with CMU. Concrete block is made with a moist curing process so that it comes from the curing area full of moisture. When exposed to the air, the block will begin to dry and shrink. This process is faster than the swelling of brick but has been known to happen over the period of a year. Accordingly, common sense dictates that shrinking block and swelling brick should not be tied rigidly together.

A backing wall of wood will have movement that is not similar to that of any masonry. Wood has large swings in moisture content and has been noted to swell and shrink according to the moisture content of the surrounding air. Again, wood and masonry must not be bound tightly together.

Porous materials swell and shrink according to their moisture content. Wood, concrete masonry, and brick all are affected by their hygroscopic properties, albeit at different rates and volumes. Materials also move in accordance with their temperature; shrinking as they cool and swelling as they heat up. A veneer exposed to weathering will likely move quite differently than a backing wall, considering the extremes in heat and moisture to which it will be exposed. Ties between backing walls and veneers must allow for differential movement. Manufacturers utilize wire and corrugated metal to provide the flexibility necessary. The building code mandates that a tie be installed for every 4 1/2 square feet of veneer with a vertical spacing of 24 inches maximum and a horizontal spacing of 36 inches maximum. Moisture controlled CMU can be used for a veneer, and the same criteria mentioned above will apply.

A major consideration in the construction of a masonry cavity wall is moisture control in the cavity. Water can penetrate into the cavity in driving rains and collect on the cavity face of the veneer.
Likewise, moisture from a warm interior of the building may penetrate the backing wall as vapor and condense on the cold cavity face of the veneer. In either case, this water will run down the cavity face of the veneer and must be directed to the exterior of the system.

This is accomplished through the use of a clear air space between the veneer and backing wall. This prevents water from being transferred into the backer wall. When the liquid has run down the wall, it hits a continuous metal, rubber, or plastic barrier, called a flashing, that stops its descent and directs it to weeps in the masonry veneer immediately above the flashing. These weeps might be holes in the mortar, rope wicks, or the latest technology, cell vents. Where cell vents are used, they allow air to move into the cavity above the flashing and escape through another vent at the top of the cavity. This process dries the interior of the cavity and helps to prevent mold growth.

The following video shows a brick veneer wall with a concrete block backing wall: [www.youtube.com/watch?v=690UM6rb0y8](http://www.youtube.com/watch?v=690UM6rb0y8). The two are joined by wire ties that hook into eyelets on the horizontal reinforcing in the block. Insulation is shown against the block wall with an air space to the brick side. Moisture control is provided with continuous flashing and cell vents at every other head joint above the flashing. A mortar net is installed to keep mortar from plugging the vents.

**Movement and Cracking Control**

Masonry swells and shrinks with changes in the temperature and its moisture content. Further, masonry changes volume when exposed to moisture from the atmosphere after manufacture. Accordingly, all masonry construction must be built with control or expansion joints in it to allow for movement. In brick, these are called expansion joints; in block, control joints. They should occur approximately every 20 feet of straight wall run, over openings, at changes in wall heights, changes in wall thicknesses, and at corners at a distance of about 1/3 of the wall height from the corner.

**Supporting Organizations**

- International Masonry Institute: [www.imiweb.org](http://www.imiweb.org)
- Mason Contractors Association of America: [www.masonrysociety.org](http://www.masonrysociety.org)
- The Masonry Society: [www.masoncontractors.org](http://www.masoncontractors.org)
- National Concrete Masonry Association: [www.ncma.org/Pages/default.aspx](http://www.ncma.org/Pages/default.aspx)
- Masonry Advisory Council: [www.maconline.org](http://www.maconline.org)
- Brick Industry Association: [www.gobrick.com/index.cfm](http://www.gobrick.com/index.cfm)
Steel and Other Metals

This section covers the manufacture, fastening, and erection of steel, as well as the use of other metals, including:

- Short history of metals
- Modern steel manufacture
- Structural shapes
- Steel terminology
- Fastening methods
- Connections
- Open web steel joists
- Fireproofing
- Steel deck
- Light gage steel framing
- Stainless steel
- Other metals

Materials Selection and Team Coordination

The architect may choose the metals to be used, but when it comes to the structural steel, the structural engineer designs the skeleton. The steel fabricator/erector works closely with the engineer to determine the proper connection designs and member lengths. After erection, the steel connections must be inspected by an independent contractor.

Environmental Issues

Metals generally take a large amount of energy to refine from ore. Fortunately, metals can be recycled, and steel, in particular, can be recycled innumerable times without a loss of strength. Accordingly, most metals are recycled, which reduces the amount of energy that is used to produce new shapes.

Building Code Applications

The Ohio Building Code covers steel in Chapter 22 and aluminum in Chapter 20. Note that in Chapter 17, Structural Tests and Special Inspections, there are numerous requirements for structural steel. The residential code has requirements for metals throughout the document.

History of Structural and Architectural Metals

The mining, purification, and alloying of metals goes back thousands of years and has a great bearing on how human beings evolved into the society of today. In building technology, metals mostly were used as decoration up to the mid nineteenth century. They had little structural use except as connecting
devices, and even then they were weak and quite expensive. Until the 1800s, nails were removed from buildings and reused because each one was hand crafted. The industrial revolution produced advances in metals technology and in methods with which metals were alloyed and mass produced.

The alloying of metals is the technology by which different elements are combined to change the nature of the base material. For example, iron (Fe) by itself is a malleable and not particularly strong metal; but when combined with the proper amounts of carbon (C), steel is produced, which is a hard, strong metal.

Two thousand years ago, the alloying of copper (Cu) and tin (Sn), sometimes with traces of other metals, formed bronze, which was much stronger than either copper or tin. It was the standard material for any strong metal that was required. At that time, metals were rather difficult to produce and were very valuable; therefore, most metals were used for weaponry and not for the building trades. Bronze and iron tools were relegated to chisels and other stone shaping implements. Occasionally they were used for clamps and chains, but were very costly.

The industrial revolution changed all that. Iron began to be mass produced and methods such as the Bessemer process and open hearth steel production resulted in large batches of steel being produced in about 20 minutes. The carbon steel produced was superior in quality to the old wrought iron since impurities were burned out and control of the carbon content was much easier to achieve.

Advances were made in processing throughout the twentieth century, with the latest innovation being the electric arc process. The formulas and strengths of steel changed through time, and at the end of the twentieth century the two major types of steel used to make structural pieces were A36, a mild carbon steel, and high strength low alloy steels.

### Modern Structural Steel

Steel is pound for pound the strongest of the structural building materials. It is also the most expensive because the manufacturing process is highly quality controlled and there is seldom a defect in the material. When designing in structural steel, an engineer is quite careful not to over-design and drive up costs. Steel is, therefore, used to its greatest efficiency with every pound supporting the highest allowable load.

Steel is manufactured in accordance with specifications from the American Society for Testing and Materials (ASTM). Carbon steel for structural use is generally designated as ASTM A36 except for hollow shapes and pipe. High strength low-alloy (HSLA) steels are manufactured according to ASTM A527 and A913. Each of the steels has a minimum yield stress (Fy), the number of pounds per square inch at which, when put in tension, the metal will leave the elastic range and enter the plastic range.

Carbon steel has an Fy = 36,000 pounds per square inch (36 kips per square inch or 36 KSI) and HSLA steels are grouped together under an Fy = 50,000 pounds per square inch (50 KSI). Obviously the HSLA steels are stronger than the carbon steel and will provide for the use of a lighter section to carry a similar load. Until the discovery of the electric arc manufacturing method, A36 steel was cheaper to
manufacture than the HSLA, but now they are competitive in cost per pound and the A36 steel is being phased out in the manufacture of major structural shapes.

Among the types of HSLA steel is weathering steel. It was developed by U.S. Steel in the 1960s to eliminate the need to coat the steel. Cor-ten, as it was brand named, would rust on its surface and then stop oxidizing. U.S. Steel clad their headquarters in it as a showcase, and it became popular as a bridge building material. One problem with this steel is that water that runs off the steel will carry a very slight amount of rust and will stain materials below it.

**Shapes**

Structural steel comes in varying shapes, or sections, the most common of which is the wide flange (W shape). It is used for both columns and beams and ranges from 4 to 44 inches in depth. The standard designation for structural shapes is a letter, such as W followed by a number designating the approximate depth, followed by another number which designates the weight per foot of the section. So a W 24 x 94 would be a wide flange beam that is approximately 24 inches in depth and weighs 94 pounds per foot of the section.

Similarly designated are M shapes that are very light W type shapes; S shapes (American standard beams); HP shapes (bearing piles); C shapes (American standard channels); MC shapes (miscellaneous channels); WT shapes; ST shapes; and MT shapes.

The W, M, S, HP, C, and MC shapes are comprised of a flange on the top and bottom of the beam separated by a web. The WT, MT, and ST shapes have a flange on the top and a stem. One could think of them as beam shapes with the bottom flange cut off. One could also think of the channel shapes as being American standard shapes that have been split vertically.

For minor structural uses and bracing, steel L shapes are often used. These are designated by the length of each leg of the angle and the average thickness of the material. Accordingly an L 6x4x5/8 would be an angle with a 6 inch long leg, a 4 inch long leg and an average thickness of 5/8 of an inch. Often when an unequal leg angle is called for on a drawing, it is accompanied by the designation LLV, which means long leg vertical, so that the craftsman will know which way to install it in the construction.

Hollow structural shapes (HSS) are tubes that are rectangular, square, or round. They are designated by their vertical and horizontal dimensions, their diameter, and the thickness of steel from which they are manufactured. Steel pipe is designated according to its interior diameter and comes in standard weight, extra strong (X-strong), or double extra strong (XX-strong).

All of the information about structural shapes can be found in publications by the American Institute of Steel Construction (AISC). Most prominent of their publications is the Manual of Steel Construction, which is considered indispensable for anyone designing in structural steel. Not only does the manual have complete information about the shapes, but also it covers the design of connections and the specifications for connectors.
Further information about structural shapes and configurations can be found at http://www.aisc.org/content.aspx?id=3226. Go to the power point presentation under Structure of the Everyday and open the presentation StructureEverydayMembers.zip 235MB. It will take some time to unzip.

**Structural Steel Terminology**

It is critical in studying construction to learn the correct terminology for the steel members as well as the designations of the shapes. Vertical members that deliver loads to the ground are columns. They may be W shapes, HSS, or any other shape.

The vertical members that deliver the loads to the columns are beams. These are usually W shapes, but could be HSS or other shapes. When there is more than one size of beam and they are connected and spanning in different directions, the larger of the beams is called a girder. Beams at the exterior of the building that carry both floor and exterior wall loads are spandrel beams. Spandrel is a term that is applied to many building elements that occur at floor and roof levels on the exterior of a building. For example, opaque glass on the outside of a building that covers the floor structure is called spandrel glass.

Often long spans are required which cannot be achieved with a standard steel shape. For this purpose, engineers will fabricate steel shapes into a truss. An open web joist is a type of truss, but the large span trusses are all custom fabricated of many steel pieces of different shapes. Where these pieces join, there is a steel plate to allow for bolting or welding, which is called a gusset plate. Gusset plates are not unique to steel construction, and wood trusses utilize them made from plywood. In 2007, the failure of the I35W Bridge in Minneapolis was the result of gusset plates that were designed too thin.

Trusses can be three dimensional as well as flat. A three dimensional truss is referred to as a space frame. Loads are applied to all members in the space frame equally so that each of the members of the frame is identical in size.

Modern steel building technology now uses rigid frames, or bents, that are a combination of steel columns and beams. These rigid frame buildings are often used to cover large expanses of floor without interior supports in buildings such as natatoriums and warehouses. Since the frames are spaced at large intervals (20 to 30 foot would be typical), there must be secondary spanning elements to which the roof and wall systems attach. For the roof, the secondary spanning elements are called purlins. On the walls, they are called girts. The purlins and girts are then covered with metal roof and wall panels that are made of cold formed metal.

The following link shows a video of a rigid frame steel building being assembled: http://www.youtube.com/watch?v=g5f2W-PSt_k.
A major problem with constructing a building of columns and beams or with rigid frames is that the vertical and horizontal positioning of the elements offers little resistance to lateral loads. Accordingly, these framing types must be braced against collapse with cross bracing or similar stiffening elements. Typically, steel angles are used to provide bracing, although steel plates and straps have been used. When cross bracing, one element of the bracing goes into compression while the other goes into tension. Since steel is superior in tension to compression, bracing can be achieved by using cables or bars that are solely in tension. Likewise, cables and bars can be used in the tension members of suspension bridges such as the Golden Gate Bridge.

**Steel Fastening Methods**

In the early years of steel construction, pieces were fastened together by the process of riveting. A rivet is a solid steel cylinder with a head on one end. The rivet is heated in a forge until it is white hot and inserted into matching holes in metal plates or members. The shaft end of the rivet is then hammered into a head by a mechanical hammer so that the shaft has a head on each end. When the hot metal cools, it shrinks and draws the pieces of metal tightly together. This forms a friction bond between the joined pieces. The problem with riveting is that it requires three workers to accomplish, which is quite labor intensive.

The development of high strength bolts made riveting almost obsolete. A bolt can be put in place by one worker and the nut tightened on to it. Primarily structural bolts are tightened to the point that they pull the joined pieces together to form a “friction” connection that depends on friction between the pieces to carry the load (also called slip critical connections). These types of connections can be accomplished with only HSLA steel bolts that conform to ASTM specifications A325 and A490. These structural bolts, referred to as finished bolts, have a hexagonal head and the grade of bolt is stamped on each head.

A connection that depends on the shaft of the bolt in shear to bear the load is a bearing type connection. Bearing connections can use finished bolts or can use bolts conforming to ASTM A307 (unfinished bolts). Generally, though not always, A307 bolts will have a square head so that they may be readily identifiable from finished bolts.

Unlike most other materials, metals can be welded together as well as mechanically fastened. The process of welding is an art as much as a craft, and welders are highly paid craftsmen. They not only must be trained in the welding of different materials, but also they must be able to weld in horizontal, vertical, and overhead positions. There are many different types of welds that can be applied, and the welders must learn to execute each of these as well. The American Welding Society (AWS) is the main agency charged with quality control specifications for welded joints. Welders must be certified according to AWS criteria before they can perform on a structural steel construction project.

The two major connecting methods for modern steel construction, friction connections and welding, both require precision. The building practitioner must remember that steel is very expensive compared to the other major structural building materials, and it is sold by the pound. Accordingly, the engineer

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should design steel structures so that every pound of material is used to its highest possible efficiency. Since defects in material are unlikely, failure of a steel structure is usually the result of errors in design or in the construction of the connections. Accordingly, tests are carried out on all connections to assure that they are of the strength specified.

Slip-critical connections require that the bolts be tightened to the required torque. This can be measured after installation by an inspector using a torque wrench, which is very labor intensive, as well as often dangerous. Gaging washers are another method of determining the torque of the bolts. These washers are manufactured with deformations in them and when the nut is tightened, the washer deformations will flatten out so that the space between the washer and the fastened material can be checked with a feeler gage. More commonly used in modern construction are tension control bolts. They are installed with an impact wrench and have a portion of the bolt that will break off when the proper torque is achieved and cause the wrench to stop the tightening process.

Welded connections require inspection to ascertain the quality of the weld. Welds that have gaps, pockets, or cracks in them are unacceptable. There are numerous methods with which welds can be tested. Destructive testing where the weld is actually broken is, obviously, not generally used in construction. Non destructive testing (NDT) utilizes a variety of techniques that subject the weld to external energy sources and measures the refracted or reflected response of the energy. These include X-ray, ultrasonic, magnetic and thermal wave.

Further information about fasteners and connections can be found at:

http://www.aisc.org/content.aspx?id=3226. Go to the power point presentation under Structure of the Everyday and open the presentation StructureEverydayConnections.zip 167MB. It will take some time to unzip.

Connections

Connections between structural steel members are critical and their design is executed by both structural engineers and specialized technicians. In many cases, connections are fairly simple and the AISC manual specifies their design. Accordingly, a technician may choose the proper connection from a table and detail it without the assistance of an engineer. Complex connections that have multiple members intersecting and eccentric loads require the attention of an engineer.

The simplest connections are beam to column or beam to beam connections that resist only shear loads. The connections will allow a slight amount of rotation in the connection and are not designed to resist rotational forces. These are referred to as shear connections and they utilize steel angles to transition the load between members. They may be bolted or welded. The most usual of these is the framed connection where the web of a beam is connected with angles to a column or the web of a girder. Where framed connections would be difficult to physically bolt or weld together, a seated connection is used. On occasion, a seat angle may be fastened to the carrying member to allow for positioning of a beam prior to the installation of a framed connection.
If the connection will be required to resist moment loads or rotational forces, its design becomes complex. Where one has a moment, one will invariably also have shear forces. In combination these two forces would be difficult to resist in a single connection. Therefore, the engineer handles the two forces as separate entities. The rotational moment forces are resisted by rigidly fastening the flanges of the beam to the supporting member, usually a column. This is achieved through welding in most cases. The shear forces are then relieved by a framed connection. Accordingly, a moment connection will almost always be combined with a shear connection.

For tall buildings, columns must be stacked one on top of the other. The connections between them are referred to as column splices. If the outside of the flanges of the column line up, as is the case with many W14 shapes, the splice will be achieved by fastening plates to the webs and flanges of the aligned members. Where alignment is not possible, a bearing plate may be welded to the top of the lower column and the upper column fastened to the plate.

**Steel Open Web Joists**

In light commercial construction, one of the most widely used steel products for the support of roof and floor systems is the open web joist (OWJ). This product is used much as joists in a wood residence are with fairly close spacing, usually two to five feet depending on the deck and loads imposed. Instead of utilizing flanges and a web as the structural shapes do, the joists will have chords at the top and bottom of the units with webs configured like the members of a truss. The chords are primarily back to back angles with the web of round steel bar welded in between them. Accordingly, open web joists are also referred to as “bar joists.” The following link shows open web joists in place and grouped for installation: [http://quincyjoist.com/products/steel-joists/default.asp](http://quincyjoist.com/products/steel-joists/default.asp)

Open web joists are specified by their depth, their series, and their strength. The series of the joist refers to the spanning capability of the joist. Most common joists are K series and have depths ranging from 12 inches to 30 inches, and spans up to 60 feet. A typical designation for a K series joist might be 24K6, which denotes that the joist is 24 inches in depth, a K series, and has a strength designation of 6. The strength designation is a comparative number denoting a higher strength with a higher number. Spanning tables should be consulted to determine the capability for each joist according to the uniform load and joist spacing. Other series designations are the LH, which is a long span joist, and the DLH, which is a deep long span, which can span up to 144 feet.

When performing renovation and restoration work, note that the series of joists have changed over the years, especially in the 1960s. Originally, the open web joist was manufactured using all A36 steel. Manufacturers began using HSLA steel for the chords and changed the designation of the joist. Then all HSLA steel was used and the designation changed again. Problematic is the fact that many of the manufacturers of these joists are no longer in business and information about historic joists is difficult to locate. One must use caution when determining the strength of old open web joists. The following link gives a short history of open web joists: [www.structuremag.org/article.aspx?articleID=919](http://www.structuremag.org/article.aspx?articleID=919).
**Fire and Steel**

Steel is forged in fire and can be destroyed by it. Though quite hard and stiff at room temperature, it does not take too much heat for steel to begin to lose its load bearing capacity. At about 600 degrees SI (1112 degrees F), A36 steel loses about two thirds of its load carrying capacity and permanently deforms very quickly. Therefore, unprotected steel in buildings, although it will not contribute fuel to a fire, will quickly become structurally compromised. The following link discusses and shows fire damage to steel structures: [http://www.structuremag.org/article.aspx?articleID=457](http://www.structuremag.org/article.aspx?articleID=457). Another link demonstrates the weakening and elongation of metals with a rise in temperature: [http://www.engineeringtoolbox.com/metal-temperature-strength-d_1353.html](http://www.engineeringtoolbox.com/metal-temperature-strength-d_1353.html).

**Cold Rolled Steel**

Thin sheets of steel can be formed without heating them. The process is either done by stamping the shape as one might with an automotive fender, or the shapes can be passed through a series of rollers. Light gage steel shapes for construction are made in this fashion.

Light gage steel studs and joists are in use throughout the U.S., and as wood costs rise it is likely that their use will increase. Steel studs are used in a manner very similar to traditional wood studs, with vertical members being installed at 16 to 24 inches on center. The vertical studs are fastened to U shaped channels at the top and bottom by screws or by a punching device. The vast majority of partition walls in commercial buildings are steel stud walls. Unlike wood, the steel stud walls are quite flexible until a sheathing is attached to them, so they cannot be erected by the same method as wood stud walls when they are to be sheathed with drywall. The channels are installed first and then the studs are put into place between the channels.

The great advantage to the use of steel studs is that they are lighter and straighter than wood and they are also fire resistant. The disadvantages are that they can interfere with radio transmissions, such as cell phones, and they are subject to rusting. Use of steel studs and light gage steel joists has not found wide acceptance in the homebuilding industry in Ohio, but steel stud houses are being erected quite frequently around the Chicago and Milwaukee areas. As homebuilders learn the light gage steel technology, they will undoubtedly apply it in Ohio also.

The use of light gage steel framing for the exterior of commercial buildings is a standard. The framing is usually covered with a gypsum/cement board that acts as a stiffener and a backing surface for the exterior finish. Load bearing steel stud walls are becoming common, but condensation within the wall system can corrode the steel, and moisture barriers in cold climates must be installed with care and diligence to ensure their integrity.

The most common roof and floor support system for light commercial buildings utilizes open web joists covered with a steel decking. Corrugated steel deck comes in two major varieties; form deck, also known as centering deck, and composite deck. Form deck is used where roofing insulation will be fastened directly to the deck and the deck will carry its own weight, the roof, and snow and wind loads.
Composite deck is made to be covered with concrete, and the concrete will bond to the deck. In doing so, the concrete resists compression forces while the steel deck resists the tension forces. This type of system is usually used for floors that require a much higher load carrying capacity than roofs.

The span of steel deck is dependent on the thickness of the steel, the depth of the corrugations, and the load imposed on the deck. Typically, spans are from two to six feet, but may be longer. The deck is usually puddle welded to the steel supports, although it can be fastened with bolts and screws. The expansion and contraction rates of wood and steel are quite different and the use of steel deck to span wood supports should be avoided. The following video link shows the rolling of metal deck:

http://www.youtube.com/watch?v=AVpm8ceHSnw.

**Stainless Steel**

Stainless steel is steel that is alloyed with mostly nickel and chromium, along with other metals. What makes this metal stainless is its ability to form a clear coating on its surface as it oxidizes, preventing rust and further oxidization. There are many different types of stainless steel and each one has its own unique qualities. Some are easily cold formed and others resist forming through cold rolling and stamping. Some types of stainless are quite difficult to weld and each type has strength and hardness qualities that are different from most others.

Stainless has been used as a cladding material for the exterior of buildings such as the Chrysler Building in New York City. Due to its expense, it is not used extensively on building exteriors, except as roofing sheeting. Its primary use is for fixtures and interior decoration. It is used extensively in commercial kitchens due to its ease of cleaning and resistance to chemicals.

**Non-Ferrous Metals**

Numerous metals aside from steel are used in the construction industry. Most are used as cladding materials and for interior fixtures and decoration. One of the oldest of the metals known to man is copper. It has been alloyed with other metals to form many types of brass and bronze. As a base metal, copper has a resistance to continued oxidization after its initial exposure to the elements. It will take on a green patina that protects the metal from further weathering deterioration. Therefore, it is highly prized as a roofing metal and can be seen on many older buildings.

Copper is also a fine metal to use for flashing, which prevents water penetration at intersections of building planes such as walls and roofs, or around windows and doors. Copper is the only metal that resists the growth of bacteria. Therefore, one may be finding many more copper based fixtures and hardware in health care facilities in the future.

Lead is another metal that can be used in sheets to form roofs. Of course the problem with a lead roof is that its weight is significant in comparison with other materials. Lead can also be used as a sealant because it is malleable enough that it can be pounded together to form a water resistant seal. Lead has
a low melting point, so it was often used to pour around pipe openings to seal them. The use of lead has fallen into disfavor because of its negative environmental impact, but it is still found in older buildings.

Tin used to be used as a roofing material, but it has fallen into disuse. Of course it is alloyed with other metals to form bronze and tin-alloy coatings such as Terneplate, which is a combination of tin and lead, usually used to coat steel.

Zinc is the primary metal that is used for the galvanizing of steel. It forms a protective barrier to prevent steel from corroding and gives galvanized steel its distinctive silvery shine. Zinc has the unique ability to act as a sacrificial metal when steel begins to oxidize. Rather allowing the steel to rust, the zinc will protect scratches and sheared edges of the steel by cathodic protection.

Aluminum is a common metal used in buildings for window frames, cladding, and flashing. Wrapping of wood members with aluminum is quite common to afford a maintenance free surface.

A major problem with the use of metals is galvanic corrosion. Certain metals, such as copper and aluminum, when put in contact with one another in the presence of moisture, will result in one metal “eating” the other. It is an electrolytic reaction between the metals that causes the transfer of electrons from one to the other. The building practitioner must constantly be aware of this problem and use great care to separate dissimilar metals. The following link is to a roofing company website that discusses this problem and shows the galvanic scale of metals. The farther apart on the scale the metals are, the more profound the corrosive action will be:


Supporting Organizations

- American Institute of Steel Construction: www.aisc.org
- Steel Construction Institute: www.steel-sci.org
- American Society for Metals: http://asmcommunity.asminternational.org
- American Iron and Steel Institute: www.steel.org

Wood

Of all the structural materials, wood is most closely linked to nature. Lumber is cut from the tree and has all the characteristics and flaws that came with the growth of that particular plant. Each tree is unique. It has characteristics that are common to its species, but grows in a slightly different manner than all other members of its kind. Accordingly, there are no two pieces of lumber that are completely alike. This presents a difficulty for the engineer and builder using it. Unlike steel, that has a closely regulated molecular and chemical structure, wood cannot be assigned a particular strength. Depending
on its species and quality, wood can be given a minimum strength that it will meet, but its ultimate design strength is always in doubt.

An examination of the structure of wood will cast light on the above statements. Consider the manner in which wood is configured. It is analogous to a bundle of straws. According to the weather during the lifetime of the tree, the cells, surrounded by cellulose walls, may be large or small; short or long. Further, the species of tree will affect the size of these cells.

During the wet temperate seasons these cells grow quickly and are large in comparison to the growth during the hot, dry times of the year. As a result, when a tree is cross cut, annual rings that indicate these seasons are visible. Much historical knowledge has been derived from old growth trees.

Trees start their life as a sprout much as any other plant. They grow vertically and in circumference as they mature. Branches sprout off the main trunk to support the photosynthesis required for plant life.

The drawing above shows the growth of a tree. The bark is a protective layer serving a purpose much like human skin. Just inside that is the cambium layer, which contains the new growth cells. The cells in the cambium layer have not matured enough to be of any structural use and are quite soft.

The sap wood is the part of the tree that maintains the flow of nutrients from the ground to the leaves, and the sugar back down to the roots. Its cells are hard enough to be structural, and this part of the tree is milled for lumber. As the tree matures, the sap wood slowly becomes heart wood and acts as the hard structural part of the tree analogous to human bones. There is no fiber strength difference between sap wood and heart wood after it has been milled and dried. The main structural difference is that the heart wood has less defects such as knots or wanes.

The annual rings are separated into spring wood and summer wood. The spring wood is a more open cell structure than the summer wood, and therefore not as dense. The summer wood, having more cell walls per thickness of ring, has a greater resistance to wear, which may be critical when using wood for flooring or other uses that require resistance to abrasion. Therefore, in the milling process, the closer together the rings are; the better.

In their live state, the cells of the tree contain free moisture, especially in the sap wood. After the tree is felled, the free moisture in the cells begins to leave the wood. This is the sap that commonly is excreted by softwood trees when they are cut or branches are broken. After all the free moisture has drained from the cells, the wood is considered to have reached its fiber saturation point, which is the moisture content at which the cells contain no more moisture, but the fibrous walls are still saturated. As the wood is dried below this moisture content, the fibers in the wood will shrink. After rough sawing, most wood has a moisture content that is above that of the air and will, therefore, shrink as it acclimates to the moisture level of the air.

The swelling and shrinking of lumber is due to its hygroscopic properties, or its ability to easily attract and give off moisture from and to the surrounding environment. Of the building materials studied, wood is easily the most sensitive volumetrically to moisture changes surrounding it. Changes in relative
humidity have a marked effect on wood, which may cause considerable shrinkage in lumber that is installed into a building at a high moisture content.

The sawing process for lumber affects how the lumber swells and shrinks and what its resistance to abrasion will be. Plain sawed or bastard cut lumber has a greater susceptibility to volume changes and abrasion than does quarter sawn lumber.

The following link shows how the hygroscopic properties of wood affect changes in volume and can cause twisting and warping: timber.ce.wsu.edu/Supplements/Moisture/Default.html.

Once the lumber is rough cut, it will usually be transported in large batches to a drying kiln to be seasoned. After seasoning, usually to 19% moisture content (MC), the lumber is planed to achieve smooth surfaces where desired. Some lumber is not dried and is surfaced in its green state, greater than 19% MC. Other lumber may have its moisture content reduced to a maximum of 15% before surfacing. Accordingly, there are numerous designations to indicate at what moisture content the lumber was surfaced. Some of them are:

- Surfaced green (SGRN)
- Surfaced at 19% MC or below (SDRY or KD)
- Surfaced at 15% MC or below (MC15)

There are also designations for what surfaces of the lumber were planed:

- Rough sawn (RS) indicates no surfacing
- S2S indicates that two sides were surfaced and two left rough
- S4S indicates that all four surfaces were finished, and is the most common

Accordingly, dimensional lumber with the designation of SDRY S4S is common. Lumber is referred to by its nominal dimensions, which are not the actual sizes. The milling and drying processes remove wood from the original sawn size. So what started out as a 2x4 is a smaller size when it reaches the consumer. The following link discusses actual verses nominal sizes in SDRY S4S softwood lumber: www.engineeringtoolbox.com/softwood-lumber-dimensions-d_1452.html.

Generally, lumber comes in lengths from 8 to 24 feet in two foot increments. Pre-cut studs are cut to length to account for installation into a standard stud that will accommodate a ceiling height of 8 feet or 10 feet. They are 92 5/8 inches and 104 5/8 inches respectively.

Even though each piece of lumber has slightly different characteristics, the builder needs to know the strength of each piece. Accordingly, lumber is grouped into classifications that establish minimum bending, compressive, and shear resistances. Each lumber grading association or council has slightly different rules for grading. The Southern Pine Inspection Bureau uses visual grading, machine stress rating and machine evaluated lumber grading. Refer to the links below:
The ratings allow for each grade of wood to be assigned minimum strengths which are shown in design value tables that show: shear parallel to grain (Fv); compression perpendicular to grain (Fc⊥); bending (Fb); tension parallel to grain (Ft); compression parallel to grain (Fc); and modulus of elasticity (E). From this information, the engineer performs the appropriate design calculations.

The strength of wood is greater in the direction of its growth. Using the analogy of a bundle of straws, the straws would be quite resistant to crushing when a force is applied along their length. However when a force is applied perpendicular to their length, the bundle will crush much more easily. So it is with compression in wood. Its strength parallel to the grain is much greater than perpendicular to the grain. Tension forces act similarly. In shear, it is quite the opposite. Wood can be split, or sheared, along its grain much more easily than perpendicular to its grain. In a beam, this is referred to as horizontal shear.

Most pieces of lumber have defects which are taken into account when grading. These defects can be a result of the growth of the wood, or a result of shrinkage during the seasoning process, or milling. Growth characteristics include knots, shakes, and pitch pockets. A knot is the result of a branch growing out of the trunk. A shake is a grain separation that is usually filled with sap in green lumber. Pitch pockets are small areas in the wood where sap has collected. Seasoning and milling defects include checks, which when they run completely through the board are called splits, wanes, and warps.

A wane is bark or cambium growth that is left on the edge of a piece of lumber after sawing. The effect of this defect on the usability of lumber varies with its size and frequency. A knot, if encased in the wood, is generally not a problem in compression, but it could have a negative effect when put into tension. Checks are usually not a structural detriment until they go from face to face in the board where they can promote horizontal shear failure.

**Board Feet**

The price of lumber is dependent on its species and quality. The lumber industry sells their product by the board foot. To calculate board feet, multiply the nominal board dimensions, such as 2x4, together and divide the product by 12 to turn inches into feet. Then the quotient is multiplied by the length of each board and the number of boards of that length. Consider a stack of 2x6 lumber that is 10 feet long with 60 pieces in the stack. The board feet would be 2x6 /12 (which is one) multiplied by 10 feet in length multiplied by 60 pieces = 600 board feet.
Diseases, Insects, and Preservatives

Wood is subject to decay and insect attack. The major reason for decay is that the moisture level of the wood is above 19% MC. Above this level, a fungus can grow in the wood and break it down. This is referred to as dry rot, although it has nothing to do with the wood being too dry.

Insects that attack the wood are termites, carpenter ants, wood borers, carpenter bees and others. More can be found on this subject at urbanentomology.tamu.edu/urban_pests/index.cfm.

Termite in northern climates generally live underground and are very sensitive to sunlight and dry air. They need dark damp places to survive. Accordingly, they have developed an ability to build mud tunnels from the ground to available food sources above grade.

To solve the problem of wood being attacked by bacteria, fungus, molds, and insects; wood preservatives have been developed. One of the first was chromated copper arsenate (CCA), which has been banned except in special applications by the EPA. Alternatives have been developed, but some of them have caused severe dermatological reactions. The following EPA site discusses CCA and its alternatives: www.epa.gov/oppad001/reregistration/cca. All the preservatives mentioned here are pressure treated into the lumber. To pressure treat lumber, the preservative is made into a saline solution and is forced into the wood under pressure in a pressure vessel. Pressure treated lumber and plywood are readily available.

Other preservatives are oil based and are more toxic than the pressure treatments. Common among these is creosote. Lumber may be submerged in it or it may be painted on. Similar to creosote but even more toxic is pentachlorophenol. Both these products are restricted in their use and are only sold to contractors with the proper credentials.

Wood can also be treated for flammability. Pressure treating and paint-on products are available to fire treat lumber and plywood. Pressure treatments turn the combustible gasses given off by heated wood into carbon dioxide and water.

Engineered Lumber

At the beginning of the 1900s, pieces of wood were commonly glued together to form laminated wood beams. These beams were stronger than wood timbers and could span long distances. In the twentieth century, the use of wood underwent a radical change. The lumber industry found ways to engineer wood products so that they could make large sheets of wood. Plywood became the first widespread use of engineered wood sheets, and became common in the construction industry in the last half of the twentieth century. This revolutionary product allowed carpenters to cover large areas quickly and with little labor. The major association that promoted the use of plywood was the American Plywood Association (APA), which is now the Engineered Wood Association: www.tpub.com/content/construction/14043/css/14043_75.htm.
Plywood is rated as interior or exterior grade depending on the quality of the plies and the type of glue used. Exterior plywood allows for the lowest grade of ply to be a C grade, while interior plywood allows for the use of a D grade ply. All exterior plywood uses waterproof glue, while interior grades mostly use water resistant glue. A notable exception to this is the common plywood known as CDX. Since it utilizes a D grade ply, it must be classified as an interior plywood; however, the X in the grade name indicates the use of exterior grade glue.

Another major engineered sheet material is oriented strand board (OSB). It utilizes wood flakes in a glue matrix. OSB has largely replaced plywood as a sheathing material and for subflooring. Its manufacturers claim that certain grades of it are water resistant and will perform as well as plywood for a lower cost.

Both plywood and OSB are given exposure ratings. They are Exposure 1, Exposure 2, and Interior. Exposure 1 is manufactured to be used in exterior applications. Exposure 2 is made to resist exposure for limited amounts of time. Interior is for use where it will not be exposed to water.

There are numerous other sheet goods that are manufactured from wood. Flake board is similar to OSB but does not have structural applications. Particle board is manufactured from sawing residue in a glue matrix and is commonly used as a backing for plastic laminates. More information can be found at www.pbmdf.com/index.asp?sid=2.

In the 1980s engineered wood manufactures began producing a number of structural products. Among these are I-joists. They are manufactured to take the place of regular lumber joists. They consist of an OSB web and plywood chords. Their strength and spanning capabilities are superior to lumber and their cost reflects this. Beam materials appeared on the market that were made of manufactured wood. Laminated veneer lumber (LVL) beams are similar to a very thick piece of plywood and are commonly used for support beams and headers. Similar to OSB is the parallel strand lumber (PSL) beam that is used similarly to the LVL, but is not as strong. More information can be found at www.extremehowto.com/xh/article.asp?article_id=60368.

**Wood Trusses**

Wood trusses are an integral part of the wood building industry. Trusses may be made of dimensional lumber joined with nail plates, or may consist of timbers or laminated beams joined with bolts and steel gusset plates. Dimensional lumber trusses are common for floor and roof supports in light wood framing and masonry bearing wall construction.

Trusses come in many configurations to suit different design solutions. They are used for roof supports and floor support. An advantage to using a pre-engineered truss system is that the manufacturer of the truss performs the engineering of the units according to the design spans required for the job. Usually, roof trusses are designed to span from one exterior bearing wall to another. When interior walls are installed below trusses, they should not fit tightly to the bottom chord of the truss because they would then form a support point that was not designed for by the engineer.
Nails

Wood can be fastened together by many means. The use of nails is ancient and has only changed in the last 60 years. The largest change in nailing has been the development of pneumatically driven, powder actuated, and electric nailing guns. The problem with these devices is one of control over the force used to drive the nail. If improperly set, these guns can drive a nail so deep that it completely pierces the primary material being nailed.

There are many different types of nails and each one has its particular use. Nails can have shafts that are smooth, twisted, or ringed to give the fastener different holding powers. The heads of the nails can be of differing shapes according to what is being held together and how much of the nail is allowed to be seen in the finished product. The size of nails is given according to the “penny (d),” which is an old English measure of the shaft length according to how many pennies need to be stacked to equal the shaft.

Screws are a more secure method of fastening wood together than are nails, but screws are more expensive due to the machining involved in their manufacture. Similarly, bolts and nuts are expensive and the labor involved to drill the wood drives the cost up further. Wood can be fastened with wood pegs and biscuits to form a secure glued joint.

There are many systems that are used to fasten together wood members for buildings. Most are made from steel and come in a wide variety of configurations. The following link is to the website of one of the largest wood fastener manufacturers. Products can be viewed by clicking on the product name: www.strongtie.com/products/alpha_list.html?source=topnav.
Chapter 6

Site

The construction of a building is a very complex undertaking. There are innumerable different systems that make up the various parts and pieces of the structure. The site of the building is one of these important systems and good designers and contractors will pay close attention to the many aspects of a site. If this is not done, a very beautiful and functional building may not meet the owner’s intended purpose.

Site Selection

As this text examines the process of building construction, the first step is to select a site upon which the building will be built. Boundaries are identified and ownership is clarified. There are many issues connected with site selection and these will be studied in greater detail as we step through the process. The site selected for construction must include a detailed survey. This survey helps to define the exact location of the property, including the property lines with their bearing and distances, the total acreage of the site, and the contour of the site. A site survey also includes existing buildings, roads, right-of-ways and utilities. The survey helps the architect define the placement of the structure on the property and how to best use the site in an efficient and effective manner. Many buildings are designed to fit a particular site. For example, a residential design may make use of a hilly terrain to include a walk-out basement.

Preliminary Design and Site Evaluation

A good architect will design a structure that not only addresses the needs of the owner, but also fits into the existing area and the site. A site visit can answer many questions regarding needs during the design and construction process. For example: what is the current condition of the site, how far is it to the nearest utility, or what is the general terrain? A prudent contractor will also make a site visit during the bidding process to help answer questions related to storage of materials, access for machinery and delivery trucks, and any earth and road work that may need to be performed.

Boundary Survey

The parcel of land, along with all structures on it, is known as real property. In order to guarantee ownership, the owner must have recorded the document by which ownership is obtained. In Ohio, land transfer documents are recorded in the office of the county recorder.

To properly identify a piece or parcel of land, it must have described boundaries. The description may be written or graphical. The written version is referred to as a metes and bounds description, and the graphical format is called a plat.
A metes and bounds description identifies real property or a parcel of land in a written prose style. The description begins with a clearly identified beginning point and each line is then defined by distance and direction, continuing around the boundary and returning to the beginning point. Every effort should be made to clarify the ownership by listing the markers at points of intersecting lines and documenting abutting owners. The area or acreage of the parcel is also given.

A plat is a drawing of a parcel of land (real property), drawn to scale, showing direction and distance of boundaries. It is a graphical representation of a metes and bounds description. It, too, clearly identifies the boundary lines, points of intersection of lines, and abutting owners.

Distance is a relatively easy concept to understand. In Ohio, boundary description distances are expressed in feet and fractions of a foot (for example, 287.49 feet). Inches and fractions of an inch, while frequently used to dimension buildings, are not used in boundary terminology.

Direction is normally expressed in bearing format. By definition a bearing is the angle that a line makes with the north or south meridian. It is formatted in degrees, minutes, and seconds, with compass points before and afterwards to indicate the compass quadrant.

The four compass quadrants:

```
N
<table>
<thead>
<tr>
<th>North West (NW)</th>
<th>North East (NE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>E</td>
</tr>
<tr>
<td>South West (SW)</td>
<td>South East (SE)</td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
</tbody>
</table>
```

An example of a bearing is shown as follows:

North 30° 25'45" East

```
N
<table>
<thead>
<tr>
<th>30° 25'45&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
</tr>
<tr>
<td>S</td>
</tr>
</tbody>
</table>
```
Examples of a metes and bounds description and the graphical version are shown below.

**Sample Metes and Bounds Description**

*Beginning at a stone monument being the southwest corner of the aforementioned Section 32; said point lying on centerline of Moose Road and being the Southwest corner of the aforementioned 4.00 acre tract.*

*Thence with the south line of the aforementioned 4.00 acre tract and the north line of a 32.13 acre tract conveyed to Abner Doubleday as described in Deed Book 1471 page 256 of the Moose County, Ohio Deed Records North 85° 14’ 19” East for a distance of 313.15 feet to an iron pin set, said point being an angle point in the north line of the aforementioned 32.13 acre tract*

*Thence with a new division line North 7°39”28” East for a distance of 46.52 feet to an iron pin set;*

*Thence continuing with a new division line North 5°16’27” West for a distance of 198.73 to an existing iron pin, said iron pin being an angle point in the north line of the aforementioned 4.00 acre tract as described in Deed Book 1987 page 237;*

*Thence with the north line of the said 4.00 acre tract and the south line of a 5.42 acre tract conveyed to James Naismith as recorded in Deed Book 2114 page 198 of the Moose County Deed Records North 84°17’22” West for a distance of 281.47 feet to a railroad spike set in the centerline of Moose Road, said point being the northwest corner of the said 4.00 acre tract and the southwest corner of the said 5.42 acre tract;*

*Thence with the centerline of Moose Road, the west line of the said 4.00 acre tract and the east line of a 12.049 acre tract as described in Deed Book 1876 page 345 of the Moose County Deed Records, South 3° 49’ 34” West for a distance of 298.67 feet the point of beginning;*

*Containing 1.865 acres more or less.*
Topography

Topography is the detail of the surface of land including relief or roughness. The relief or shape of the land is indicated by contour lines, a line of equal elevation.

The designer and the construction contractor must be able to read contour maps by understanding the message they deliver. One might look at this as a language all its own. Some characteristics of contour lines are:

- Contour lines are continuous, eventually closing back to themselves
- Contour lines never cross
- Contour lines do not “Y” off
- Contour lines that are close together represent steep slopes
- Contour lines further apart indicate flatter slopes
Contour lines run parallel along the sides of a stream and form a “V” at the centerline of a stream, with the “V” pointing upstream

Contour lines form a “U” shape and point downhill along ridges

A designer chooses the location of a building on a site and then determines the final shape of the topography. It is very likely this final shape will not match the existing topography. The design process involves developing a topographic map with contour lines of the existing surface and then developing the contour lines to depict the finished surface after the building and other structures are in place. The construction team must use this finished grading plan to make the site match the design.

More explanation of contour lines can be found at:
http://raider.muc.edu/~mcnaugma/Topographic%20Maps/contour.htm

Utilities

Utilities are critical to a building and its site. They must be available and properly sized to meet the needs of the building. A designer or owner cannot take for granted that particular utilities will be available. Before any final decisions are made about a site, proper research must be undertaken to guarantee utilities are available and will meet the needs of the building usage. Depending on the location of public utilities, private service lines might need to be extended to buildings. Proper placement of private utilities is important to their longevity and acceptable service. There are five main categories of utilities to be discussed:

- Storm drainage
- Potable water
- Sanitary sewage disposal
- Electric and natural gas
- Communications

Storm Drainage

Buildings and other site improvements will alter the effects of storm water runoff, typically increasing the amount of runoff. The direction of flow may be altered due to changes in the topography. Good design practice dictates that grading plans are developed to assure that water is directed away from the buildings. Hard surfaced areas such as parking lots should be graded so that water does not collect or pool. Storm sewers may be needed. The proper sizing of storm sewers is the responsibility of a civil engineer.

Some typical drainage structures are curb-inlet catch basins, drip inlets, and manholes. Drip inlets and catch basins collect water from the surface. Manholes are access points for maintenance. These are
usually located where two or more branches of a storm sewer meet and/or where a sewer changes direction.

Since the hard surface of a site is increased by building construction, it is logical that the amount of storm water runoff will be increased, which could create flooding on downstream property. For this reason, site design must include facilities to slow the amount of this runoff. Two methods are used:

- Detention structures are those that temporarily store water and release it at a slow rate. These can be above ground ponding areas created by grading or underground structures such as tanks or vaults.
- Retention structures are those that permanently store the water in lakes or ponds.

Both of these can be amenities to the site if properly designed. In addition, retained storm water can be used for irrigation or fire protection. More information can be found at [www.stormwaterauthority.org](http://www.stormwaterauthority.org).

**Potable Water**

Occupants of buildings must have clean water. This can be provided in private systems (such as wells on site) or in public systems which are a network of lines with proper pressure delivering treated water to an entire community.

Buildings must have proper fire protection. This too can be provided on site with the private wells (or retaining structures), or in the public systems.

The United States Environmental Protection Agency (USEPA) website provides the basic information about private wells: [www.epa.gov/safewater/privatewells/basicinformation.html](http://www.epa.gov/safewater/privatewells/basicinformation.html).

**Sanitary Sewage Disposal**

Just as clean, safe water must be available for use in a building, proper disposal must exist for sanitary waste. Private systems can be septic systems, which clean the water before it is returned to the ground. An excellent site discussing septic systems and the effects on our environment is:


Public systems are sewer lines that carry the waste to a central treatment plant that clean the water to a standard acceptable to be returned to the ground or streams.

The USEPA estimates that twenty percent of the housing units in the United States are served by septic systems versus eighty percent served by centralized systems. Looking at this from another perspective, 50 percent of the septic systems are in rural areas, 47 percent in suburban areas and the remaining three percent in central cities.
Electric and Natural Gas

Electricity is a necessity in our society. In Ohio, it is supplied by public distribution agencies throughout the state. Natural gas is supplied to many parts of the state. Building owners and designers must consider the availability and economic impact of these utilities in the design and long term use of a building.

Renewable energy should not be overlooked. Solar and wind energy may be able to contribute to the heating and cooling of the building.

Site Remediation

There are relatively few construction sites that have not had some sort of prior construction or activity on them. Parcels of land that are being considered for development may currently have anything from an old barn to a gas station to an industrial manufacturing plant located on them. Before construction can begin, not only do those structures need to be removed, but also anything on site that is contaminated with hazardous wastes must be addressed. For example, an industrial plant that has buried chemicals on the property will need to have those chemicals removed and the associated ground around the contaminated area analyzed and possibly replaced as well. A gas station would need to have the underground tanks removed before a residential development could begin.

The detailed level of cleanup or site remediation will be determined by water and soil samples. This cleanup process is dictated by state and federal government agencies such as the EPA (Environmental Protection Agency). In some instances, the site remediation may qualify for federal funding.

Previous use of a building site may have contaminated the soil. The Ohio Environmental Protection Agency (OEPA) is charged with enforcing laws concerning soil contamination. They require that a site be free of pollutants before a new building is constructed. It is critically important that the groundwater is not compromised by materials deposited on the soil. The process of determining if a site is compromised involves collecting samples of soil in the field and testing it for contaminants. If the soil does contain unacceptable amounts of unsafe chemicals, remediation efforts are required. More information on site remediation can be found at www.epa.state.oh.us and www.phmsa.dot.gov/regulations.

Earthwork: Excavation, Embankment, and Compaction

As noted previously, a site is seldom shaped exactly as needed to construct a building and other structures. High spots (hills) have to be flattened or low spots (valleys) have to be filled. The operations required for this activity can be divided into:

- Excavation: the removal of soil to create the final grade surface for the project. In construction, the word “cut” is often synonymous with the word excavation.
• Embankment: the placement of material in low areas to raise the surface to the requisite elevation. The word “fill” is also sometimes used to describe this activity.

• Compaction: the compression of soil into a more dense material. Proper compaction will make soil structurally capable of supporting structures.

Examples of excavation equipment can be found at the Komatsu Equipment website www.komatsueq.com.

Examples of compaction equipment can be found at the Bomag USA website www.bomag.com.

Some links to observe excavation and compaction equipment in use are:

• http://www.youtube.com/watch?v=_9HSvZOq8n0
• http://www.youtube.com/watch?v=VERrirRboL4&NR=1
• http://www.youtube.com/watch?v=2zhfaRcFz-Y&feature=fvw
• http://www.youtube.com/watch?v=2q6xnCQNo-0

Demolition

Before construction begins, unwanted structures on the site must be removed. Usually this will be accomplished with a few pieces of heavy machinery that knock down the structure and remove any foundation. For structures that have no significant value in reclaimed or recycled materials, such as an old dilapidated garage, it will simply be demolished, loaded into dumpsters and taken to a construction landfill.

When a building project is conceived, a decision must be made whether to retain any existing structures or demolish them. Structures may range from large multistory buildings to small outbuildings. Demolition can range from sophisticated implosion to hand removal.

Building implosion is the strategic placing of explosive materials and timing of its detonation so that a structure collapses on itself in a matter of seconds, minimizing the physical damage to its immediate surroundings. See http://en.wikipedia.org/wiki/Building_implosion

In addition to the videos available on the above site, the following links show other implosions and the mechanical removal of a smaller structure:

• http://www.youtube.com/watch?v=EQG0coZ4M6w&feature=related
• http://www.youtube.com/watch?v=_yrpQrYdvTY&NR=1
• http://www.youtube.com/watch?v=IVcdRqrG8TI&NR=1

Deconstruction or Re-Use

The United States government estimates that the average lifespan of a commercial building is only 78 years. After this time the building is no longer suitable for the purpose for which it was intended, or the wear and tear from occupants and environmental elements render the building unsafe. As our nation’s buildings and infrastructure begin to age the question arises of what to do with these existing buildings.
There is a national movement to deconstruct these buildings and to reuse, recycle or repurpose the building materials.

Deconstruction is much different than demolition. Demolition typically uses heavy machinery to tear down the building and send the mutilated contents to a landfill. Think of deconstruction as reverse construction. Deconstruction is this systematic unbuilding of a structure much in the way that it is constructed. Materials that can be reused such as framing members, doors, windows, cabinetry, machinery, and appliances are removed and reused in the construction or renovation of another building.

Building materials that have little value to be used again such as dry wall, carpets, and concrete are recycled. Other items such as copper pipe, electrical wiring, and various steel components are also recycled. Some architectural detail items such as mantles, window sashes, and decorative components might be repurposed. Repurposing is using a building material in a new and different way from which it was originally designed and built. For example, the brick face of a building may be repurposed as pavers for a patio.

When deconstructing a building it is necessary to follow all the safety regulations that one would normally follow in constructing a building. It is also important to understand the way in which a building was constructed to be safely deconstructed. Load bearing walls and structural supports should be some of the last pieces to be removed from a deconstruction project.

**Clearing and Grubbing**

After a site has been selected it may need to be prepared before beginning construction. Clearing is generally referred to as removing anything from a surface such as trees, shrubs, vegetation or other unwanted materials. Grubbing is removing unwanted materials from underground, including stumps and boulders. It is important to note that not all vegetation will necessarily be removed for construction. Part of the architect’s plans may leave some mature trees on site to provide aesthetics and immediate shading for the building upon completion.

**Topsoil Removal**

The “Soil Mechanics” section below refers to the inert soil particles of rock, and notes that the outer layer of our planet usually also consists of soil referred to as topsoil. This uppermost layer of soil has the highest concentration of organic material from the decomposition of vegetation. Plants concentrate their roots in topsoil, and obtain most of their nutrients from this layer. Unfortunately, this mixture continues to decompose, making the soil weak structurally. For this reason topsoil is stripped off the areas upon which structures are to be built, stored, and later used on those areas that will have vegetation.
Soil Mechanics

Soil mechanics is the study of soil in the context of its engineering characteristics. Early studies in the science of geotechnical engineering dates back into the 1700s; however the concepts of studying the material and predicting its performance from a structural perspective began to take shape in the twentieth century. Some of the early major contributors include Kurt Atterburg, Arthur Cassagrande, and Kurt Westergaard. Many of their tests, apparatus, and theories are still recognized and used in analyzing soils today. While it is not a perfect science, geotechnical engineers can identify soil, its characteristics, how it will perform under loading, and methods to improve its structural strength.

As a beginning point let us look at the evolution of our planet. Like the existing stars, our planet started out as a molten mass of gas and dust. The surface began to cool and harden but the core of this planet remains a fiery liquid. The hardened outer crust is now referred to as rock. Some of this cooled and hardened rock may be projecting out and is the surface material. Rock provides a solid foundation upon which to build. However, most of the earth’s surface is covered with soil. This soil may only be a few inches deep or up to many feet thick. Since buildings will be located on sites with the soil overburden, it is important to understand the structural mechanics of soil.

Soil consists of particles of broken rock that have been altered by chemical or environmental processes such as weathering and erosion. The American Society of Testing Materials (ASTM) has classified four basic soil particles into three categories by size.

ASTM Particle Size Standards [www.astm.org]:

<table>
<thead>
<tr>
<th>Particle Type</th>
<th>Diameter Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>75 mm (3&quot;) down to 4.75 mm (0.2&quot;)</td>
</tr>
<tr>
<td>Sand</td>
<td>4.75 mm (0.2&quot;) down to 0.074 mm (0.003&quot;)</td>
</tr>
<tr>
<td>Silt and clay*</td>
<td>0.074 mm (0.003&quot;) with no lower limit; can be invisible to the naked eye</td>
</tr>
</tbody>
</table>

*The difference between silt and clay is that silt is an inert rounded particle of rock, while clay has a plate-like structure created by chemical change.

Soil seldom or never exists naturally in only one size and shape, but rather is a mixture of the four basic particles. ASTM has grouped the various mixtures into fifteen groups known as the Unified Soil Classification System (USCS). The various mixtures are identified by the major soil particle.
Visual classification is possible, but laboratory tests on samples are necessary to verify a soil class.

A critical characteristic to note is the cohesiveness of the soil mixture. Soil mixtures that are predominantly gravel, sand and/or silt will crumble when dry and are known as *cohesionless* soils, while soil mixtures with a high level of gravel will stick together when dry and are known as *cohesive* soils. Each mixture takes careful analysis by geotechnical engineers in order to be counted on to support a building.
Cohesionless soils can be excellent surfaces upon which to build, if they are contained, because they can be compacted and little additional settlement will occur when building loads are applied. Cohesive soils, in which clay particles make up a large percentage, can have unique structural characteristics and geotechnical engineers have to carefully analyze the individual soil and design foundations accordingly.

One special material to be considered is the highly organic soils. These may be buried due to the natural transportation of various soil materials, but it almost always exist on the earth’s surface and is commonly called “topsoil.” The soils described above have been transported to their present location by natural transportation phenomena such as wind or water. This layer is relatively thin (3”–12”) and consists of partially decomposed organic plant material. It is good for agricultural purposes, but is very weak structurally and is always removed before any construction commences.

Other major organizations that classify soil are the American Association of State Highway and Transportation Officials (AASHTO), [www.transportation.org](http://www.transportation.org) and the US Department of Agriculture (USDA), [www.usda.gov/wps/portal/usda/usdahome](http://www.usda.gov/wps/portal/usda/usdahome). The differences among the various organizations’ classifications are small and the general characteristics they identify are similar. More information on soil classification can be found at [www.en.wikipedia.org/wiki/Unified_Soil_Classification_System](http://www.en.wikipedia.org/wiki/Unified_Soil_Classification_System).

A structural designer enlists the help of a professional to analyze the soil on the building site, regardless of the initial soil classification, and decide its bearing capacity (its ability to support loads). With this information, the designer can take steps to improve the soil’s strength.

**Soil Testing**

Designers must investigate the soil and be sure it will support building loads. The procedure is to: obtain soil samples; perform laboratory tests to classify the soil and its strength characteristics; design foundations accordingly; and then perform tests during construction to be assured the soil does indeed have the necessary strength. The section on earthwork contains more information on this topic. Soil mechanics has evolved into a science where professionals can predict how soil will perform under the loads of a building. They can evaluate the soil and specify the activities necessary to improve the strength.
Chapter 7

Structural Design

Structural Considerations in Building Design

Buildings are our protection from the elements. They keep us warm in the winter, dry when it is raining, and can protect us from the criminal activities of others. Building codes set the minimum standards that must be met in order to allow occupancy. First and foremost, design centers around safety in the event of fire. Most of the major disasters and loss of life in this country related to structures have occurred because of fire. Another critical issue is that a building must be structurally sound. Major design elements for structures are as follows:

Loads

*Gravity loads* are those that respond to the Earth's gravitational field and are characterized as being vertical. These are the “downward” loads. These are the main consideration when calculating floor and foundation designs.

*Lateral loads* are those that are caused by wind, earthquakes, blasts, or any force that acts perpendicular to gravity loads.

*Live loads* are loads that can move or be relocated during building use. Floor live loads include people, desks, chairs, stacks, etc. The building code lists the allowable minimum live loads for floor design. Roof live loads are any moveable load on the roof, excluding those due to natural causes such as wind, rain, and snow.

*Dead loads* are loads caused by the mass of the building itself and any components of the building that would not normally move. These include partitions, finished ceilings, HVAC duct work, and ceiling mounted lighting. During renovation, interior walls that are considered dead load may be moved, and changes caused by their relocation should be considered in structural terms.

*Rain loads* are considered to be vertical and spread over the horizontal plane of the roof. Well drained roofs seldom have a problem, but low slope roofs may have ponding, especially if the roof drains are blocked. Accordingly, an overflow drainage system is necessary.

*Wind loads* include windward loading, leeward suction, and roof uplift. Variations in wind loading are caused by height above ground and surrounding terrain and buildings. “Building importance factor” is a rating given to buildings that house certain essential functions such as hospitals, fire stations, police facilities, emergency response facilities, pumping stations, water and sewer treatment plants, etc. Buildings that are critical in emergency situations are given high importance factors that require them to be designed to resist natural, and sometimes manmade, forces. High wind situations include hurricanes and typhoons, tornadoes, and high wind rain storms. Wind speed given in code is based upon the peak gust speed at 33 feet above grade. These differ according to location and are mapped out in the building code.
Earthquakes generally produce ground motion in a horizontal direction so part of their load is lateral. There are also wave motions and vertical motions that make calculation of an earthquake’s effect on structures quite difficult. Soil conditions have a great deal to do with the damaging effects since loose soils tend to propagate earthquake shocks in long powerful waves and hard, compact soils and rock tend to cause short waves of a greater frequency. The height and flexibility of a building will determine its reaction to earthquake loads and discussion of seismic design is beyond the scope of this discussion.

**Structural Member Reactions to Loads**

Below are some of the basic terms that apply to the stresses that are caused in structural members when they are subjected to the loads described above. Structural members can be designed to resist one or more than one of these stresses.

- **Stress:** force/area designated in pounds per square foot, kilos per square meter, pounds per square inch
- **Compression:** pushed together
- **Tension:** pulled apart
- **Shear:** the ripping of a material similar to the ripping of a piece of paper, or the action of scissors (shears); typically shear occurs where opposing forces act on a material such as a meeting of a column and beam

When structural members are subject to stress they typically react with some sort of strain.

- **Strain:** change in length of a material when subjected to stress
  - Compressive
  - Tensile
  - At some point in the strain a material will reach its ultimate strain and will fail
- **Modulus of elasticity:** an expression of the stiffness of a material (psi, pa); stiffness of a material, expressed by modulus of elasticity, has a great effect on the performance under load
- **Bending:** imparts compression and tension stresses into a material; maximum stresses will be in the extreme fibers of the material and will decrease toward the center of the section. The following link discusses bending in beams. See [http://en.wikipedia.org/wiki/Beam_%28structure%29](http://en.wikipedia.org/wiki/Beam_%28structure%29)
- **Bearing:** resistance to compressive forces as found in columns or where beams sit on walls; bearing strength depends on the compressive strength of the material; in bearing, materials must be sufficiently confined so that they do not blow out in a lateral direction (perpendicular to the loading)
• *Structural failures:*
  
  o Bending failures happen when loading causes the material to exceed its compressive or tensile strength; in the case of a beam, the top material will crush or the bottom material will tear
  
  o Column failures usually are a result of buckling, or bending, of the column; if a column is very short and stout, it may crush; buckling can be reduced by bracing or using a modified shape. The following link discusses buckling: [http://en.wikipedia.org/wiki/Buckling](http://en.wikipedia.org/wiki/Buckling)
Foundations are the structures that transfer the weight of the structure to the earth. Loads can be dead loads, live loads, snow loads, and others. The soil’s strength capacity must be determined by the geotechnical engineer as discussed in the earlier “Soil Mechanics” section, and the size, shape, and materials of the foundation itself must be designed by a structural engineer. The building design must protect against settlement or structural failure of the soil.

Foundations can be defined as shallow or deep.

Shallow foundations transfer building loads to the soil near the surface.

Shallow foundations transfer building loads to the soil near the surface. These structures are usually Portland cement concrete and occasionally wood. They spread the load over the soil. The very bottom portion of the foundation system, that part that comes in contact with the ground, is called the footing. In shallow foundations they spread the load over the ground so that the soil has the strength to bear the load of the building. Loads of buildings are calculated, soils are tested to find their bearing strength, and shallow foundations are designed.

A mathematical example:

Assume a portion of the weight of the building being transferred to the ground at a point is 90,000 pounds. If it is found that the soil can support a bearing stress of 2500 pounds per square foot (psf), design a square footing to safely transfer the building load to the soil.

The answer is 6 feet by 6 feet, which has an area of 36 square feet. How did we arrive at this?

Stress equals force divided by area or: Stress = Force/Area.

Rewriting the equation: Area = Force/Stress.

Substituting numbers into the equation:

- Area = 90,000/2500
- Area = 36 square feet
- A footing 6 feet by 6 feet would produce the required area of 36 square feet

When the soil can support a building near the surface, shallow foundations are usually the most economical. In many building designs, particularly wood frame residential buildings, the walls will support the loads of the roof and floors. When these loads eventually reach the ground, the walls are supported by strip foundations under the wall. When the loads are supported by columns or posts, a large load may be developed at one point and a pad footing must be designed specifically for that load. This is the case in the example above.
Another critical design consideration is the effect of the water in the soil freezing. When water freezes, it expands. In the soil this is called frost heave. If footings are placed on soil near the ground surface, the water in the soil may freeze, heave and move the foundations and the entire structure. Therefore, the building code requires that shallow footings be placed below the surface to a depth where freezing temperature will not occur (32 degrees Fahrenheit).

A detailed discussion on shallow foundations can be found at http://en.wikipedia.org/wiki/Shallow_foundation

Deep foundations penetrate beyond the surface soil to find strength to support a building. Examples of deep foundations are piles or caissons. These are typically steel, concrete or occasionally wood. The strength is gained by bearing on stronger support material such as the rock core of the planet—visualize a table and its legs. These can also develop strength to support the load of a building by the friction between the deep foundation and the surrounding soil.

Chapter 9

Structures

Wood Framing

Wood is perhaps one of the oldest building materials. Its versatility makes it a common building material in North America. House framing and some light commercial framing take place with stud grade lumber. Whether or not wood can be used in commercial framing typically depends on the building code and how the building will make use of fire suppression sprinklers. At a certain height, a building constructed entirely from wood becomes impractical, as the size of the framing members at the bottom are so large they become less cost effective than steel.

The spacing of this lumber and span is determined by species, size and capacity. Such tables found in local building codes help designers choose framing material that are suitable for the specific application. These will be reviewed by a plans examiner before being approved for construction.

The Sill Plate

In residential construction, wood begins with a rough sill plate that attaches the floor to the foundation. This sill plate fastens to either concrete block or concrete walls via anchor bolts. The anchor bolts are placed into the wet concrete and given intervals. The anchor bolts have a hook at one end, resembling the letter J (sometimes referred to as J bolts) and threads at the other. The rough sill sits flat on the concrete or block with the bolts penetrating through the wood. A nut tightens the sill to the foundation. Many times, because the foundation wall is not perfectly level, shims are used to adjust the sill plate to be exactly level. Remember, the floor will rest on top of this plate, so if the plate is unlevel, the floor will be unlevel. Because the foundation wall may also be wavy or slightly out of square, it may also be necessary to make fine adjustments in the placement of the sill plate so that it is square and matches the dimensions on the foundation.

Girder

In addition to a sill plate on the foundation wall, framing may need to take place on the inside of the structure to accommodate the floor. This is typically done with a girder that sits on top of concrete or concrete block piers. This girder is typically made up of built-up lumber, such as three 2x10’s staggered in placement and nailed together, engineered lumber or a steel beam. Pockets in the foundation wall help secure the girder in place and will be placed so the top of the sill plate matches the top of the girder. Anywhere the girder is supported along its length, there is a corresponding footing.
**Floor Joists**

Floor joists, or parallel framing members that span from the outside foundation wall to the girder, are set on edge and toe nailed into the sill plate and girder. Spans that are greater than 8’ in length require a cross brace, called bridging, in the middle to help keep the joists from twisting and help distribute weight from one joist to another. Bridging can be either solid pieces of wood, wood cross bridging or metal cross bridging. On the outside edge of the floor joists, a rim joist is nailed at a ninety degree angle to the floor joists to cover the void left by the spacing of the floor joists. At the point where the floor joists butt each other, such as on top of the girder, code calls for overlap of the joists. The joists will also be nailed to each other.

**Floor Decking**

After the floor joists are installed the floor deck and can begin. Floor decking is either 4x8 sheets of 3/4” oriented strand board (OSB) or plywood that has a tongue on one side and groove on the other. As it is being installed the tongue slides into the groove to create a tight fit. The decking is fastened with both construction adhesive and nails. The floor decking, or subfloor, will provide the base for coverings such as carpet, linoleum or tile. From this point on arrangements and should be made to keep the wood surfaces dry to prevent unnecessary warping and weathering of the wood. This can be accomplished with tarps or getting the structure dried in as soon as possible.

Openings in the floor for things like stairs require additional framing members for structural strength. Depending on the size of the opening, the floor joists around the opening may be doubled up with headers at both ends of the opening.

**Wall Framing**

For homes that are being constructed with prebuilt wall panels, the wall panels can now be set in their given location on the floor and nailed in place. For wall framing that will take place on site, the floor system can be used as a work surface. It is most common to build walls in sections on the floor and then tilt them up into place. Framers will start by laying out the top and bottom plate that will sandwich the studs in between. The bottom plate, or the framing member that will touch the floor, needs to be pressure treated if the wall is going to be touching a surface that could wick moisture such as concrete slab for a house built without a crawl space or basement. In much of the United States the wall framing is constructed with 2x4’s. In applications where builders wish to increase the amount of insulation in the walls or for other structural purposes, 2x6’s is may be used.

When fastening the wall to the floor, it is important to remember to have the nails actually go into a floor joist. Nails that connect with only the subfloor do not provide as much strength. For walls erected on a concrete slab, power actuated nailers use gun powder to drive a nail into the concrete at high speeds.

Framing members that go from the bottom plate to the top plate without touching another framing member are called studs. In order to reduce time on site many builders will order pre-cut studs, or “pre-cuts” that are 92 5/8” for an 8’ wall.
Walls that have an opening such as a door or a window need special consideration. In order to distribute the weight from above around the opening a header is installed. This header will be sized based on opening width and building code. It will run the length of the opening and rest on trimmers at both ends. Larger openings might call for two trimmers. In order to make the headers the correct thickness, the header material (such as a 2x10) will be doubled with a 1/2 inch piece of OSB or plywood sandwiched in between. Doing so will result in a header that is 3 1/2” or the thickness of the stud wall.

If the opening is a door, the bottom plates and will be cut out of the opening after the wall has been erected. If the opening is a window, the rough sill needs to be installed at the correct height for the window to sit on. Shorter pieces that go between the rough and the bottom plate or the header in the top plate are called cripples.

For walls that will contain plumbing, especially training waste and vent piping, a 2x6 wall is built. This allows enough framing material around the plate to provide structural strength. In contrast, a 2x4 wall that is 3 ½ inches thick and has a 2 inch hole drilled in it to accommodate a drainpipe only offers ¾ inch worth of material on either side of the pipe. It is a weak point in the wall and has the possibility of having a drywall screw or nail pierce the pipe.

On exterior walls, 4x8 sheets of ½” OSB or plywood is nailed to the studs and the joist to provide a surface on which exterior cladding materials such as siding can be installed. Starting this sheathing at the sill plate allows the sill plate, floor joists and wall studs to be tied together creating a strong system that is better able to withstand high winds that starting the sheathing at the wall’s bottom plate.

To tie all of the walls together a second top plate, called a double top plate, is installed. This plate overlaps the wall sections to help provide a ridged system that will adequately support the framing from above, such as another floor system or roof system. If a second story is called for, the floor framing would then be installed on top of these walls, just as it began on top of the sill plate.

During the process, it is important to keep walls square and level. This can be accomplished with diagonal bracing

Roof Framing

After the walls have been framed and erected, the roof framing can begin. For most residential construction this is accomplished with roof trusses that are built to specs in a factory and then shipped to the building site. These can be set up with the help of a crane or, depending on the height of the building, with several workers. While the typical spacing is 24” on center, it is important to follow the truss manufactures plans to ensure that the roof system is assembled properly. Proper bracing, including diagonals, is a must.

For building that will not use trusses, the roof framing must be accomplished through rafters. These are measured and cut on site and require more skill than erecting trusses. Understanding angles, slope, rise and run are necessary to stick frame a roof that meets code and is structurally sound. If a roof is going to use rafters, ceiling joists will also need to be installed, since there is no bottom cord like there is with a truss. Other framing members such collar ties help keep the rafters from spreading.
Depending on the style of the roof, soffits may need to be framed. Subfacia is also installed on the ends of the truss or rafter. Any overhangs would also be addressed. After the roof is framed, 4x8 sheets of 1/2” OSB or plywood are fastened to the framing. This will provide the surface on which the shingles will be nailed into. Once the sheathing is nailed down and covered with tar paper, the building is considerably more weather resistant.
Chapter 10

Exterior Finishes and Cladding

The exterior skin of a building performs a multitude of functions. It must separate the interior of the building from the elements by shedding water, resisting heat flow, and being a barrier to wind forces. The exterior finish must also be able to move in response to outside temperature swings. Ideally, exterior finishes should also be as maintenance free as possible.

As has been discussed, masonry veneer is one of the most widely used finishes due to its resistance to weathering and its low maintenance qualities. Brick and CMU, however, have a high thermal transmission so they must be used in combination with systems that can offer a high thermal resistance. In addition to thermal resistance, the backing wall for masonry must have sufficient structural stability to compensate for masonry’s lack of tensile strength. Masonry is not impervious to water so systems must be put in place to move any water that penetrates or condenses within a cavity wall to the outside. Discussion of these cavity wall systems is available under the chapter on masonry.

Numerous buildings are faced with stone panels. The stone for these is quarried and polished. Slots and grooves are machined into the back of the stone panels so that they can be attached to a backing wall. As with masonry, stone has little insulating value so the backing wall must provide thermal resistance.

Wood as an exterior finish is widely used due to the ready availability and low cost of the material. The problem with using wood is its weathering qualities. As discussed previously, wood can rot so it must be coated with a moisture resistant material such as paint. This system requires periodic recoating and can be a maintenance problem. Wood also expands and contracts with temperature and humidity which can cause it to crack and work loose from structural backing materials if it is not properly installed.

There are exterior finishes that are almost maintenance free and generally impervious to weathering. Chief among these is glass. It is impervious to water; therefore, it weatheres quite well. The problem with the use of glass is that the framing system must be carefully designed to accommodate thermal movement and leakage of water at joints. The glass itself must be carefully designed so that it can resist wind loads during storms and, in many cases, resist impact loads from both the interior and exterior. The following link discusses glass curtain wall systems. Special attention should be paid to the PDF details of the framing at the end of the link: [http://www.wbdg.org/design/env_fenestration_cw.php](http://www.wbdg.org/design/env_fenestration_cw.php).

Metals such as aluminum, copper, stainless steel, weathering steel and coated sheet steel have excellent weathering properties and are commonly used as exterior finish materials. The most widespread use of metal as an exterior finish is in pre-engineered metal buildings such as those shown in the link below. Links within the site will show how these panels lock together: [http://www.butlermfg.com/building_systems/wall.asp](http://www.butlermfg.com/building_systems/wall.asp).

Metal sheet can be assembled into insulated panels which can be used in framing systems similar to glass curtain walls. Insulated metal panels are finding a home in custom designed buildings of many different types. The following link discusses metal panel systems. Attention to the links at the bottom of the page will aid in understanding these systems: [http://www.wbdg.org/design/env_wall_panelizedmetal.php](http://www.wbdg.org/design/env_wall_panelizedmetal.php).
The following link is to a proprietary manufacturer. It shows some of the different types of panels available: http://www.insulated-panels.com/.

Prior to the middle of the twentieth century, a lime and cement based finish called stucco was used widely in temperate climates where freezing and thawing was not a major problem. It is still in use, but has been largely replaced by a synthetic stucco system called the Exterior Insulation and Finish System (EIFS). EIFS has become hugely popular and is used in a variety of building types in a variety of climates. The principle behind the system is to apply rigid insulation to the exterior of a support wall and coat the insulation with two or three coats of polymer based stucco. The stucco is usually trowelled onto a plastic fiber mesh and the finish can be colored to a large variety of hues. The following link will discuss further EIFS: http://www.wbdg.org/resources/eifs_as.php.

One of the pioneers of this system was Dryvit. The following link is to their home page which describes their proprietary system. Other manufacturers have similar systems: http://www.dryvit.com/home.asp?country_id=1.

All exterior finish systems must be carefully designed to allow for thermal expansion and resist water penetration. Control joints are installed where the finish material is not panelized. These joints must be filled with a sealant that has sufficient elasticity to move with the material and still maintain moisture resistance. In the case of framed systems such as glass or metal panels, the joints between the framing system and the panels utilize gaskets and sealants. Again, these must accommodate movement in the panels. The following link provides information on a wide variety of sealants and their application: http://www.wbdg.org/design/079200.php.

In conclusion, any exterior finish needs to accommodate thermal expansion and contraction and resist the elements. These objectives are usually provided by a system of which the exterior skin is just one component.

**Stone Facing**

When stone is used in interior spaces it is usually applied as a veneer and comes in thicknesses ranging from one inch to four inches. Stones are laid in a bed of mortar and anchored to walls with corrugated metal ties. Larger stones require at least two wedges be laid under them in each course until the mortar hardens. Then they are removed and the holes they created are filled with mortar to complete the look.

Stone with distinctive patterns such as marble may lend itself to some specific pattern arrangements. The patterns vary depending on whether the marble is cut with or across its setting bed. The blend pattern allows panels from a variety of stone to be arranged at random. The side-slip or end-slip pattern uses panels from the same block of stone placing them side by side or end to end. The end-match or book-match pattern rotates each of four panels around a central pivot point.

Veneer stones such as granite, marble, limestone and slate are cut into slabs using a gang saw. A gang saw has a series of parallel steel blades in a frame that moves back and forth to cut the stone. Some of the saws use diamond tipped blades while others are fed a cutting abrasive in a stream of water.
Chapter 11

Thermal and Moisture Protection

Thermal and moisture protection may seem to be divergent topics. Thermal protection of our buildings is usually in the form of insulation, but can also include how we design with the sun, occupy the building and use resources to heat and cool it. Moisture protection seeks to control how our building interacts with moisture in all of its forms (vapor, liquid, ice), both from the inside and the outside.

We will discuss in the chapter how our buildings can be insulated and how important that aspect of the construction is. Then we will move on to moisture control and discuss how to keep our buildings from becoming damaged or dangerous as a result of moisture. Finally, we will examine the close link between thermal and moisture control, and the important work that must be done to maintain a quality built environment.

11.1a Energy and Buildings

Owners and designers must consider the overall impact of their designs on the environment and how a building consumes energy. According to the United States Energy Information Agency, buildings use approximately 40% of the energy consumed in the United States. This energy is used to heat and air condition the interior of the buildings, as well as illuminate them. It does not include the energy used to operate computers, equipment or appliances.

Another 8% of the energy generated in the United States is put into the construction of our built environment. When combined with the operation of our buildings, nearly half of the energy we produce goes into our buildings. It is this reality that drives some within the built environment professions to work to develop buildings that are less reliant on energy, use materials that contain less embodied energy, and require less energy to operate.

Edward Mazria, an architect who founded architecture2030, a not-for-profit organization dedicated to decreasing the carbon footprint of our built environment, makes an argument that we must accept where we are today, reliant on fossil fuel energy sources to heat, cool and operate our buildings. You can follow the rise of the use of fossil fuel across the globe, ramping up steadily since the Industrial Revolution. Along that same path we can track the amount of carbon dioxide released into, and trapped within, our atmosphere. The trend is for us to continue demanding energy at an ever-increasing rate for the foreseeable future. If our continued demand for energy results in the estimated impact on the environment scientists predict, the world will soon be a less hospitable place.

Mazria suggests there are two approaches to addressing this undeniable situation. On one hand we could simply seek more forms of energy, dig for more coal, tap more oil wells, etc. Perhaps there are even clean energy options, such as nuclear or hydro power. But this escalation of production will be expensive and consume tremendous resources in the process. Another alternative is to simply build buildings that require less energy to operate. This idea was presented in Chapter One of this text.
11.1b Environmental Issues

For many businesses and residences, the energy and associated cost of conditioning the indoor environment, either through heating or cooling, is an expensive proposition. However, the successful operation of a facility is usually closely tied to its level of comfort for its occupants. As a result, building owners need a system to assure this comfort. Working in conjunction with the owner, designers and contractors must coordinate the acquisition and installation of both thermal control systems and moisture and vapor control systems.

As a primary function of a building designer, the thermal and moisture performance of a building is critical. Facility owners need advice and consultation on the methodology best-suited to maximize their building’s performance. Often analysis will be required to help determine the upfront construction cost of a particular system or solution. This cost must be compared to the cost of operation and maintenance of the system. Some owners will refer to this as return on investment (ROI). Software can be a critical tool in providing the analysis of thermal alternatives.

11.1c Thermal and Moisture Protection

Thermal and moisture protection include some of the most important aspects of constructing a durable, safe, and environmentally responsible building. Thermal protection refers to the ability to insulate the building, allowing the interior of the building to maintain a comfortable temperature, heated or cooled, while using as little energy as possible. Moisture protection refers to keeping water or water vapor out of a building or its components. These combined concepts are critical to the longevity of construction.

Thermal protection includes the requirement for structures to resist the transfer of heat (energy) from area to area, usually from indoors to outdoors. This is referred to as the resistance value, or R value. Materials are tested and their resistance is measured using standard scientific methods. As various assemblies are designed (walls, roofs, floors, etc.), the total R value is calculated. The assembly R value is used to predict the thermal performance of the structure. The design of structures and their accompanying systems require in-depth knowledge and significant specialization to assure proper design, specification, procurement, installation and maintenance.

Every space that is conditioned (heated, cooled, humidified, etc.) requires thermal and moisture protection. It is critical for the designers, contractors and owners to work together to install the most appropriate materials for the desired performance. With many materials, a variety of performance levels are available at a variety of costs.

11.1d Analysis Tools

In Chapter One we discussed the idea of Building Information Modeling (BIM). This approach to building design allows architects and engineers to construct virtual models of their buildings and use various tools to analyze them. Predicting a building’s energy consumption is among the most informative analyses we can conduct.
Some websites provide tools to help designers, contractors and building owners analyze the performance and ROI of various systems:

- **Department of Energy**—renewable resources:  
  [www.nrel.gov/analysis/analysis_tools_tech_build.html](http://www.nrel.gov/analysis/analysis_tools_tech_build.html)

- **Department of Energy**—commercial analysis options:  
  [www.doe2.com](http://www.doe2.com)

- **Lawrence Berkeley National Labs**—home energy analysis tool:  
  [http://hes.lbl.gov](http://hes.lbl.gov)

- **Energy Star**—program to support efficiency, residential and commercial:  
  [www.energystar.gov](http://www.energystar.gov)

- The US Department of Energy provides free downloads of energy analysis software. Most building authorities will accept either the commercial or residential versions of this analysis.

- The **COMcheck** materials have been developed to simplify and clarify commercial code compliance with the International Energy Conservation Code (IECC), ANSI/ASHRAE/IESNA Standard 90.1, and state-specific codes.

- The **REScheck** materials have been developed to simplify and clarify residential code compliance with the Model Energy Code (MEC), the International Energy Conservation Code (IECC), and state-specific codes.

- The US Department of Energy’s Building Energy Code Resource Center has compiled a series of short videos to instruct designers, contractors and owners in various aspects of insulation and energy conservation. Their index of videos is at: [U. S. DOE video library](http://usenergy.gov).

Thermal and moisture protection are vital aspects in designing, constructing and maintaining an environmentally responsible structure. Careful consideration should be given to each component of these systems. Leadership in Environmental and Energy Design (LEED), a program spearheaded by the U. S. Green Building Council (USGBC), provides guidance for many areas of building, including thermal and moisture performance. LEED offers degrees of certification of structures, and provides validation of the quality and predicted performance of many structures.

A facility owner may dictate the thermal and moisture selection based on a variety of reasons. The designer and contractor, however, are responsible for assisting the owner in making the most responsible environmental decisions possible. Most owners are sophisticated enough to recognize and accept the environmental responsibility.

Many organizations provide guidance for the responsible selection of equipment. These include Energy Star and LEED, the flagship effort of the USGBC. The USGBC’s website includes a tremendous amount of information on LEED, the certification system for existing buildings, new buildings, and neighborhoods. Additionally, anyone interested in the design, construction and operation of buildings may become a LEED accredited professional (AP). This credential requires individuals to pass a rigorous examination in one or more areas of expertise. Within the design and construction industry, the attainment of LEED AP is prestigious. Additional information is available at [www.usgbc.org](http://www.usgbc.org).
11.1e Supporting Organizations

Various organizations represent the manufacturers and industry in general. Their websites include lists of manufacturers, educational materials, and upcoming industry events. Webinars and webcasts are sometimes available, as are blogs and frequently asked questions. Explore the various websites for more information. Some examples are:

- Steep Slope Roofing
  - Roofing contractors: www.nrdca.org and www.nrca.net
  - Tile roofing: www.tileroofing.org
  - Asphalt roofing: www.asphaltroofing.org

- Membrane Roofing
  - EPDM Roofing: www.epdmroofs.org

- Joint Protection
  - Adhesives and sealants: www.ascouncil.org
  - Asphalt, including sealants: www.asphaltinstitute.org

11.2 Building Better Buildings

Since this is a construction text, we will focus on creating better buildings which will require less energy to build and operate. To do this we must use a guide, such as the International Energy Conservation Code (IECC), as a baseline to judge buildings. Currently, all new buildings in Ohio must comply with the IECC, either in prescriptive or performance standard. The IECC stipulates what amount of energy a building should consume. This baseline is rather low, so our goal should be to exceed the expectations or requirements of IECC.

One of the primary methods we use to make our building efficient is to insulate them. Typically, we insulate all of the exterior walls and the roof. We may partially or completely insulate walls below grade. We should insulate the floors of spaces that project out from our building. There are a variety of materials available to achieve this insulation, as well as locations where it may be placed in the building assembly.

Insulation should be thought of in terms of resisting the transfer of heat. This resistance is expressed in units of R. So as we are thinking of our building construction, we should be aware of the R values of basic materials and how we might achieve an acceptable whole building R value. Some building materials, such as wood, have significant R values and are chosen because of this. Others, such as glass, have virtually no R value, so the remainder of our building must balance out this deficiency. Many high R value materials, are engineered just for the purpose of adding the resistance to the assembly. In most installations, the insulation material is encased within the wall or roof assembly and out of sight.
11.3 Insulation

In order to maintain comfort for building occupants while minimizing the energy requirements of the structure, it is necessary to consider the insulation requirements for both heating and cooling.

Common insulation types:

- Batt (fiberglass)
- Loose (cellulose)
- Foam (polystyrene or polyisocyanurate)

The US Department of Energy has compiled a complete fact sheet on various insulation materials and methodologies. It provides a basic understanding of insulation materials. A summary of the Fact Sheet follows. You can access it at: U. S. Department of Energy Insulation Fact Sheet.

Building code will help determine a minimum requirement for insulation performance. Work with the building designer, contractor and owner to determine the optimal building performance. Careful consideration must be given to the ventilation of spaces such as attics or rafter spaces. These must be ventilated to allow moisture-laden vapor to escape.

11.3a Batt Insulation

Many types of insulation will require a protective cover, and may not be exposed as the building is occupied. Batt insulation is typically placed within wall, attic or floor cavities to provide thermal isolation. It is often made of fiberglass and is available in rolls or flat sheets. The fiberglass may be covered with a paper backing, or may be bare. It is usually cut at sizes representing the average placement of studs (16” wide or 24” wide).

11.3b Blown-in Insulation

Blown-in loose insulation, available in bulk, may be installed on level or slightly sloped areas. Often made of cellulose, loose insulation may also be installed in wall cavities if a support method is appropriately designed (netting to support material, or glue to adhere to other building materials.) When installing, care must be taken to assure even distribution and placement.

11.3c Foam Insulation

Foam insulation may be sprayed in place. It will expand to fill cavities. Consider the effects of its expansion and its impact on the overall structure. An advantage of foam insulation is that it can completely fill a stud space, even around wires and pipes, where batt insulation may not.
11.3d Rigid Insulation

Rigid foam insulation is available in board or sheet sizes. It may be cut and fixed in place with adhesive or fasteners.

11.4 Sources of Moisture

Most building materials are subject to some degradation by exposure to moisture. Building systems must be designed to resist the transfer of moisture to the inside of the structure.

11.4a Liquid

The most common way for moisture to enter a building is in its liquid form. Leaks may occur that allow rain or groundwater to infiltrate the building envelope. This leak may not be immediately apparent, leading to a variety of maintenance and health concerns.

11.4b Vapor

Moisture may also enter a structure in the form of vapor. This vapor may migrate through building materials that are not adequately protected. Small openings in the building will also allow the transfer of vapor. Vapor can migrate through construction materials, entering into construction assemblies, like walls and roofs. Vapor will typically move from the warm side of the assembly toward the cool side of the assembly. (This is related to the thermal conduction process.) As vapor migrates into cooler materials, it will reach an important temperature referred to as the condensation point or dew point. This is the temperature at which vapor molecules condense to form moisture. This moisture will be in contact with the various materials within the assembly. Dew point is well defined and graphed, and mitigating efforts are suggested in:

Controlling Mold in Residential Construction

David R. Bohnhoff, PE, PhD

University of Wisconsin Madison

Vapor also enters enclosed attic spaces. It is important to provide paths for moist air to leave attics, allowing drier fresh air to be drawn in at the same time.

11.4c Condensation

Another source of liquid is condensation. When the vapor in air reaches a critical temperature, referred to as the dew point, condensation occurs. This condensate must be addressed to prevent damage to the structure and discomfort the occupants.
Building code provides specific ventilation requirements for these spaces. Attic ventilation should be placed at high and low locations of the attic, allowing for exhaust of warm air at high locations and intake of cooler air at low locations.

Energy Star provides complete attic venting information, as well as a downloadable guide with graphics, instructions, glossary and more:

EnergyStar Attic Ventilation

11.4d Ice

While it is not common for ice to enter a building, the build-up of ice often leads to water infiltration, as evident in “ice dam” conditions on sloped roofs. Ice dams are explained, including graphics, photos, prevention efforts and more by the University of Minnesota Extension Service:

University of Minnesota

11.4e Dampproofing and Waterproofing

Dampproofing is the application of a material to reduce the likelihood of moisture transfer to the inside of a structure. Dampproofing assumes no hydrostatic pressure is pushing the moisture toward the building.

Waterproofing is the application of a material to prevent the transfer of moisture in liquid form to the inside of a structure in the presence of hydrostatic pressure.

Dampproofing and waterproofing may appear to be identical applications, often a spray-on asphaltic compound designed to resist moisture. It is often applied directly to the foundation or sub-grade structure. It is critical for a building to provide comfortable spaces for occupants.

11.5 Roofing

Roof slope is often expressed as a ratio of rise to run, or distance travelled vertically to distance travelled horizontally. The unit of measure is not relevant, as long as it is consistent. For example, the roof depicted below as a ratio of rise to run of 6 units to 12 units.

Roofing materials must be selected with the roof slope in mind. Roofs with a slope greater than three units in 12 units are usually considered steep.
11.5a Steep Slope Roofing

A steep roof is actually a system built of multiple components.

Common steep slope roofing materials include shingles of several materials.

- Asphalt and fiberglass shingles
- Wood shingles or shakes
- Cement shingles
- Metal shingles

Most are applied using a typical installation method of nailing the shingles to a substrate in an overlapping manner. The structure of a roof is determined by the design, but for steep slope roofing typically includes rafters (individual framing members) or engineered trusses (assemblies constructed offsite and placed as a group). Framing details, including rafter and truss installation, are provided by the American Wood Council in a free download.

GAF Corporation is one of the largest roofing material manufacturers. Their website includes a variety of instructional videos on various aspects of roofing selection, installation and maintenance: GAF Corporation.

11.5b Low Slope Roofs

Flat roofs (less than a 3:12 slope), often receive a membrane roofing system, which can be built-up or single-ply versions. Single ply roofing options, per the Single Ply Roofing Association:

- Thermosets
- Thermoplastics
- Modified Bitumens

Thermosets

Thermoset membranes are compounded from rubber polymers. The most commonly used polymer is EPDM (often referred to as "rubber roofing"). Another thermoset material is neoprene, although this particular formulation is no longer widely used for roofing. Thermoset membranes are successful for use as roofing materials because of their proven ability to withstand the potentially damaging effects of sunlight and most common chemicals generally found on roofs.

Thermoplastic

Thermoplastic membranes are identified by seams that are formed using either heat or chemical welding. These seams are as strong or stronger than the membrane itself. Most thermoplastic
membranes are manufactured to include a reinforcement layer, usually polyester or fiberglass, which provides increased strength and dimensional stability.

**Modified Bitumen**

Modified bitumen membranes are interesting hybrids that incorporate the high tech formulation and prefabrication advantages of single-ply with some of the traditional installation techniques used in built-up roofing. These materials are factory-fabricated layers of asphalt, modified using a rubber or plastic ingredient for increased flexibility, and combined with a reinforcement for added strength and stability.

A short video is available highlighting the application of single ply roofing. Explore the other available resources as well: [http://www.spri.org/video/SPRI_bb.wmv](http://www.spri.org/video/SPRI_bb.wmv).

**Built up Roofs**

Built up roof membranes, referred to by the acronym BUR, have been in use in the US for more than 100 years. These roof systems are commonly referred to as “tar and gravel” roofs. BUR systems generally are composed of alternating layers of bitumen and reinforcing fabrics that create a finished membrane.

The number of plies in a cross section is the number of plies on a roof: The term “four plies” denotes a four ply roof membrane construction. Sometimes, a base sheet, used as the bottommost ply, is mechanically fastened. Built up roofs generally are considered to be fully adhered if applied directly to roof decks or insulation.

**11.5c Flashings and Terminations**

Buildings include the intersection of many different types of materials. Special attention needs to be paid to these intersections. Materials expand and contract as their temperature changes, as well as when they absorb or shed moisture. Buildings also move due to settlement, seismic activity, wind loads, live loads or other loads.

Joints between materials must be designed, installed and maintained to assure proper performance. In many instances, metal flashings or joints will be needed to make these various transitions.

While Ohio does not qualify as a coastal region, the Federal Emergency Management Administration has developed a [manual for coastal construction](http://example.com) which includes flashing details for roof-to-wall and deck-to-wall applications. These graphics and technical information are valuable tools.

Many of the terminations of roofing and walls require specialized materials to make a weather resistant condition. These products or assemblies are classified as Roof and Wall Specialties. While there are many manufacturers of Roof and Wall Specialties, Johns Manville has organized an extensive library of downloadable pdf format details. Explore these details for additional information: [Johns Manville Library](http://example.com).

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Chapter 12

Openings

Doors

Doors are portals in and out of spaces. They serve many different purposes, including separation of spaces, privacy, security, separation of environments, and psychological markers of transition. Doors can be opaque, translucent, or transparent depending on their design, and can offer visual connectivity without environmental or sonic transfer. They can be made of most any material, most commonly wood, steel and fiberglass.

Door Operation

The most common way that a door moves is by swinging on hinges mounted to the door leaf and the frame. These types of doors can be very secure and are easily manufactured and installed. The top, bottom, and side edges of a door leaf are referred to as the top rail, bottom rail, and stiles. The frame of the door consists of a head, threshold, and jambs. The hinges are mounted on the hinge stile and jamb, and the latching hardware is located on the strike stile and jamb.

Other common modes of door movement include tracks. For most main doors, tracks are overhead mounted to the head of the frame. These doors include bypass doors, folding doors, accordion doors, and surface mounted sliding doors. A pocket door utilizes a track that extends the length of the frame head and into a cavity in the wall. Overhead doors often use a jamb mounted track, as is common in sectional garage doors.

Wood Doors

Wood doors are typically flush, meaning a flat surface or panel. Flush doors come in hollow core or solid core construction. Hollow core wood doors offer little security except for visual privacy. They consist of surface panels of thin plywood separated by cardboard strips. The edges of stiles and rails are solid wood pieces, with blocking for the latching hardware.

Solid core wood doors are similar in construction except that the cardboard core is replaced with a solid panel of wood blocking of fiberboard. This solid core allows the doors to achieve a fire rating.

Panel doors are typical of doors that were produced in the 18th and 19th centuries and are of stile and rail construction with panels in between.

Commonly, residential wood doors are sold along with the wood frame and are referred to as pre-hung doors. The hinges are already attached to the unit and latching hardware is not included.
Steel Doors

Steel doors come in flush and panel configurations. The flush steel doors are often referred to as hollow metal doors, and are typically mounted in hollow metal frames. Often the door leaves will have a core of solid fire resistant material that allows them to achieve a high fire rating. They are built similarly to the flush wood doors, only with steel. The hollow metal frames can be installed in stud walls or masonry, and come either welded or knock down. Each manufacturer has details of how the frame is attached to the wall, and the common methods are shown below. Steel frames allow for the door frame assembly to be fire rated, and it is critical that the fire rating of the door leaf match the rating of the frame.

Hollow metal doors and frames are common in institutional settings where a high fire rating is required and the doors will be subjected to very frequent use. They also offer higher security than wood doors. Fire rated wood doors may be used with a hollow metal frame as long as the ratings of the door and frame are similar.

Fire Ratings

Any time that a fire rated wall or partition assembly is penetrated, the opening must achieve a fire rating as prescribed by the code. Fire rated doors are required to have closers, latching hardware, and hinges made of steel. The following link discusses fire ratings of doors and the requirements for them:


Egress

The means of egress in a building refers to the way out of the structure. Doors within the means of egress must be of a specified width according to the number of occupants that will use them. Any egress door that has an occupant load of 50 or more people must swing in the direction of egress. Doors serving an occupant load of 100 or more must be equipped with panic hardware.

Handing

The swing of doors is specified as right hand, left hand, right hand reverse, and left hand reverse (RH, LH, RHR, LHR).

The inside of the door is considered to be the opposite of the direction of egress. Rated wood doors are manufactured with a slight bevel on the strike stile so that the edge of the door will not hit the jamb in its swing. This bevel must be ordered correctly.

Hinges

Door hinges are made from a variety of materials and in a variety of configurations. The parts of a hinge are the leaves, the knuckles, and the pin.
Most people are familiar with the hinges for residential doors which are made of brass and use a loose pin that can be easily removed so that the door can be removed from its frame. The graphic above shows a commercial hinge that has bearings in its knuckles to facilitate frequent use. Without the bearings, a commercial hinge would grind the knuckles down by friction.

It is not always desirable to have an easily removable pin. Frequent operation of a hinge may drive the pin up and out of the knuckles. Accordingly, most commercial hinges use a nonrising pin that grips the knuckles. Non-removable pins are locked in place with a set screw that is inaccessible when the hinge is closed. For very high security applications, the hinge pin may be welded into the knuckles and is referred to as a fast pin.

**Latching Hardware**

Latching hardware usually works by means of a latch and a strike plate. The latch tongue is beveled and spring loaded so that it will recede into the mechanism when it hits the plate and then pop back out when it is fully engaged.

The latching hardware is operated by a knob set or lever set. If there is no locking mechanism, the assembly is called a passage set. If the set has a manually operated locking mechanism such as one would have on a residential bathroom door, it is referred to as a privacy set. If it is combined with a key locking mechanism it is called an entry set.

**Lock Sets**

There are many types of individual lock sets that can be installed in doors. Mortice locks are combined with the latching hardware and have a separate key cylinder. Dead bolt locks are bolt type locks that are separate from the latching mechanism.

Panic hardware is a type of latching hardware that simply requires pressure against it to open. It was developed as a result of fires that occurred in the early twentieth century.

**Closers and Other Hardware**

Door closers automatically close a door after an occupant has passed through it. Most of these are surface mounted and exposed, although some types are concealed in the frame or door. Spring loaded hinges can be used to perform the function of a closer.

There are numerous other types of door hardware, including door pulls, kick plates, astragals, synchronizers, door bumpers, and various electrical and automated devices. The following link is to a large builders’ hardware supplier: [www.builders-hardware.net](http://www.builders-hardware.net). Under their Division 8 products tab there are links to most of the hardware manufacturers.
Windows

Windows are manufactured products that include a frame, sashes that move, and glass. They are made from wood, vinyl, fiberglass, aluminum, and steel, in addition to the glass. Windows can be fixed with no moving parts or may move in a variety of ways.

Double Hung Windows

Double hung windows consist of a frame and two sashes, both of which slide vertically. The main problem with these windows is that they only provide a maximum of 50% ventilating opening. This is overcome by their simplicity of movement that requires no opening mechanism and only a means of keeping them from closing with the force of gravity. A similar window with a stationary top sash is called a single hung window.

Horizontal Sliding Windows

Horizontal sliding windows (sliders) are very similar to taking a double or single hung window and turning it 90 degrees. There are some differences, however, in how the water is shed from the unit and the tracking. These sliding units may have a central fixed unit with sliders to each side and are available in large widths. They are quite similar to a patio door.

Awning Windows

Awning windows are hinged at the top and open from the bottom. They perform well in the rain due to the fact that most only open about 30 degrees. The disadvantage of these is in the complexity of their opening mechanism.

Casement Windows

Casement windows operate like a reverse swing door: hinged on the side. As with the awning windows, their operating mechanism is complex and can be problematic. They allow for 100% ventilation, but can be damaged if open in high winds.

Glass

Glass production is an ancient art, and for the majority of its existence it has been used to make containers and decoration. Its widespread use as a building material did not occur until the mid 1800s. With the development of the method to draw glass across rollers in 1900, sheet glass became more available and the price of glass dropped. Sheet glass was typically wavy because of the manufacturing process. The solution was to grind the surface imperfections out of the glass, which was an expensive process that produced plate glass.
In the early 1960s a method was developed to draw glass out over a bath of molten tin, which produces a smooth glass called float glass. Float glass is now the standard for all window glass production around the world.

Another problem with glass is its brittle qualities and its breakage into dangerous shards. The development of safety glass has solved this problem.

**Tempered Glass**

If normal annealed glass is heated close its softening point and quickly cooled it develops internal stresses that cause the glass to be strong and resistant to breakage. This is known as tempered glass. When the glass does shatter, it breaks into pebble like pieces that have few large sharp shards.

One problem with tempered glass is that it cannot be worked after the tempering process; it cannot be cut, drilled, or ground without it shattering. Due to the internal stresses, tempered glass has been known to shatter for no apparent reason as the stresses work on slight defects in the glass. Further, the internal stresses make this glass not very fire resistant although special fire rated tempered glass has been developed. More information about the fire rated tempered glass can be found at [www.safti.com/fireglass.html](http://www.safti.com/fireglass.html).

**Laminated Glass**

Laminated glass consists of sheets of plastic sandwiched between glass sheets. The resulting composite is impact resistant and, with enough layers, can resist the impact of a bullet. A problem with laminated glass is that the plastic layers will melt with heat so it does not provide a high rated fire resistance.

**Wire Glass**

Wire glass is annealed glass that has a wire mesh in its center. It is made by taking two sheets of hot glass and pressing the wire mesh between them. It is actually weaker than annealed glass of the same thickness; however, the wire holds the glass in place if broken so that heat will not readily pass through an opening. If smaller pieces are used, it can have a high fire rating.

**Architectural Glass**

Architectural glass has the ability to reduce the amount of solar radiation entering through a glazed opening. There are two major types: heat absorbing and reflective.

Heat absorbing tinted glass absorbs the radiant heat of the sun and will rise in temperature as it is exposed to the radiation. As a result, this glass will expand more than clear glass and allowance must be made for the resulting stresses. If heat absorbing glass is partially shaded or heavily draped, it has been known to fail due to unequal expansion.
Reflective glass reduces heat gain in the building by reflecting the sun’s radiation, reflecting to the side that has the most light. Therefore, at night it may act opposite of the way it does during the day.
Chapter 13
Plumbing, Piping, Pumps, and HVAC

Modern buildings give us the ability to work and live safely, comfortably and effectively in modern structures of today. Imagine a modern high-rise with large expanses of exterior glass. Sprinkler systems and smoke control/pressurization systems protect people from fire until evacuation can remove them from the affected space. Without domestic water, plumbing and waste piping, the facility would not be practical (or very sanitary).

Plumbing Fixtures and Equipment

Plumbing fixtures and equipment include the familiar residential fixtures such as toilets, sinks, bathtubs, and shower receptors, and basins, as well as commercial urinals, flushometer valves, drinking fountains, water coolers, emergency fixtures (eyewashes and safety showers), and domestic water heaters.

A typical residential toilet includes a float valve to allow the tank to fill for use in flushing. Most commercial fixtures use flushometer valves, which provide a fixed quantity of high pressure water for flushing.

A urinal has a flushing device and drain for flushing away urine. A urinal is simpler than a toilet due to the requirement to only flush away liquids. Designs for single and multiple users are common. See www.global-b2b-network.com/.../sell_urinal.html.

Lavatories and sinks come in a variety of designs for residential and commercial applications.

Bathtubs and showers are common in residences, but may also be present in medical, sports training, or other commercial facilities.

Drinking fountains and water coolers differ by whether the units have mechanically-cooled water with a self-contained refrigeration system for water coolers, or just provide tap water for drinking fountains.

Safety showers and eye wash stations, either separately or together, are used to provide a water deluge or flush to remove harmful chemicals from the body or the eyes. See http://www.sepmarfirex.com.au/repairs.html.

Domestic water heaters traditionally consisted of tanks with heating elements. Today, however, there are a number of tankless heaters or instantaneous hot water heaters available that can be used to eliminate the standby losses from a traditional water tank. Some are added to a domestic furnace and some are designed to provide stand-alone service. See www.deltaplumbinghsv.com/water_heaters and www.energysavers.gov/.../index.cfm/mytopic=12820.

Backflow prevention is typically accomplished with two check valves in series. This isolates an incoming water system from a downstream system. Generally, an air gap is required. Backflow preventers require annual inspection and periodic refurbishment from trained plumbers. See http://www.febcoonline.com/Featured/MasterSeries.
Pipe

A primary element of the building infrastructure is piping. Piping is used in a variety of subsystems, including:

- **Building services piping**
  - domestic water
  - plumbing
  - sanitary waste and venting
  - storm drainage
  - heating and cooling
  - refrigeration
  - miscellaneous areas such as swimming pools and fountains

- **Process piping**
  - process air
  - gases
  - process water and waste
  - other industrial processes

- **Fire protection piping**

The most common pipe found in larger buildings is steel, although residential construction uses much more plastic piping today. In smaller sizes, joints are typically screwed, while larger sizes are most often welded, with flanged connections where frequent removal of equipment or other requirements to break into the piping are required. Mechanical joint options also exist, as provided by vendors with proprietary designs.

Steel is not used whenever there are issues of material compatibility with the fluid to be carried (some refrigerants or corrosive or acidic fluids), or in cases where corrosion reactions with moisture could contaminate the product (breathing air and medical gases are good examples). Stainless steel is a common but more expensive option. Galvanized steel is often used in areas where piping is exposed and exterior corrosion is an issue.

Copper is another popular choice for many piping applications, including some plumbing applications and most refrigerants. Note that certain refrigerants such as ammonia are run in steel piping, as they are incompatible with copper. While copper can be screwed, it is more commonly brazed or soldered. Copper is often interfaced with steel systems; in this case, a dielectric union is required to prevent corrosion due to contact between dissimilar metals.
Waste piping is most often run in cast iron because it better absorbs the intermittent sound from periodic flushing of waste through the system (unlike plastic piping used in homes, which has no sound-absorbing characteristics). More information can be found at http://reference.findtarget.com/search/cast%20iron/.

Plastic and composite pipes of various compositions are the other most popular type of piping used within buildings. PVC (polyvinyl chloride) and CPVC (chlorinated polyvinyl chloride) are often used for plumbing and sprinkler piping, especially in residences. Plastic pipe is usually screwed, welded or glued together. Other materials such as fiberglass are used for miscellaneous applications where other alternatives may not be acceptable due to material compatibility, temperature range, strength, weight, or appearance concerns. More information can be found at http://www.rd.com/advice-and-know-how/stepbystep-pictures-and-instructions-to-use-cpvc-plastic-plumbing-pipe/article112937-2.html.

**Pipe and Equipment Insulation**

Piping is generally insulated for one of four reasons:

- **Temperature control**: making sure there is little heat loss or heat gain to the piping. This can both save energy and insure that the process requirements of the system are met (for example, 44 degree water produced in one place is delivered at nearly 44 degrees elsewhere). A subset of this requirement is to prevent the pipe temperature from influencing the space through which it passes.

- **Safety**: piping that is too hot or too cold can present hazards to personnel coming in contact with such piping and is often insulated where it might inadvertently come in contact with occupants or workers.

- **Condensation**: piping whose temperature may be below the dew point of the space through which it passes should be insulated to prevent condensation of water present in the air on the piping material. This condensation can create problems ranging from nuisances (dripping water), to safety hazards (slippery spots on the floor), to corrosion of the outside of the pipe itself to damage or destruction of facility components (and possible associated health concerns, such as mold growth).

- **Sound control**: in some cases, piping is insulated to reduce sound transmission either between spaces or to prevent noise generated within the pipe (such as rushing water, pulsing steam, etc.) from being objectionable in adjoining spaces.

The most common pipe insulation is fiberglass, with or without a vapor barrier. Fiberglass is made of spun glass and incorporates air pockets within the material, decreasing both heat transfer and sound transmission. This insulation is generally jacketed with a heavy paper or aluminized plastic coating (foil-lined if also used as a vapor barrier) and can be further treated or covered for use in rugged environments. Common covers are canvas (indoors), thin plastic (indoors), or thin sheet metal (outdoors).

More information can be found at:
Older buildings may contain asbestos insulation, which has been associated with respiratory diseases and is no longer used. Asbestos insulation in good condition can remain in service if it is not disturbed; if it is damaged, it should be abated by trained professionals. This is also an issue in demolition and deconstruction; asbestos abatement must be done first so that any dust generated is contained and removed prior to other demolition. More information can be found at www.topasbestosremoval.co.uk/howtoremoveasbestospipeinsulation.php.

Another type of insulation, especially used on HVAC piping, is a flexible elastomeric (expanded, closed-cell, cross-linked rubber type compound) that provides both thermal insulation and a vapor barrier in a single product. This flexible foam material is not appropriate for high temperature installations. See www.just-insulation.com/armaflex.html.

Fire Protection Piping

Most commercial buildings today require automatic fire protection (sprinkler) systems to protect people and equipment from the destruction caused by fire. Commercial sprinkler piping is steel, usually with screwed fittings. Residential sprinkler piping is plastic. The major fixtures required on sprinkler systems are the sprinkler heads. Heads can be normally open in a deluge system (where, when the system fills with water, all heads discharge water) or set to open individually based on reaching a temperature of 160°F, using either a glass bulb that breaks or a fusible link that melts to open the head. More information can be found at www.fivestarfire.net/SERVICES.html.

Piping and Valve Identification

It is important that all mechanical equipment be properly labeled and identified. Piping can be color-coded with paint and labeled with either stencils or pre-fabricated markers. There is an American Society of Mechanical Engineers (ASME) Standard with standard pipe and label colors for many different process fluids. Valves can be tagged with service and reference numbers tied back to a valve schedule. More information can be found at:

- www.centurybusinessproducts.com/safety.html
- www.pipemarkers.com

Valves

Mechanical systems require valves to direct, control, and isolate flow. There are a number of different valve types commonly used in mechanical service. Most valves are made of steel, stainless steel, or bronze. Some plastic and PVC valves are used in corrosive environments. Spirax-sarco has an excellent website on basic valve operation: http://www.spiraxsarco.com/resources/steam-engineering-tutorials/control-hardware-el-pn-actuation/control-valves.asp.
Valves used to isolate sections of line include:

- **Ball valves**: allow for positive shut-off and smooth operation. They are the most expensive of the isolation valves, especially in larger sizes.

- **Gate valves**: provide system isolation and are the least expensive of the isolation valves available. Valves infrequently operated may not offer positive shutoff due to build-up of material beneath the seat. Animation of a gate valve operation is shown at [www.poolplaza.com/pool-school/plumbing_valves_gate.shtml](http://www.poolplaza.com/pool-school/plumbing_valves_gate.shtml).

- **Butterfly valves**: used in both throttling and shutoff service. Positive shutoff against high pressure may not be possible. Tight shutoff valves are very expensive.


Valves used to control flow quantity include:

- **Globe valves**: provide precise flow control through high pressure drop and resistance to flow in the system. They should be selected to match system pressure characteristics. In flow-to-close globe valves, fluid pressure acts with valve closing and tight shutoff is possible. In flow-to-open globe valves, flow pressure pushes against the valve port. These are good for quick-opening valves. More information can be found at [www.spiraxsarco.com/resources/steam-engineering-tutorials/control-hardware-el-pn-actuation/control-valves.asp](http://www.spiraxsarco.com/resources/steam-engineering-tutorials/control-hardware-el-pn-actuation/control-valves.asp).

- **Angle valves**: act as both flow control valves and elbows, having a lower loss than a globe valve and separate elbow. They are frequently used on radiators and other small systems. More information can be found at [web.tradekorea.com/upload_file/prod/marketing/mkt_files/company/t/topvalve/img/oimg_CA00186602.jpg](http://web.tradekorea.com/upload_file/prod/marketing/mkt_files/company/t/topvalve/img/oimg_CA00186602.jpg).

- **Needle valves**: used for flow control on very small lines, with similar performance to globe valves. More information can be found at [www.industrialvalvesindia.com/MANUFACTURER_EXPORTER_MINIATURE_NEEDLE_VALVES.htm](http://www.industrialvalvesindia.com/MANUFACTURER_EXPORTER_MINIATURE_NEEDLE_VALVES.htm).

Valves used to direct flow include:

- **Three-way mixing valves**: throttle flow between two ports and are used to control flow to coils, heat exchangers, or other process equipment.

- **Three-way diverting valves**: allow flow through one of two ports to common. Some diverting valves may be used for throttling service, while others are two-position. More information can
be found at www.spiraxsarco.com/resources/steam-engineering-tutorials/control-hardware-el-pn-actuation/control-valves.asp.

- Other specialized valves: exist to serve special processes; for example, 4-way ball valves. More information can be found at www.jdvalves.com/four_way_ball_valves.htm.

### Pumps

There are two major classifications of pumps:

- **Positive displacement pumps** move a fixed quantity of fluid relatively independent of upstream or downstream pressure. They can be further subdivided into rotary and reciprocating pumps (as well as some other specialty items). Positive displacement pumps of different designs can be used to move fluids which are highly viscous, contain abrasives, or require moving a constant volume of the fluid regardless of the downstream pressure. Vacuum pumps are used to remove air and noncondensables from refrigeration systems and are an example of a positive displacement pump. More information can be found at www.driedger.ca/ce2_pdp/CE2_PDP.html.

- **Kinetic pumps** add energy to the system by increasing the pressure of the fluid. These are very sensitive to increases in the downstream pressure; as system resistance increases, pump flow decreases. Primary classifications include centrifugal pumps and regenerative turbine pumps.

### Rotary Lobe and Rotary Vane Pumps

A unique rotary positive displacement pump is the peristaltic pump, used in medical, pharmaceutical, or other industries where being able to completely clean and sanitize all elements touching the process fluid is required. More information can be found at http://www.process-controls.com/Burlington_Pump/viking_vane_pumps.htm.

“The peristaltic pump uses rollers to compress the phaco outflow tubing in a peristaltic manner, thereby creating flow. The compression of the rollers on the tubing with the rotation of the pump physically moves fluid and creates a continuous ‘milking’ action on the fluid column.” (www.osnsupersite.com/view.aspx?rid=16841).

### Reciprocating Pumps

Operating similarly to a reciprocating compressor, these positive displacement pumps are used in hydraulic systems to create high output pressures. More information can be found at www.edgeroamer.com/sweethaven/mechanics/hydraulics01/default.asp?iNum=0301.
**Kinetic and Centrifugal Pumps**

Kinetic pumps convert mechanical energy into hydraulic energy by means of centrifugal action. Regenerative turbine pumps provide high head increases at lower flows, while centrifugal pumps are low-head, high flow pumps. More information can be found at:

- [www.pumps.org/content_detail.aspx?id=1768](http://www.pumps.org/content_detail.aspx?id=1768)

Centrifugal pumps are used as circulating pumps in domestic water systems, as well as in most HVAC applications. Efficiency decreases as pressure or viscosity increase. More information can be found at [www.driedger.ca/ce1_cp/CE1_CP.html](http://www.driedger.ca/ce1_cp/CE1_CP.html).

Centrifugal pumps come in many configurations. Horizontal split case pumps are used in many pumping applications. They have a straight-through piping configuration and are usually of a double suction configuration, meaning the fluid enters on both sides of the impellor. Double suction pumps are more balanced, which is easier on the bearings and shaft seals. Two mechanical seals are required around the shaft, or stuffing boxes containing packing material wetted by the fluid for proper lubrication may be used. Pump packing is easier to replace than mechanical seals but handling the dripping of fluid that keeps the packing lubricated may be a nuisance (wet floors, etc.).

The bearings are readily accessible for maintenance. The motor is attached to the shaft to the side of the pump, so the footprint is larger than that of some other straight-through pump configurations. See [rbapump.thomasnet.com/category/fairbanks-morse](http://rbapump.thomasnet.com/category/fairbanks-morse).

Vertical split case pumps have the suction line either at a right angle to the discharge (usually on top), or both the suction and discharge are on top of the pump. With no lower bearing or shaft seal required and reduced floor space required, this configuration has many applications. See [www.taco-hvac.com/products.html?current_category=376](http://www.taco-hvac.com/products.html?current_category=376).

Vertical in-line pumps have no lower bearing or shaft seal required. The motor is mounted vertically above the pump. This simplifies maintenance and minimizes required floor space. These pumps come in both large sizes (for major distribution loops) and small sizes for applications such as circulating water through a heating or cooling coil. See [www.pattersonpumps.com/vip.html](http://www.pattersonpumps.com/vip.html).

Self-priming pumps have a casing with an integral reservoir to trap water during the off cycle. When the pump is started, water is recirculated through the impeller, reducing the pressure in the suction line sufficient to cause atmospheric pressure to fill the line with liquid.

Multistage pumps are used to develop higher discharge pressures in high-head applications.

**Heating, Ventilating, Air Conditioning and Refrigeration**

The equipment required to control temperature, moisture levels, air movement and healthy indoor air quality are numerous and varied. Consider a typical central heating and air conditioning system for a house. There is the furnace which includes a fan, some type of heating coil (typically natural gas or electric), a cooling coil (which requires a refrigeration system to produce cold refrigerant), an air filter,
ductwork to distribute the air throughout the house, diffusers and registers to discharge the air into the spaces or pull return air back to the central unit, and a control system (thermostat) to tie it all together.

There may also be additional air cleaning equipment and a humidifier to add moisture to the space (the cooling coil typically acts to dehumidify, or remove moisture from the space). Depending on the type of heat provided, there may be a separate boiler and associated pumps, as well as a chimney or stack (required for any furnace or boiler operating off of a fossil fuel such as natural gas, oil, coal, etc.). Different heat pump configurations, such as geothermal (ground source) or solar-assisted, add additional options. In commercial and industrial buildings, the equipment function is similar although typically larger and more complex. More information can be found at


Heat Generating Equipment

Heating sources can be as simple as an electric coil and as complex as a large, coal-fired boiler. Boilers can be large enough to meet the needs of a college campus or small enough to service a single house. Boilers produce steam or hot water to be used in heating systems, as well as for process needs, such as a laundry. Steam can be used directly in heating coils or can be used to heat water through a heat exchanger. Sources of energy for boilers can be coal, natural gas, oil, propane or electricity.

Furnaces are a special category of heat generating equipment. They consist of both the heat source and the fan required to distribute the heat throughout the space. These are primarily used in residential applications. The most common heat source is natural gas, although oil and propane can also be used. Burning fuel inside a heat exchanger warms the air passed across it for delivery to the space. More information can be found at:


Refrigeration Equipment

Cooling, whether for process or comfort needs, is provided using a refrigeration system; in comfort applications, this is generally referred to as air conditioning. Refrigeration is applied in two forms; directly through a refrigerant coil, or indirectly through a chilled water coil, the water being cooled by refrigerant in a chiller. Home units use the refrigerant directly in the cooling coil, as do most refrigeration systems found in supermarkets, cold storage warehouses, etc. Water chillers are generally applied for large building or campus applications where there is more than one cooling coil (multiple air handlers), or for systems such as hockey floors, although the water is replaced by a secondary coolant that does not freeze at such high temperatures, such as a saltwater brine or glycol solution.

Water chillers consist of the chiller package (a heat exchanger and refrigerant compressor) and a condenser (which is a heat exchanger that rejects heat from the refrigeration process). The condenser may be a heat exchanger tied to a cooling tower or may be air-cooled. Cooling towers and air-cooled condensers are placed outside. More information can be found at:

- www.rd.com/images/tfhimport/2005/20050401_A_C_Tune_Up_page003img001_size2.jpg
Heat Exchangers

Heat exchangers are used in many applications for heating and cooling. All coils are air-to-fluid heat exchangers (the fluid may be steam, hot water, refrigerant, etc.). A common type of heat exchanger is the shell and tube exchangers. One fluid is on the shell side and the other on the tube side. The fluids can be water, steam, refrigerant, etc. A special category of heat exchanger is the heat pump.

Heat pumps are used to move heat from one area to another. A residential heat pump works like an air conditioner in the summer and uses a reverse process in the winter. While a residential heat pump looks just like an air conditioner to the casual observer, the outside condensing unit operates year-round. In colder climates, a supplemental source of heat is required when the outside temperature is cold (in general, below 25-30 degrees Fahrenheit). Equipment that adds moisture to the air stream (humidifier) is also considered a heat exchanger, although the primary purpose is the addition of moisture rather than heat. More information can be found at:


Air Handling Units

Most residential units do not directly introduce outside air into the space; residential occupancies are low enough and air exchange happens due to people coming and going, as well as infiltration through and around building components (around windows and doors, for example). In larger facilities, however, there is not enough infiltration and air turnover to maintain a healthy environment without replacing some of the space air with outside air (or air that has been cleaned). This keeps carbon dioxide levels from increasing to unhealthy levels as well as controls other contaminants and odors in the space. Air handling units combine the equipment required to bring in this outside air, central filtration and fans, as well as various combinations of heating coils, cooling coils, and humidifiers (if required). Air handlers are connected to ductwork to distribute the conditioned air to the space. More information can be found at www.controlpix.com/store/product.php?productid=44&cat=4&bestseller=Y.

Air Distribution

Air distribution equipment consists primarily of ductwork, fans, air cleaning devices (primarily filters) and terminal units. Ductwork is used to provide a path for the conditioned air.

- Galvanized steel, which is soft sheet steel coated with zinc, is the most common material used for HVAC ductwork. It is resistant to atmospheric corrosion and the coating holds up well to repeated bending. It cannot be used where high moisture, high acid or high temperatures (>400°F) are present.
- Stainless steel is an uncoated, high grade steel with additives (chromium, nickel, etc.). It can have a finish that varies from unpolished to mirror-like and is tougher and smoother than galvanized. It is suitable for corrosive and high temperature environments.

- Aluminum is corrosion-resistant and lighter than galvanized with similar strength. It cannot be used at high temperatures and is more costly than galvanized.

- Copper has a high corrosion resistance but, due to cost, is generally used only in architectural metals.

- Lead has a high corrosion resistance and is used in acid baths and x-ray booths.

- Zinc is corrosion-resistant but very brittle as compared to galvanized steel.

- Plastics, including PVC, CPVC, FRP, and others are used in certain chemical environments. PVC and CPVC may require special fire protection due to smoke generation hazards. This is generally used only when other alternatives are unavailable.

- Duct board is a rigid fiberglass panel that combines the duct and insulation into one product. Becoming more common in homes due to reduced cost, it is not commonly used in larger commercial or industrial facilities.


All ductwork should be sealed. Duct leakage affects both fan performance and the ability to meet heating and cooling load. Some estimates show that 10–15% leakage is common on unsealed ductwork, which can result in increased fan energy consumption of 33–52%. (United McGill Corp.'s Engineering Report No. 145, Duct Leakage and System Performance). Duct sealants should have:

- 60-70% solids to reduce shrinkage
- High adhesive strength (even when oil is present)
- High cohesive strength (bonds to itself)
- Good aging characteristics
- Not water-soluble—will soften and fail if exposed to condensate
- Meet NFPA and UL standards for smoke and flame spread rating

**Fans**

Fans are devices used to move air to and from spaces (typically) as well as to circulate air within a space. There are two major classifications of fans: centrifugal fans and axial fans. More information can be found at [http://www.anaheim.net/utilities/ea/PA_32.html](http://www.anaheim.net/utilities/ea/PA_32.html).

Centrifugal fans pull air along the shaft and discharge it radially away from the shaft. They can be divided into three classes based on the shape of their blades.
• Forward-curved centrifugal fans move high volumes of air at low static pressures. They have low blade speeds, lower initial costs and lower efficiency than other centrifugal fans and are often used in packaged air conditioning units. See www.aicyairsystems.com/products__services.

• Backward-inclined centrifugal fans operate over a wide pressure range with high blade speeds. They have higher initial costs and higher efficiency than forward-curved fans and are used in many larger HVAC systems. They have a fan wheel whose blades are inclined away from the flow. See www.howden.com/en/Library/HowThingsWork/CentrifugalFans/CentrifugalFanImpeller.htm.

• Backward-inclined centrifugal fans with airfoil blades operate over a wide pressure range with high blade speeds. They have the highest initial cost and the highest efficiency of all centrifugal fans. Used in many larger HVAC systems, the airfoil fans have blades shaped like airfoils. These minimize turbulence between the blades, improving overall fan performance and efficiency.

Axial fans pull air along the shaft and blow it in the same direction. They can also be divided into three classes:

• Propeller axial fans move high air volumes at very low static pressures. They are low cost and are not suitable for most HVAC system applications. They may be mounted in a ring or may be hung free (such as a ceiling fan). See http://news.thomasnet.com/fullstory/5826.

• Tubaxial fans have propellers mounted in a tubular enclosure. They handle large quantities of air at low static pressures. Relatively compact, their straight-through design may eliminate elbows. See www.indiamart.com/.../tube-axial-fan.html.

• Vaneaxial fans are tubaxial fans with flow straightening vanes, making them more efficient and more costly than tubaxial fans.

**Air Cleaning Devices (Filters)**

Air cleaning devices consist primarily of mechanical air filters and electronic air cleaners. Most filters are made of fibrous media (often fiberglass) and have varying efficiencies. Standard residential filters remove larger particles reasonably well but are not particularly efficient at removing smaller particles, such as viruses, bacteria, mold spores and cat and dog allergens. More efficient filters are available which will remove these smaller particles more efficiently. Most commercial applications use medium to high-efficiency filters. Specialty filters can be used for other contaminants, such as odors and contaminants from tobacco smoke. While a variety of electronic air cleaners exist, they are not typically used in commercial facilities unless there is a specific contaminant of concern. See http://www.epa.gov/iaq/pubs/airclean.html#Understanding.

**Air Terminal Units and Air Devices**

Air terminal units and air devices consist of dampers, mixing and variable air volume boxes, and diffusers, register and grilles. Dampers are used to direct control or isolate flow in systems:
• Isolation dampers include blast gate and parallel blade dampers

• Control dampers are used to modulate the flow of air to meet space requirements

• Balancing dampers are used to add resistance to the system and match the airflow to the system design

• Fire and smoke dampers are required to prevent passage of fire, smoke, or both where ductwork penetrates fire or smoke walls

Mixing and variable air volume boxes consist of one or more dampers and the associated controls to either regulate the amount of airflow into an individual space based on the heating or cooling load, or to mix two airstreams to provide a given space with a specific temperature of air. Mixing boxes can be either constant total volume or variable volume. Reheat coils may be included in the box for additional heating, especially in applications where precise humidity control is required.

Diffusers, registers and grilles are the devices located in the room through which the air enters the space. Diffusers are horizontally (ceiling) mounted supply devices typically used in commercial structures. Registers and grilles are horizontally (wall) or floor mounted and may appear identical, but registers are generally adjustable devices used for supply air and grilles are non-adjustable devices used for return air. Grilles can also be ceiling-mounted.

HVAC Instrumentation and Controls

All systems require controls. Residential systems use thermostats to turn equipment on and off in response to space temperature. Systems installed today have electronic thermostats which can perform functions such as setback and scheduling, which can help reduce energy consumption when the space is unoccupied or during the overnight hours.

In commercial systems, controls are much more complex. Fans must operate during all occupied periods to insure that adequate outside air is brought into the facility. In addition, there are dampers, coils, terminal devices (such as VAV boxes), etc. that all must be made to work together to provide effective, efficient control. While many older control systems consist of pneumatic or electronic controls, new systems typically used direct digital controls, which are microprocessor based and provide remote communication and troubleshooting capabilities. These digital controls allow for much more complex control schemes than were practical with prior control systems, such as control of outside air based on a combination of load and occupancy information. DDC systems are often part of a Building Automation System that provides integration of other control functions with the HVAC controls, including lighting control, security access, etc.

Testing, Adjusting, and Balancing (TAB)

Buildings and building systems are becoming more complex and their subsystem operations are more interdependent than ever before. Testing, adjusting, and balancing are critical steps in the commissioning of new systems and should be performed whenever there is a system change or as required to maintain system performance. TAB fulfills three functions:
- Testing to document existing conditions
- Adjusting to match contract requirements
- Balancing to provide acceptable space conditions in accordance with the system design requirements
Chapter 14

Electrical

While many scientists have observed and theorized about electricity for the past several centuries, it is only in the past 200 years that considerable progress has been made in the field of electricity and electrical engineering. Almost all aspects of our modern lives depend on electricity. It is an integral part of a building and will provide the power necessary for HVAC systems, lighting, comfort and entertainment. Electricity will continue to be a major factor in industrialized society for the foreseeable future. Many building designers now look for ways to not only save energy costs through good design, but ways to incorporate electrical generating devices such as solar panels into the style of the building.

In order to generate electricity, power plants are scattered all over the country. They range from burn fossil fuels (coal, natural gas and oil), to nuclear, hydro (water), geothermal, wind, solar and thermoelectric.

All power systems in the United States are connected together making up what is called a power grid. It is comprised of high voltage alternating current (AC) that can have voltages as high as 765,000 volts. By comparison, the voltage from a typical building receptacle is 120 volts. Alternating current can travel further distances than direct current (DC) with less loss of energy.

From the power plant the voltage may drop several times via transformers. Common light commercial and residential voltage is 120/240 volts. Industrial uses may require voltages much higher than this to run specific pieces of machinery.

The power requirements of a typical residential household have increased over the past several decades as our homes have become more inundated with electrical devices. Before consumer goods such as televisions, microwaves, and computers, they typical home was wired with a 100amp or less service. An amp is a unit of measure of electricity. The larger the amperage, the more power available for consumption. Nowadays, homes generally have a 200amp service.

This service comes from the transformer to a distribution panel inside the structure. This panel (sometimes referred to as a breaker box or fuse box) distributes electrical service throughout the rest of the building. Depending on the needs of the various locations in the building, wires or conductors will be run inside of wall cavities, ceilings, floors and chases.

These conductors are most commonly copper and aluminum. Differences in thickness, or gauge, allows different amounts of electricity to flow. For a typical home receptacle, the wire may be either 14 gauge or 12 gauge. A 14 gauge wire can handle up to 15 amps, while a 12 gauge wire can handle up to 20 amps.

By multiplying amps by voltage we get watts. Calculating wattage will help determine power requirements and the number of devices possible on each circuit. A 20 amp circuit can have a maximum of 2400 watts, though most electricians like to stay around 80% of maximum (1920 watts) to allow for variances and additions to the circuit. Too many devices on a given circuit (set of conductors) will trip the breaker resulting in a disruption of power. This disruption is to prevent the wires from getting too hot and starting a fire.
Commercial applications require that the conductors be run inside of a protective case called a conduit. This is to protect both the wire and occupants. This conduit can either be rigid or flexible and can be made out of plastic or steel (EMT).

Current codes require the use of a Ground Fault Circuit Interrupter (GFCI) in wet environments. A GFCI receptacle will turn off power to anything plugged into it when the devices senses a loss of current. This would include bathrooms, kitchens, basements, garages and exterior applications.

On the job, one of the first tasks to be completed is the installation of a temporary electric pole. This pole will serve as the main power point during construction, taking the place of generators which can be costly and noisy to run. The pole is wired by the energy company to a transformer. It will have a meter to record usage, a disconnect and a receptacle.

As construction begins, and as the building becomes weather tight, electrical utilities can begin to be installed. This is often referred to as rough electrical and usually only consists of wires, conduit, and boxes. The exact location the wire takes is left up to the subcontract performing the work. One simple residential plans, the electrical prints would only show relationships between devices such as a switch and light, amperage requirements for things like stoves and furnaces, but would not necessarily show each receptacle or the wiring from the panel to a set of devices.

After the rough electrical (and plumbing) is completed and inspected, the studs (including wires) will be covered up with materials such as drywall. Holes are cut in the drywall for the electrical boxes containing the wires. A good electrician will label the wires in the box to take the guesswork out of where the wires lead. The boxes will house receptacles and switches.

After this point electricians would return to the site, usually after painting, to complete the finish electrical work. This would include switches, receptacles, lighting, and wall plates. A final inspection will help lead to the certificate of occupancy.
Chapter 15

Lighting

There are many types and styles of lighting used in residential and commercial buildings. There is task lighting used to illuminate a work area and selective lighting used to illuminate objects of interest. There are many lamps that can add light at a lower level in a room and many styles of overhead or ceiling lights.

There are three areas of lighting of primary interest to designers:

- Health
- Function
- Aesthetics

Lighting for health relieves the strain on eyesight, fights fatigue and depression, physical discomfort and headaches. Being aware of the recommended levels of illumination needed for schools, hospitals, offices and factories for example, will alleviate these concerns.

The Illuminating Engineering Society publishes recommended levels of lighting intensity stated in foot-candles, meaning the quality of light required to do certain tasks. Light can be controlled by reflectors and diffusers manipulating the glare that lighting can create and controlling the brightness so illumination has quality as well as quantity. Consideration must be given as to what the function of the space is and what task is going to be performed when selecting the best lighting. For example, restaurants do not require the same lighting considerations as a theater or surgical room, so knowing what the function is going to be is critical to the decision making process.

There are three basic types of lighting used in buildings:

- Incandescent
- Fluorescent
- Halogen

All three can be used as direct or indirect lighting or combinations of the three.

Lighting is chosen for aesthetics in certain areas. Since there are too many types of lights to list it is important to understand that lighting can also be sparkling, dramatic or even sensual. A need for variety due to the many tasks and functions of various buildings results in the many forms of lighting from which to choose.

Dependence on lighting is evident since buildings are designed with only natural light streaming through windows that are covered to control the intensity of that light. Getting light into the interior spaces of a building requires knowledge in the types and styles of lighting. Having light helps maintain a healthy
environment allowing the occupants to function efficiently while enjoying the aesthetics in which they work and live.
Chapter 16
Conveying Systems

Conveying systems cover the wide expanse of lifting and moving people and materials. They can be as simple as a dumbwaiter that transports food, mail and small items from one floor to another. Conveying systems can also be as large as a crane and hoist that lifts and moves materials that weigh tons.

Dumbwaiters

Dumbwaiters transport small items between floors in a building. They are most often found in large homes and buildings that offer food service to their clients or guests. Dumbwaiters are also found in hospitals, libraries and office buildings where they can transport medicine, books, and mail.

A dumbwaiter is a mechanism that consists of a movable frame in a shaft with platforms attached to the frame that moves up and down. The size is mandated by code with standard heights at 3, 3 1/2, and 4 feet. The maximum platform size is 9 square feet. The units can be operated manually with an endless rope and pulley system. This is attached to the hoisting mechanism and an automatic braking mechanism.

Electrically powered dumbwaiters can be used in buildings of any height. Different types do have some limitations. The drum type is one that is restricted to a maximum rise of 40 feet, but the traction type can rise to any height that the motor is capable of lifting. Electric dumbwaiters have varying speeds of 50–150 feet/minute, can open from all vertical sides, have an assortment of door types, and may be counter loading or floor loading.

Elevators

Elevators are vertical transport systems that transport people between floors of a building. An elevator system consists of a hoisting mechanism that is connected to a car or platform. This car or platform then moves vertically, in most cases, on guides that are attached to the fire-resistant sides of a hoistway.

The first reference to an elevator was by the Roman architect Vitruvius around the year 236 BCE. He reported that Archimedes had built a lift somewhere near where the architect was working. This elevator was a cab attached to a hemp rope that was thrown over a support and pulled up by the other end with men or animals.

In 1793, Ivan Kulibin designed an elevator using a screw lifting mechanism. By the 1800s, there were many types of freight elevators used to lift materials. Most of these ran hydraulically where a pump would apply water pressure to a plunger or steel column inside a vertical cylinder to raise and lower the elevator. To make this work, the pit below the elevator had to be equally as deep as the height of the elevator shaft.

Then in 1850, Henry Waterman invented the standing rope control mechanism, and in 1852, Elisha Otis introduced the safety elevator, which prevented the car from falling if the cable should break. By 1857,
the first Otis passenger elevator was installed in New York City. The first electric elevator was built in 1880 by Werner von Siemens, and the safety and speed of electric elevators was improved by Frank Sprague. Further developments occurred improving the safety, speed and appearance of elevators. With the passing of the Americans with Disabilities Act, elevators have become an integral part of nearly all public buildings over three stories high, as well as many private homes.

**Residential Elevators**

Residential elevators are designed to move people from one floor to another in a building. They come in a variety of sizes and may be wheelchair accessible. Residential elevators may use hydraulic or electric traction systems very similar to commercial passenger systems. The cars are steel reinforced, come in a variety of finishes, range in size from 36–48 inches and handle up to 450 pounds, depending on its load capacity.

**Elevator Hoistways**

A hoistway is a vertical fire-resistant shaft. It is enclosed and the elevator moves through this shaft. The hoistway is accessed by doors that open into the shaft when the elevator is called to the opening on that floor. It has a pit at the bottom of it, where buffers are required. Buffers are energy-absorbing units that absorb any impact should the elevator descend below the normal level. Some hoistways have penthouses at the top where the machine room can be placed. Code may require that the hoistway be vented in case of fire.

**Hoistway Doors**

Hoistway doors are installed in the openings of the shaft at each floor level. They are rated as a 1-1/2 hour fire door and are controlled by an automatic operating system. Codes specify the type of doors required for each type of elevator. Doors close automatically when the elevator car leaves the landing zone, an area 18 inches above or below the floor. The elevator car will not move if all doors are not closed and locked. The doors cannot be opened from the landing side except for emergencies.

**Machine Rooms**

Machine rooms are designed as part of the hoistway. They provide a fire-resistant area that will house the required equipment to operate the elevator car, such as hoisting machinery, controls, hydraulic oil, and pumps. The area must be air conditioned to control the temperature. If the machine room is located in a penthouse, the floor must be strong enough to hold the dead weight of the machinery and accessories plus the live weight of the maintenance crew. With new technology; traction motors that boast gearless units; permanent magnet drive units that are more efficient and compact and electronic processors that replace the mechanical relays, traction elevators can now be built without a dedicated machine room.
Hoistway Sizes

Hoistway sizes are specified in the National Elevator Industry Standard and the Elevator Engineering Standard Layouts. Each hoistway must be sized according to the clear inside dimensions that a hoistway must be to accommodate the elevator car and all required cables and moving equipment.

Elevator Code Standard

Codes are established by the American National Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks, ANSI/ASME A17.1, and local building codes. Standard sizes and shapes for elevators are determined by the National Elevator Industries, Inc. (NEII).

Elevator Types

There are passenger elevators, freight elevators and hospital elevators. Passenger elevators are designed to transport people from one floor of a building to another. Passenger elevators are used in many places other than buildings, such as ships, mountainous resort areas, and transportation stations, but the principle remains the same: passengers are transported from one landing area to another. Freight elevators carry materials from one floor to another, and can be large enough to transport heavy equipment such as cars and fully loaded trucks and trailers.

Hospital elevators are found in medical facilities. These elevators are equipped with a “Code Blue” service for emergencies. When activated, the system will automatically select the elevator nearest the floor where needed and return it to that floor, regardless of where the elevator was headed or its passenger load. Passengers in the elevator car are alerted there is an emergency with an alarm and flashing lights that prepare them to exit the elevator car as soon as the hoistway doors are opened. All buttons are disabled upon its arrival until medical personnel reactivate the elevator with a “Code Blue” key, select the floor they want, and close the door with the close door button. The elevator will then go directly to the selected floor without stopping.

Electric Traction Elevators

Electric elevators are operated by traction machines. This is an electric motor connected to a driving sheave. Gear-driven traction machines provide slower rise speeds and gearless direct drive machines provide high riser speeds. When power is lost in an electric traction elevator system, all elevators come to a halt and one by one, each car returns to the ground floor, opens its doors and shuts itself down.

Geared Traction Elevators

Geared traction machines are driven by AC (alternating current) or DC (direct current) electric motors that use worm gears to control movement of the car. This is achieved by rolling steel hoist cables over a drive sheave (gearbox) that is attached to a high-speed motor. Typical riser speeds range from 350 to 500 feet/minute for passenger elevators, and 50 to 200 feet/minute for freight elevators.
**Gearless Traction Elevators**

Gearless traction elevators are low speed, high torque motors that are driven by AC or DC motors. With gearless traction machines, the drive sheave is directly attached to the end of the motor. They can reach speeds up to 2000 feet/minute or higher but typically range from 500 to 1200 feet/minute. A brake is mounted between the drive sheave and motor to hold the elevator.

In each case, geared or gearless, cables are attached to a hitch plate on top of the elevator car and then looped over the drive sheave to a counterweight attached to the other end of the cables. The counterweights are located in the hoistway on a separate rail system that works the opposite direction that the car is driven. This counterweight is equal to the weight of the elevator car and 40–50% of the load capacity of the elevator.

**Car Safeties**

Car safeties are a device designed to stop movement of the car and hold it in position. When the car exceeds a safe speed, it is automatically activated by applying brake shoes against the rails, stopping the car and switching off the power to the motor.

**Roping**

Elevator cars must be suspended from a minimum of three hoisting ropes. This wire rope is made of steel strands laid helically around a hemp core and each strand is made of steel wires helically wrapped around a steel core. The roping affects the performance of the traction type elevator.

**Hydraulic Elevators**

Hydraulic elevators are used for low-rise situations because the pressure cylinder must be sunk into the ground a distance equal to the length of the cylinder. The car is mounted on top of the hydraulic pressure cylinder and is forced to rise as hydraulic oil is pumped under pressure to the bottom of the piston. The car lowers when oil is released from the pressure cylinder into a tank until needed again. Hydraulic elevators are used to transport freight and people, are cheaper than electric and the mechanism is simpler.

In older hydraulic elevators, those built before 1972 when the code changed, only one hydraulic cylinder was required. If it fails, it is necessary to remove the piston. Since this is such a major job, a new piston is installed rather than repair the old one. The hydraulic oil also leaks from these units so that pits are now lined with PVC liners to contain potential environmental contaminants. In recent years an inverted hydraulic jack was invented that is eliminating this costly process of drilling into the ground, helping to eliminate the threat of corrosion to the unit and increasing safety.
**Escalators**

Escalators are inclined, continuous moving stairs with handrails that transport people from one floor to another. They are used where elevators may be impractical, but use of stairways may be too slow for the anticipated crowd. Common places they are found are in airports, arenas, convention centers, department stores, hotels, shopping malls, transit systems, and public buildings. Escalators have little or no waiting interval, can be used to guide people toward exhibition areas, main entrances or exits, and can be waterproofed for outdoor use.

Escalators can be used as a required means of egress if they meet all requirements for emergency egress stairways, such as providing smoke and fire protection and a sprinkler system. Escalators can move many more people faster than elevators, traveling at typical speeds of 90–100 feet/minute.

Escalators are powered with constant speed alternating current motors. Maximum inclination of an escalator, from a horizontal surface, is 30 degrees, with a standard rise up to approximately 60 feet. Escalator widths are typically 24, 32, or 40 inches wide. Newer escalators have single pieces of aluminum or steel steps that move on a system of tracks in a continuous loop attached to a welded steel truss structural frame. Components include:

- landing platforms, where the gears and curved sections of the tracks are kept
- truss, a hollow metal structure that is attached to the top and bottom landings by supports
- two tracks built into the truss to guide the stop chain
- stops
- handrails

There are three typical configurations:

- Parallel: up and down escalators side by side, or close to each other
- Crisscross: stacked and all going in the same direction
- Multiple parallel: two or more together that travel in one direction next to one or more traveling in the opposite direction


**Moving Walks and Ramps**

Moving walks are slow moving, approximately 1.5 mph, or high speed, approximately 9–12 mph, horizontal conveyor belts designed to move people. Moving ramps have a maximum incline of 12 degrees and may move people up or down an inclined area. They may be connected together or used individually. Both come in varying widths and are capable of going very long distances. The sides of the moving walks and ramps usually have balustrades covered with a moving handrail going at the same
speed as the walk or ramp. A steel structural system supports the moving walk or ramp that is electrically driven. Moving walks and ramps are built in two styles:

- **Pallet type:** a continuous set of flat metal plates joined together; may or may not have rubber added for better traction
- **Moving belt:** built with mesh metal belts or rubber walking surface over metal rollers

Both have grooved surfaces that mesh with comb plates at each end.

The first moving walk was introduced at the World’s Columbian Exposition of 1893, but not until 1954 was a commercial moving walk installed. It was constructed inside the Hudson Manhattan Railroads Erie station, built by Goodyear. It was 277 feet long and moved up a 10 percent grade at 1.5 mph. Since then, moving walks and ramps have been installed at many of the world’s airports, museum exhibits, zoos, theme parks, and general public transportation.

**Lifts**

Wheelchair lifts are used to move a wheelchair and its passenger from one level to another. One type of lift is a steel platform with steel sides, entry and exit gates. The platform is covered with a rubber skid-proof surface and is operated by an electric motor that is controlled by the passenger. The wheelchair lift does not operate until all gates are secure and the wheelchair and its passenger are in place. These lifts can be installed in vans, buses and other vehicles of transportation.

A wheelchair stair lift moves the wheelchair and its passenger up or down stairs on a platform with side closures that are attached to a steel rail system that is fastened to the wall or the stair treads. This system can transport up or down a multilevel straight stair. For stairs with turns, two lifts are required.

Another type of stair lift is for people who have difficulty climbing stairs. This lift has a chair that runs along a steel or extruded aluminum rail that is mounted to the wall or the stair treads. This stair lift is capable of moving around corners and across landings, allowing the passenger to disembark safely away from the top of the stairs. Newer models use rechargeable batteries and direct current (DC). This allows the system to work during power outages. Controls are usually located on the arm of the chair and many have radio frequency or infrared remote controllers.

Chairlifts are a type of aerial lift that consists of a continuous steel cable loop strung between two terminals. The cable continuously circulates between the terminals and intermediate towers allowing the chairs to move in opposite directions. Chairlifts are commonly used at ski resorts, amusement parks, tourist attractions, and in urban transport.

**Facility Chutes**

A facility chute is a vertical or inclined passage through which objects can be passed through by means of gravity. Chutes are common in older high-rise residential and commercial buildings. This is to allow rapid transport of trash, laundry, mail, or construction debris from upper floors to the exterior of the building, the entry floor, or the basement area. For example, high-rise apartment buildings, office complexes and hospitals require tons of trash to be removed daily in a safe, efficient and sanitary way.
Hotels need to transport bedding and other linens from many rooms per floor to the laundry located away from the guests. In both cases, chutes, in their many shapes and sizes, are economical and efficient.

**Shuttle Transit**

Shuttle transit systems are fast, efficient means of horizontal transportation where the distance between points are impractical to walk. A few uses for shuttles are between airport terminals, remote parking areas and office and retail complexes. Shuttle transit systems operate much like elevators, only horizontally rather than vertically. Several cars operate within the same system, allowing passengers to board cars as needed. They use standard gearless traction machine drives and cable equipment to operate. The steel cable is attached to the side of the shuttle car. A steel guide and power rails are adjacent to the running surface where the vertical load is supported by air-cushioned pads on the bottom of the car and the guideway. The guideway running surface can be a single or double lane track.

**Conveyors and Pneumatic Tubes**

Several types of conveyor and pneumatic tube systems are used to move materials within commercial buildings. Conveyor systems move materials from one place to another within the building. They allow quick and efficient transportation for most materials that make them popular in the packaging and material handling industries.

Conveyor systems are commonly used in many industries to move items of all sizes, shapes and weights. They include a belt, rollers and segmented moving surfaces. Some types of conveyor systems are:

- Gravity roller conveyor
- Gravity skatewheel conveyor
- Belt conveyor
- Wire mesh
- Plastic belt
- Belt driven line roller
- Line shaft roller conveyor
- Chain conveyor
- Screw conveyor
- Chain driven line roller conveyor
- Overhead conveyor
The flat or troughed belt is used to move items from one area to another. Rollers may be solid roller units or skate roller units. Solid rollers can be gravity operated or power operated. Solid rollers can be gravity operated or power operated. Gravity operated skate roller conveyors are used for light-duty packages. The segmented moving surfaces are made of flat sections joined with hinge-like connectors.

Pneumatic tubes use compressed air or a vacuum system to transport small items through a complex of tubes. Although very popular at one time, modern methods of transportation have replaced many. Still using this method are banks, hospitals, pharmacies, factories, and larger stores and restaurants that transport money from the cash registers, to a safe in a remote area of the building.

Pneumatic tube systems are computerized to serve many purposes. They transport tube-like carriers, typically 3-3/4 inches to 5-3/4 inches in diameter and 15–16 inches long. The carriers move through a system of piping and are controlled by a computerized control center. It can be a single zone route or have multiple zones, depending on its usage. Another pneumatic system used in hospitals and hotels is larger and used to transport linens and/or trash. These are an improvement over gravity fed chutes that may become clogged and have to be cleaned out. With a pneumatic tube system, linens or trash can be placed in bags sized to fit through the tube.

Suggested Links

- http://www.schindler.com/
- http://savariaconcord.com/
- http://www.silvercross.com/
- http://fujitecs.com/
- http://greenbuilder.com/
- http://acsflex.com/
- http://www.constructionway.com/
- http://products.construction.com/
- http://eilifts.com/
- http://automatedconveyors.com/
- http://acsflex.com/
- http://abbeyaccess.com/index.php?n=1&id=1
- http://inclinator.com/
- http://elevators.en.alibaba.com/
- http://ohiolifts.com/
• http://abilitystairlifts.com/
• http://theescalatorcompany.com/
• http://us.kone.com/corporate/en/Pages/default.aspx
Chapter 17

Equipment

Equipment includes many of the elements that help define or enable a building to function in its intended use. For example, bank vault doors and teller assemblies enable a bank to provide the services we are accustomed receiving. Projectors and screens allow theaters to show movies. Dock levelers and bumpers make it possible for warehouses to accept and send freight deliveries from trailers. Refrigerators, ovens, and dishwashers allow restaurants to serve food. All of these examples are equipment allowing a building to function as designed.

MasterFormat

A note of clarification: with the 2004 expansion of MasterFormat, hydraulic equipment (valves, gates, etc.) has been placed in Division 35. Additionally, water treatment equipment (grit collectors, oil/water separators, filters, and sludge digesters) has been placed in Division 44. These divisions, along with some other former content of Division 11, are beyond the scope of this text.

The 2004 update to MasterSpec includes further breakdown and refinement of Division 11. Additional clarification, along with manufacturer links, directories and sample specifications can be found at arcat.com. The primary Division 11 sections are:

11 10 00 Vehicle and Pedestrian Equipment
11 20 00 Commercial Equipment
11 30 00 Residential Equipment
11 40 00 Foodservice Equipment
11 50 00 Educational and Scientific Equipment
11 60 00 Entertainment Equipment
11 70 00 Healthcare Equipment
11 80 00 Collection and Disposal Equipment
11 90 00 Other Equipment

Coordination and Selection

As equipment helps define the function of a building, the building owner must be involved in the specification and selection of the equipment. Building owners rely on equipment to allow their businesses to be productive and profitable, so the selection of appropriate equipment is essential for their success.

Large businesses which build, operate, and maintain multiple facilities may have an in-house department to coordinate the selection, purchase, installation, and maintenance of their equipment. This information may be shared with the design and construction team in the form of standard details, procedures, and expectations. Often this information is included with the project manual as prepared by the designer. In some cases a business’s equipment is considered part of their trade secret, giving them a competitive advantage.
Designers and contractors should always closely coordinate with the owner’s staff early in the design process to assure smooth design, specification, installation, and maintenance of equipment. Consider the bank example from above. Designing, specifying, and constructing a bank vault is a complicated and secretive process. The bank owner may be involved in deciding how large the vault should be, what specific elements it will include (safety deposit boxes, cash storage, electronic storage, etc.) and where it will be in the bank to allow appropriate access by staff and customers. The design must also accommodate the structure of the vault, including:

- Foundation support
- Floor, wall, and ceiling/roof construction
- Roof construction
- Access control/doors
- Ventilation
- Lighting
- Security systems

Vault systems may require installation early in the construction process, with key components embedded or cast into the structural walls to prevent compromise. Contractors need to coordinate procurement, delivery, installation, and subsequent protection of the various components throughout the construction process.

**Environmental Issues**

For many buildings, especially manufacturing facilities, operating equipment is a vital activity. Mechanical equipment typically requires power to function. The design and coordination of adequate energy/resource supply is critical. Working in conjunction with the owner, designers and contractors must coordinate the acquisition and installation of:

- Water supply
- Discharge (water or waste)
- Electric
- Natural Gas
- Steam

A facility owner may dictate the majority of equipment selection due to a variety of reasons. The designer and contractor, however, are responsible for assisting the owner in making the most responsible environmental decisions possible. Most owners are sophisticated enough to recognize and accept the environmental responsibility.
Many organizations provide guidance for the responsible selection of equipment. These include Energy Star and LEED.
Chapter 18

Special Construction and Specialties

Special Construction encompasses many of the unique structures and components included in specific buildings. Much Special Construction is modularized, allowing for quick design and installation. Examples of Special Construction include:

- Air-supported fabric structures
- Dormitory unit modules
- Detention cell modules
- Planetariums
- Grandstands
- Swimming pools
- Ice rinks

These structures and their accompanying systems require in-depth knowledge and significant specialization to assure proper design, specification, procurement, installation and maintenance.

MasterFormat

The 2004 expansion of MasterFormat relocated several important items formerly included in Division 13. A complete review of MasterFormat 2004 is beyond the scope of this text, but the following are the primary changes:

<table>
<thead>
<tr>
<th>Subject</th>
<th>New Division</th>
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<tr>
<td>Incinerators</td>
<td>44</td>
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<td>Storage Tanks</td>
<td>21, 22, 33</td>
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<td>Filters/Water Treatment</td>
<td>44</td>
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<tr>
<td>Process Control</td>
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<tr>
<td>Instrumentation</td>
<td>40</td>
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<tr>
<td>Solar Equipment</td>
<td>23</td>
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<tr>
<td>Integration</td>
<td>25</td>
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</tbody>
</table>
The 2004 update to MasterSpec includes further breakdown and refinement of Division 13. Additional clarification, along with manufacturer links, directories, and sample specifications can be found at [www.arcat.com](http://www.arcat.com). The primary Division 13 sections are:

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13 60 00 Entertainment Equipment
13 70 00 Healthcare Equipment
13 80 00 Collection and Disposal Equipment
13 90 00 Other Equipment

**Coordination and Selection**

As special construction is unique to an owner’s design requirements, the building owner must be involved in the specification and selection of the system. Building owners may be dependent on these special construction systems for the function and profitability of their businesses. In some cases, such as ice rinks, the special construction accommodates the central function of the facility.

Large businesses which build, operate, and maintain multiple facilities may have an in-house department to coordinate the selection, purchase, installation, and maintenance of their equipment. This information may be shared with the design and construction team in the form of standard details, procedures, and expectations. Often this information is included with the project manual as prepared by the designer. In some cases a business’s equipment is considered part of their trade secret, giving them a competitive advantage.

Designers and contractors should always closely coordinate with owner’s staff early in the design process to assure smooth design, specification, installation, and maintenance of Special Construction systems and components. Consider the example of an ice rink—it is seldom a designer’s or contractor’s idea to include an ice rink in a facility. This is typically the decision of the owner prior to involving either a contractor or designer. However, the inclusion of an ice rink requires significant design and coordination effort.
Environmental Issues

For many buildings, especially manufacturing facilities, operating equipment is a vital component. Mechanical equipment typically requires power to function. The design and coordination of adequate energy/resource supply is critical. Working in conjunction with the owner, designers and contractors must coordinate the acquisition and installation of:

- Water supply
- Discharge (water or waste)
- Electric
- Natural Gas
- Steam

A facility owner may dictate the majority of equipment selection due to a variety of reasons. The designer and contractor, however, are responsible for assisting the owner in making the most responsible environmental decisions possible. Most owners are sophisticated enough to recognize and accept the environmental responsibility.

Many organizations provide guidance for the responsible selection of equipment. These include Energy Star and LEED.

Specialties

This section covers the building process called specialties, furnishings and additions to a building that are installed permanently. It might be considered as all of those things that are not specified elsewhere. On large projects, interior designers or landscape architects would be the design professionals charged with the responsibility to guarantee that these items have been specified.

Some have very specific functions for the building or its occupants; others may be put into the building for their architectural style. The Sweet’s Catalogue published by McGraw Hill Companies is a fantastic reference to the myriad of products available that will make a building more functional. What follows is a partial yet significant list of the specialties.

Visual Display Boards

Every classroom in a school needs an erasable surface on which to write. These surfaces are often placed in meeting rooms or even in individual offices or rooms in a single family residence. For years the most popular surface was a chalk board, which was a slate surface. Chalk was the common writing tool and it was easily erasable. While the original product may have been black or dark grey slay stone, manufacturers developed many other surfaces that had other colors such as green and blue.

In the mid 1980s concerns were expressed about the health risks and allergies caused by chalk dust, as well as the effect it may have on electronic equipment. A new marker board made its appearance and has now become the standard. This new material is a hard white surface that can be written on with dry
erasable pens. These surfaces are made of several different materials ranging from white gloss paint on metal to a ceramic fired on a steel surface. An advantage of whiteboards with a steel backing is that they also attract magnets. One of the biggest drawbacks is that if the surface is marked with a permanent ink, it is indeed permanent. The porcelain type product, which is environmentally friendly, can help contribute to LEED certification.

Tack boards also fall into this category. These can range from full walls with a tackable surface to a small board discreetly placed for a specific subject.

**Partitions**

Partitions for restrooms, shower rooms, dressing stalls, or other areas where privacy is required are a specialty. The building code would specify the number of plumbing units needed in a building, depending on the use, but the interior designer must provide the privacy units. The industry has a multitude of suppliers with choices of material (metal or plastic), as well as color of finish. A unique movable partition is the curtains used to provide privacy between hospital beds.

**Louvers**

A louver is an opening provided with one or more slanted (fixed or movable) fins to allow flow of air, but to exclude rain or sun, or to provide privacy. Louvers first appeared in the 15th century, and although of crude construction, they allowed passage of air from outside to in (to cool a building and retain privacy) or the opposite to allow the steam of cooking to pass to the exterior.

Today there are louvered openings for fans or simply louvered coverings over openings for the air movement in an HVAC system. Louvers are used to cover vent openings in attics or under soffits. Windows may be constructed with the slats or blinds placed between double panes of glass. A popular use of the louver concept is the jalousie window that was popular in the 1980s.

**Corner Guard**

A small item easily taken for granted is a corner guard placed on wall to protect the wall covering itself (paint or wallpaper).

**Access flooring**

Computer rooms, clean rooms, or even a basement may have an access flooring system. This is raised flooring that allows for access underneath for cabling. This is another area where using this specialty can contribute to LEED certification.
**Fireplaces and Stoves**

Fireplace screens and inserts are specialties that enhance the décor and comfort of a room.

**Flagpoles**

Public buildings should display the American flag, a state flag, and possibly a flag associated with the organization. The flagpoles may be mounted on the exterior or prominent public rooms in a building.

Flagpoles may be ground mounted or wall mounted. Residential buildings will often display the American flag.

**Identification Devices**

Signage is definitely a primary method of delivering a message. City planners argue the country suffers from a disease known as sign blight. This argument has merit when too many signs actually become a negative effect. A passerby is so inundated by the continuous flow of signs that he or she becomes oblivious to the message. And a number of signs, close together, with multiple colors, can detract from the appearance of a neighborhood. Zoning codes have governing regulations on signs, but the impact can only be taken so far so that equality and free speech still exists.

When well done, signs can be an important part of identifying places, and delivering a message, both on the interior and exterior of a building. Signs can come in many forms. Electronic message boards are just one more method of delivering a message.

The items in or around a building that are important to the function of the building include:

- Lockers
- Fire protection and emergency equipment
- Protective covers
- Coat racks
- Telephone specialties

**Cupolas**

Another building feature that is included in specialties is copulas. These are small, often dome-like, structures placed on the top of a building. Early in our country’s history, architects included them in buildings for the functional use of emitting air or light, and they often served as lookout points. Today, they are included as an architectural feature.
This section has introduced only some of the many items that fall under the category of specialties in building construction. As mentioned previously, they may be overlooked when considering the major components of a building, but they are extremely important to make the building functional.
Chapter 19

Interior Finishes

Buildings consume an enormous amount of energy and create a large amount of waste contributing to air pollution through burning fossil fuels and the chemical release of pollutants found in such common materials as paint and carpet. To sustain the environment, architects, designers, and contractors must be aware of the materials they are suggesting that their customers use in the building project. Designing and building with sustainable, “green” building materials, will help clean our water sources and improve the quality of our air and land by using them more responsibly.

This section covers the history of materials selected for covering the interiors of a building and the method by which it is done. It will introduce many of the methods by which these materials are manufactured and explain why materials are used in the manner that they are. It will also explain properties of the materials that cover walls, ceilings, and floors, as well as how they affect the environment in residential and commercial architecture. Other considerations include acoustical considerations, appearance, codes, cost, durability and fire resistance.

Since this section refers to interior finishes that apply to the materials that cover walls, ceilings and floors, think about the materials that might be used for these applications. For example, consider plaster and gypsum board for walls and ceilings; hardwood, carpet and tile for the floors; and perhaps some of these materials could also be used on the ceilings or walls instead. Designs using sustainable materials and creativity are only limited by the imagination.

Basic Finish Materials and Methods

Finishing can be considered as either interior finishing or exterior finishing, using materials that may include cladding, doors, windows, exterior trims, paint, and moldings. Exterior finishing may be extended to include sidewalks, patios, decks, parking areas and even the landscaping that compliments and completes the building. While interior finishing will include ceilings, walls, flooring, and stairs, it will also include trim, molding, casing, cabinets, and fixtures that meet the owner’s requirements and those of the buildings occupants.

Interior finishing depends on the requirements desired by the owner. The architect or designer assists the owner in these selections, or may be the primary decision maker during this phase of the project. In either situation, materials must be selected not only for their aesthetics, but also for their durability, sustainability, cost, and maintenance. Interior finishing must complement the needs of the owner and the building usage requirements so that the occupants have a pleasing environment in which to work or live.
Metal Support Assemblies

Metal support assemblies have more often been found in commercial applications than residential, although this is rapidly changing as environmental issues influence our building requirements. Cold-formed metal studs are placed at 16” o.c. (on center) or 24” o.c. to accommodate the width and length of common sheathing materials often used in the completion of walls. Studs carry the vertical load, while sheathing or diagonal bracing adds strength to the plane of the wall.

Materials used to finish the wall determine the fire-resistance rating of the assembly. If using plaster as a finish material for walls, metal lath, which is made of expanded metal or wire fabric then galvanized or coated with a rust-inhibiting paint for corrosion resistance, may be used so that when plaster is applied to the wall it has a surface that it can adhere to while curing.

Ceiling Support Systems

Metal lath is also used to finish ceilings, as furred metal lath attached to steel joists, or as metal lath suspended from steel joists. When using the first method, consideration must be given to the deflection and movement of the structure to prevent cracking of the plaster ceilings. In the second method, the metal lath is supported by framing channels and furring channels suspended with wire hangers from the roof. The channels are usually spaced up to 4’ o.c. perpendicular to the joists, and the lath is attached to the channels.

Lath and Plaster

Plaster is one of the oldest known substances used as a building material. Plaster found in the pyramids, even though it is known to be more than 4000 years old, is still hard and durable today. Some tools used to apply plaster include floats, screeds, trowels, hawks, scratching tools, hammers, utility knives, nails, and lath.

Long before metal lath became common, wood lath was used. Wood lath are narrow pieces of straight grained wood, usually one inch wide, which are cut into short lengths to suit the distances at which the studs are placed. The lath strips are usually no longer than 4’–5’ because the plaster needs a break joint to minimize cracking during the curing process. Wood laths are butted end to end around the room from floor to ceiling at 3/8” apart.

Attached to the lath is a finish called plaster. Although plaster is still commonly used, it is now more often found in restoration than in new building projects. Plaster has been used for thousands of years, but early gypsum plaster, such as plaster of Paris, had a very short, uncontrolled setting time that made it difficult to use for large-scale projects. However, it was used extensively for decorative and fire-resistant purposes.

Gypsum Plaster

Gypsum is a sedimentary rock-like material that is unique in that it can be calcined (heated) to give up some of its chemically combined powder and water, then restored to its original form when water is
added. Because of this it can be easily formed into nearly any shape or molded into a form or sheets more commonly known as gypsum board (drywall) that are highly fire-resistant and easy to work with. Plaster is applied in layers depending on the type and strength of the base used.

The most common form of applying plaster is the three-step process beginning with the scratch coat. The scratch coat is applied directly to the lath between 1/4 to 3/8 inches thick and while still soft is raked so the next coat will have a surface on which to adhere. The second coat, known as the brown coat, is the most important and tedious of the three steps. Wall screeds, which are narrow strips of plastering, have to be formed, plumbed, and leveled in which to create a form that will be used as a guide that will help achieve a vertical or horizontal surface in which to apply the second coat. Before finishing, the second coat requires a scouring process that consolidates all the materials, helps harden it and prevents it from cracking. Then to achieve perfect adhesion with the third coat, the surface is passed over with a wire brush or nail float. The third coat is a setting coat, which is about 1/8 inch thick that prepares the wall for further decorating when completed.

Gypsum plaster is made from powdered calcined gypsum, aggregates, mineral or organic fibers, and lime. The gypsum acts as the primary binder in the plaster mixture while the other components act as filler providing workability, strength and stability to products. This mixture creates gypsum plaster that is applied directly to walls and ceilings as a finish material or used to create gypsum board, known more commonly as drywall. These boards are made of a paper liner wrapped around an inner core of gypsum plaster and are more commonly used than the three-step wet process of plastering.

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Note the dark ring where the wall and ceiling come together. The ceiling was done first and allowed to completely dry, then the wall was finished, creating the wet area on the ceiling where it is absorbing some of the moisture from the wall. It will dry completely in several days without leaving any watermark or stain.(Photo courtesy of Wikipedia.org)

**Veneer Plaster**

In some circumstances a veneer plaster, used over “blueboard”, a drywall whose paper is blue-gray in color, may be formulated as a finish plaster and added to this process. Veneer plasters can be used as a thin monolithic base coat over which another finish plaster is applied. Veneering is sometimes used in place of the taping, spackling, and sanding process used by most drywall contractors. It reduces material costs but labor costs are greatly increased. It is also used as a repair solution for cracked or damaged plaster rather than replacing the entire wall or ceiling. A single coat of veneer plastering can eliminate unevenness in a surface, small nicks, and gouges.

**Gypsum Board**

Gypsum plaster is made into several types of boards used for many different applications. Its major advantage over plastering is time. A job that could take weeks to do when being plastered can be done quickly, efficiently, and economically in days using gypsum board. Gypsum board is highly fire resistant and sound resistant when used in walls, ceilings, and floors. When used in partition walls, it is applied from the floor to the ceiling or roofline, creating barriers around heating equipment, commercial kitchens, and numerous high-risk areas. It is also used as a fire and sound-resistant agent in areas such as joining walls in restrooms, multi-unit apartment buildings, and hospital rooms.
Some of the many types of gypsum boards are:

- Regular whiteboard: 1/4 to 3/4 inches thick; used in residential and commercial applications
- Pre-decorated: board that has the finish applied
- Green board: contains an oil-based additive in the paper that makes it water-resistant; used in areas such as bathrooms, showers, locker rooms and kitchens where there are high levels of humidity present
- Backer board: regular drywall; used where more than one layer of board is required such as between apartments in a building or offices and hospital rooms
- Core board: 1" thick board used in shaft walls to protect electrical, mechanical and conveying equipment, such as elevators and stairwells
- Linerboard: has a special fire-resistant core enclosed in a moisture-resistant paper; used in stairwells, corridors, chaseways, and shaft walls
- Sound-deadening board: made from wood fibers; used to suppress noise levels
- Soundproof board: a laminated drywall made from gypsum, other materials, and dampening polymers
- Blueboard: forms a strong bond with finish plastering, providing water and mold resistance
- Mold-resistant board: paperless drywall; can be used everywhere
- Enviroboard: made from recycles agricultural materials
- Lead-lined board: used around radiological equipment
- Foil-backed board: used to control moisture
- Controlled density (ceiling board): available only in ½" thickness and is significantly stiffer than regular white board
- Fiberboard: strong enough to support weight; more fire, sound and moisture-resistant; is also stronger than regular gypsum board; resists impact damage and mildew damage
- Cement board: made with Portland cement; durable, water and fire-resistant backer for tile, slate, and stone used in showers, saunas, kitchens, baths, hot tubs, and pools

During construction, the job is usually split in two. The “hangers” come in first to attach the board to the ceilings and walls, and the “tapers” or “mudmen” complete the job by finishing the joints and covering the nail heads with drywall compound and tape.

To start a job the hanger marks out the measurements on the sheet of drywall with a chalk line, cuts the board to size by scoring down the front with a utility knife, breaks it backwards along the score, scores down the break line on the back, and finally finishes the break by snapping it forward. The hangers attach the sized sheet of drywall to the ceiling or wall, making sure to cut out holes for outlets, switches, and lighting.
It is then attached to the wall or ceiling with drywall screws. Nails will “pop” (come back out of the drywall) from the constant movement that is common to a structure. Drywall screws support the boards more securely and are less prone to “pop” from the everyday movements of a building. After the boards are attached to the ceiling joists or wall studs, the second crew will conceal the joints by using joint tape and several coats of joint compound. The compound is allowed to dry and then sanded until a smooth finish is achieved and the surface is ready to be decorated with another finish.

This is an example of drywall with joint compound, a common interior building material. This photo shows drywall hung vertically, which usually creates more joints to be finished.

**Tile**

Depending on its end use, tiles come in many sizes, shapes, patterns, and colors. Tiles have been known to maintain their integrity for centuries. They have been discovered in early Egyptian and Babylonian excavations that date back more than 5000 years. Decorative and functional tiles also played an important role in Greek and Roman architecture.

In the fourteenth century, an Italian town named Faenza developed a highly decorative tile that is now known as faience tile. A century later, Holland started production of its famous delft tile, characterized with designs in blue or violet. In 1867, in Pittsburgh, Pennsylvania, Samuel Keys introduced a process to make ceramic tile called the dust-press method. Due to improved manufacturing methods and installation techniques developed in the United States, the tile industry made more progress in the past half century than in the previous ten. Much of this progress is due to the diligent research and educational advancements made by the Tile Council of America.

Tiles are hand made from natural clay or a manufactured composition made of other ceramic materials, quarry stone, or metal. They are relatively thin in relation to their facial area. Tiles can be textured, smooth, embossed, patterned, sculptured, or engraved and are available glazed or unglazed. They are available in many types, sizes, and shapes and can be cut into nearly any configuration. Tiles are fired in kilns at very high temperatures that result in a material that is tough, dense, and durable enough to be water-resistant. A tile is difficult to stain, easy to clean, and its colors rarely fade. Tiles are suited for use in nearly every facet of construction, including residential, commercial, institutional, and industrial buildings. Interior use of tile can be found on floors, walls, ceilings, fixtures, and furnishings.

Tile can be made from many resources other than ceramic. Popular materials used for wall tiles are copper, glass, plastic, steel, stone and wood, among others. Floor tiles can include cork, metal, quarry, rubber, slate, and wood, while ceiling tiles may include any of these or it may be made from lightweight acoustical materials.

Some of the most common tile types are ceramic, metal, quarry, and brick paver tiles. Many ceramic tiles are made from natural clay or non-metallic minerals fired at high temperatures in kilns. They are often cut into modular sizes to facilitate their installation before the firing process.

Metal tiles are lightweight, easier to handle, quicker to install and less costly than ceramic tiles. Quarry tiles may be glazed or unglazed, are made from natural clay or shale and are usually made in 6” or larger tiles. They are an excellent floor tile due to their ability to be impervious to dirt, moisture, and stains. They also resist freezing and abrasion, so they can be installed in high traffic areas that may be exposed to changing environmental conditions. Paver tiles are similar to quarry tiles but are thicker and larger.
They are weatherproof and can be used on floors that are prone to heavy-duty loads. Bricks are used to produce a durable finish floor. Brick pavers are thinner than a standard brick, usually ranging between 1/2" to 2-1/2" thick. They are also weatherproof and can be used in many interior spaces.

There are many tile-setting products; each possessing a variety of special properties intended to make them suitable for setting tile. The mortar used depends on the tile backing. There are special formulated mortars for tiles that require a waterproof membrane or need to be chemical resistant. Grouting materials are also available in many types to meet the requirements of the different tiles and their exposure to environmental conditions. Color additives can give the grout a distinct look and finish, while other additives can improve curing time or allow more elasticity for the finished product.

Any surface that the tile is being applied to must be structurally sound. Floors should be engineered to control maximum deflection when under a full load, and walls should be plumb with square corners making sure that any backing material does not vary more than 1/8" every 8’. Tiles should be cut with the proper tools and laid out on a smooth surface to make sure the desired pattern is achieved and the tiles will fit in the space allowed. All accessories, such as beads, coves, bullnoses, and trim should be laid out, be prepared with a chalk line, and be straight, level, plumb, and an even width.

There are two popular application processes called the thinset process and the thickset process. The thinset process requires the tile to be bonded to a continuous, stable backing with a thin coat of mortar or an organic adhesive. The backing should be gypsum plaster, gypsum board, or plywood, except in wet areas where concrete backerboard should be used instead. If applying to a masonry surface, it should be clean, in good condition, and free of efflorescence.

In the thickset process, the tile is applied over a bed of Portland cement mortar. Using a thick bed of mortar allows the tile to be accurately sloped toward drains and away from corners. The setting bed is from 1-1/4"–2" thick on floors and 3/4"–1" thick on walls. Either the thinset or thickset process can be used on floors and walls, depending on the tile being set.

**Terrazzo**

The origin of terrazzo dates back to the beginning of the Common Era, having evolved from the practice of placing mosaic tiles on walls and floors. It was first used in Roman times when the Romans used crushed bricks and lime mortar to create thick hard surfaces. After the mixture hardened, it was ground and polished by hand. Later, decorative chips were added from broken mosaic tiles, creating much more colorful terraces and durable finished floors.

Modern day terrazzo is a matrix of mostly marble or granite chips, Portland cement, and water or a synthetic resin. It is placed over a concrete underbed, steel decking, or wood subfloor that is structurally sound. After this matrix has hardened but not completely cured, the surface is ground or chemically peeled to expose the aggregate, then polished to a smooth finish. Terrazzo provides a dense, extremely durable, smooth surface whose coloring is controlled by the size and color of the aggregates and binder.
There are four types of toppings classified by their appearance:

- Standard terrazzo with small chip sizes
- Venetian terrazzo featuring large chips with small chips as fillers
- Palladian, made of random fractured slabs of marble up to 15” in length and small chips as fillers
- Rustic terrazzo, a uniformly textured finish in which the matrix is depressed, exposing the aggregates, but is not ground or polished

All four types use a matrix of Portland cement or chemical binders such as epoxy, polyester, and polyarylate, latex and conductive. Conductive is a specially formulated matrix that allows electricity to be conducted with regulated resistance. It is often used in surgical areas where static electricity may cause injury to humans or damage to sensitive equipment or where explosive gases are a hazard.

Pigment may be added to any matrix in order to create multiple designs, patterns and colors of terrazzo. Metal dividers and control strips create designs and control cracking. They are made of brass, aluminum, plastic and white alloy of zinc for interior usage. Aluminum should not be used with a Portland cement matrix. It is suitable for a matrix of chemical binders.

There are several accepted systems used to create terrazzo depending on the size of the aggregate chosen for the floor, the weight that the sub-floor will support per square foot, control joint strip locations, panel size and divider locations. Isolation membranes may be required to prevent the transfer of stress from the sub-floor to the underbed (Portland cement or chemical binder) and topping (terrazzo finish). This condition is referred to as being unbounded, where a bonded underbed is rigidly attached to the sub-floor supporting the finished terrazzo. Metal reinforcement is required for the underbed in most cases. The reinforcement should be corrosion-resistant welded wire fabric at least 16 gauge thick with wires spaced no more than 2” o.c.

Because it is expensive to hand assemble the decorative topping chips for large areas or to create a specific design, the tesserae (stone, vitreous enamel or marble) is assembled in a shop and mounted on paper, then placed on top of the matrix while it is still wet. After the paper is removed, joints are grouted and the entire installation is ground and polished. Curing is necessary so that the topping can develop maximum wear properties. Materials used for this purpose are polyethylene film, non-staining, non-asphaltic, water-resistant building paper, and clean water. Spray on curing compounds can be used to help cure surfaces except on slabs that are going to use a thinset, chemically bonded or monolithic topping, because it may prevent bonding of the underbed and the topping. To complete the finish, a penetrating sealer should be used.

**Wood Flooring**

When selecting finish-flooring materials, the architect or designer must take into consideration the various types of subfloors. Wood flooring needs to be installed properly over subfloors that may be concrete slabs, OSB (oriented strand board), plywood, or cellular steel floors with concrete slabs. They also need to be aware of the acoustical requirements, building codes, fire resistance ratings, heating requirements, traffic loads, color, textures, and finish materials specified by the owner or occupancy requirements.
Wood flooring is a finish flooring material made from both hardwoods and softwoods. Some of the most common hardwoods are oak, bamboo, beech, birch, cherry, and maple. Softwoods include most pines, fir, and hemlock trees. Wood flooring is graded according to its species and the location of its origin. The associations that control the grading of wood flooring products specify requirements for kiln drying, grading, and control of moisture levels and establish standard sizes for the flooring.

Wood flooring is available in quartersawed, cut across the grain and plainsawed, cut with the grain, and is produced in four basic types: strips, planks, parquet, and solid end-grain blocks.

- Strips are usually cut to a standard pattern that can be side-matched or end-matched. The top is usually a bit wider than the bottom so when installed the tops fit snugly and the bottoms are slightly separated. Strips are usually 2-1/4” wide by 25/32” thick and come in random lengths.
- Planks are made the same as strips but come in widths from 3-1/2” to 8” wide.
- Parquet consists of usually small individual strips of wood or blocks that have been made into a decorative geometric design and is usually installed with mastic.
- Solid end-grain blocks come in variable sizes with a 9” block being the most common. The unit block is made of short pieces of strip flooring that are joined edgewise to form square units.
- Laminated blocks use three or more plies of veneer laminated together until the desired thickness is achieved. Slat blocks use narrow slats of wood preassembled into patterns to make blocks from 9” to 30” in size.

Wood flooring is classified as either solid or engineered. Solid wood flooring uses the same wood species throughout the entire piece and engineered wood flooring is a combination of a surface veneer that is laminated to one or more plies of a wood veneer from a less expensive wood species that provides stability and strength. The typical profile is known as tongue-and-groove. When wood flooring is laid this allows the various strips, planks, and parquet or solid-end grain blocks to be aligned accurately and creates a tight fit with level joints.

The wood flooring may be pre-finished by the manufacturer or finished on site by the contractor. Since wood floors are sensitive to moisture an underlayment such as building paper or a vapor retarder should be laid over the subfloor first. Then all the wood should be brought into the room where it is being installed, removed from the packaging, and allowed to acclimate to its environment for several days before starting installation.

To begin installation, contractors will chalk line a starting point, remembering to allow space around the perimeter of the wall to accommodate the natural movement that the floor will encounter due to changes in temperature and relative humidity. Then the contractor will start laying the wood flooring at a corner along the chalk line, blind nailing through the tongue that will be facing into the room away from the wall. This allows the individual pieces to be aligned accurately and creates a tight fit with level joints.

The wood flooring may come packaged in random lengths to allow staggering of the end seams so that they will be less noticeable as the floor progresses. If not, the contractor will take the cut end piece from the first row and use it to start the second row, allowing a natural staggering of the seams. The wood flooring may be pre-finished by the manufacturer or finished on site. If already pre-finished, the floor will only have to be cleaned. If the wood flooring is unfinished, the contractor will need to sand
the floor to remove any high spots or roughness in the wood, then clean and stain the wood before applying several coats of a clear polyurethane finish to protect the floor from abrasion, dirt, wear, oxidation, and moisture.

**Parquet Flooring**

Parquet means pattern and parquet flooring consists of pieces of wood flooring put together to form a decorative pattern. There are many geometric designs including those that use diamonds, triangles, squares, round and rectangular shapes. Most parquet floors are formed into a block as a solid unit or as a layer of veneer laminated to a plywood base with adhesive. Most solid units and laminated blocks are tongued on two adjoining sides or opposite edges while the other two sides are grooved assuring alignment with other blocks to form the larger pattern. These blocks have the same conditions as any wood flooring. They must be treated as so and installed properly.

**Stone Flooring**

Stone flooring typically consists of limestone, sandstone, polished marble or granite, and split-face slate. When using stone flooring there are many factors to consider. The subfloor must be able to support the weight of the stone because stone is typically ½” thick and weighs about 7.5 psf (pounds per square foot). Other considerations should be given to the color and texture of the stone finish and its abrasion and slip-resistance. The stone can be cut and laid in any number of design patterns giving it much versatility. Stone flooring is laid in Portland cement mortar, the thickset method, much like ceramic tiles.

**Resilient Flooring**

Linoleum, the original resilient flooring, was invented in England in 1860. Resilient flooring is commonly used in all types of buildings as an economical, reliable and long lasting product produced in tiles or sheets. It is a product that springs back into place after being compressed by being walked on and can easily be cleaned without the use of chemicals or specialty products. Resilient flooring can withstand most permanent deformations or damage, but heavy furniture may cause damage without the use of adequate protection.

When considering resilient flooring, physical properties of the product must be considered. Appearance and cost are two factors that play an important part in making this decision. Resilient flooring has a vast variety of patterns, styles, designs, textures, and colors to choose from in either sheet that commonly come in 6′, 9′, 12′ and 15′ widths or tiles that are available in 12″ to 36″ squares. Because it is easy to install and economical to produce, resilient flooring is very cost friendly as well.

Resilient flooring is resistant to a number of chemicals, such as alcohols, oils and grease. Because it is a resilient material, it maintains its integrity and appearance. Since resilient flooring comes in varying hardness of finish materials, from soft to hard, heavy furniture without proper support under the legs may cause permanent damage to the flooring if the wrong finish is chosen or poor installation of the product is done. Resilient flooring also has the ability to resist the spread of fire, static electricity, and water, which makes it one of the top two most used floor coverings.
Resilient tiles are usually made from solid vinyl, a vinyl composition or rubber. Sheets are made from similar materials but provide fewer, if any, joints in the installation process. Both tiles and sheets are installed with an adhesive applied directly to the clean and level subfloor whether wood or concrete. Since the tiles and sheets are thin, usually 3/32”, all holes and blemishes in the subfloor must be filled, sanded and leveled before installation of the flooring. Any debris or abrasive left on the surface of the subfloor can cut through the resilient flooring over time.

Other types of resilient flooring include cork tiles and static-control flooring. Cork can be sanded, left natural, waxed, stained, or coated with acrylics or polyurethane, which makes it unique. With static control flooring it is imperative to direct the electrical charge to a reliable grounding source rather than through sensitive equipment in areas like manufacturing plants, surgical rooms, computer and electronics labs, and explosive environments. Static control flooring is available in many styles and colors.

**Carpet**

Carpet is the other one of the two most popular floor coverings along with resilient flooring. It is widely used in commercial and residential construction because of cost, maintenance, and durability. Carpet is available in nearly every color and a wide range of fibers and textures. Because it comes in many widths, it can cover a large area quickly, add comfort and warmth to an area and provide soundproofing by reducing noise and sound reflection.

Pile fibers are made from both natural and synthetic materials such as wool, a natural fiber, and acrylic, modacrylic, nylon, polyester and polypropylene or olefin, all synthetic fibers. Wool is a strong fiber with good resistance to damage caused by sunlight, aging, and abrasion, and is mildew-resistant as well. Since most households and businesses replace the carpet within a 5–10 year period, wool is one fiber that with good care can last much longer and be very cost effective in time. The synthetic fibers share many of the same qualities. Most are resistant to mildew, fading from the sunlight, aging, and chemicals. They are soft, resilient, soil resistant, and quick drying.

Carpet construction includes woven carpets using the Axminster, loomed, velvet, and Wilton methods. Methods of construction other than weaving are the tufted, knitted, flocked, and fusion bonded construction. Although each is somewhat different from the other, what is common is the terminology used. Pile yarns are the exposed top of the carpet that takes the wear and tear and are made from the fibers previously mentioned. The backing yarns are made of weft yarns, meaning the yarn runs the width of the carpet, and the warp yarns that run the length of the carpet. Stiffer yarns also run the length of the carpet, adding strength and stability.

The Axminster construction method is woven on a loom and is cut pile of an even height. This is what is commonly called a plush carpet. After a carpet is completed using this method it is so stiff and heavy that it can only be rolled lengthwise. Loomed construction creates a carpet that has a low-loop single level pile that is bonded to a thick rubber cushion. Velvet construction can produce a textured surface or tweed effect but cannot produce a patterned design. The last of the woven carpet methods is the Wilton looms that can produce embossed textures or sculptured finishes by adjusting and cutting the pile.

Carpet making methods, other than those woven on looms, include the tufted construction method that takes the pile and stitches it, much like a sewing machine, onto a backing material. It is then coated with
a latex-bonding agent and attached to a second backing material like course jute. Tufted carpets are available in many different styles. Knitted carpeting is made by looping the pile, stitching and backing into one operation, then spreading latex onto the back of it to bond it all together and give it added strength. Flocked construction electrostatically sprays strands of pile onto an adhesive coated backing. As the pile becomes embedded it stands up vertically, then a second backing is added to the whole thing and it is left to cure. The last method is fusion bonded construction where the pile is fed through two sheets of parallel backing then cut in half and divided into two where a second backing is added to each piece.

Carpet has to meet specifications established by the Federal Housing Administration, the American Standard Testing Materials, and the General Services Administration. These specifications include:

- pile yarn weight (W), which is the average weight of pile yarn in ounces per square yard without any backing
- pile thickness (T), which is the height of pile tufts above the backing in inches
- pile density (D) which is the weight of the pile yarn per unit of volume in the carpet, stated in ounces per cubic yard

Carpet is often installed over a cushion to increase the life of the carpet, make it softer to walk on, reduce noise and add insulation. Some carpets have a cushion attached to the back of them made from foam that often adheres to the subfloor when trying to remove the carpet so it can be replaced. Cushions are made of urethane foam, cellular rubber, felted animal hair or jute and can be installed over nearly any dry, clean surface including other floor finishes as well as uneven or irregular surfaces.

Most residential sheet carpeting is cut to size, stretched and installed using wood tackless strips that have been attached around the perimeter of the room to hold the carpet tightly in place. Carpet can also be bonded directly to the subfloor with mastic or bonded to the cushion after it has been bonded to the subfloor.

**Special Flooring**

Resinous flooring has become more popular as the chemical technology that it takes to produce it has improved. It is applied in its liquid form and when cured provides a uniform surface that is flexible and seamless. Although the flooring is thin, it has excellent bonding features, is strong and is resistant to impacts and abrasion. There are three systems:

- Decorative system, where aggregates are combined in an epoxy resin matrix
- General commercial and industrial systems, which are similar to the decorative system, where the aggregates are combined with a thicker and high performance epoxy
- High performance or special use systems, which are formulated for specific environmental exposures

Floating floors such as laminated hardwood flooring use a wood veneer with an acrylic topcoat over pressed board or plywood that resists scratching and marring of the surface. These look so similar to hardwood flooring that it is difficult to tell the difference without close inspection. These floors float
over a cushioned water resistant membrane. A unique tongue and groove design allows them to snap together easily. Replacing them is easy when damaged. They also come in strips, planks, and blocks for a variety of styles and finishes besides wood.

Other floors include cushioned hardwood floors used for gymnasiums, auditoriums and dance studios. The base is usually concrete covered with a 6-mil vapor barrier, rubber pads on top of the vapor barrier, and wood sleepers that lie on top of the pads. To complete the floor, the strip hardwood flooring is placed on top of the wood sleepers.

Access floors are included in this category. These floors consist of modular floor panels placed on top of metal adjustable pedestals. This allows room for mechanical equipment to run underneath the floor as well as overhead.

There are also brick floors, which are great for sunrooms, kitchens, recreation areas, and rubber floors, which are used around swimming pools and athletic locker rooms.

**Acoustical Treatment**

Controlling sound within a building is critical in the design of our residential and commercial spaces to help maintain a healthy, enjoyable environment in which to live and work. Acoustics is the science of controlling noise. Some of the first applications occurred in the design of old opera houses and the now highly technical arenas and concert halls. Sound control is critical in hospitals and health care facilities, recording and broadcast studios, theaters and media rooms. More common is the need for acoustical control in multi-unit dwellings, residences, and small businesses. The average household is inundated with many sounds on a daily basis, such as the air conditioner or furnace cutting on and off, the refrigerator, dishwasher, washing machine and clothes dryer on the interior, and from the exterior, the lawn care equipment, traffic, and airplanes overhead.

Acoustics are analyzed from the exterior envelope of the building to the interior and back. The critical areas of sound transmission come from roofs, eaves, walls, windows, doors and penetrations through these areas for venting or any other purpose. Sufficient control demands good design considerations based on building usage and building code.

Interior spaces can be enhanced with sound absorbing and reflecting properties used on walls, ceilings, and floors. Ideal acoustical substrates are those without a face or finish material that deflects rather than absorbs the sound. Covering the acoustical substrate with fabrics will heighten the acoustical absorption and improve the quality of the surrounding environment in the process. Mineral fiberboard is a common substrate used with fabrics, wood, or acoustical tile to control the acoustics within the room. In order to improve and control the acoustics, architects and designers must use materials that deflect and absorb sound, blocking it with wall placement and general layout and covering it up with background sound, which is the least disruptive and the most economical.

**Acoustical Ceilings**

Acoustics include the generation, transmission and effects of sound waves. Acoustical materials are used to control these sound waves within a given area. Since sound is the sensation produced by vibrations being transmitted through the air to the human ear and it travels in all directions from its
original source, then it must be understood how it works to be able to control the noise it makes. The frequency of sound is measured in the number of cycles of like waveforms per second, and wavelength equals the velocity of the sound divided by its frequency. The frequency of sound ranges from low to high and varies rapidly and constantly. Sound intensity then depends on the force that sets off the sound wave vibration. Sound transmission class (STC) is a single number rating. This number represents the effectiveness of a material or an assembly of materials such as a ceiling to reduce the transmission of sound through it.

To help isolate an area and reduce the noise level from the surrounding sounds, the ceiling needs to be built free of any rigid attachment to the building structure. To simplify it, ceilings should be suspended from rather than attached directly to the roof. Ceiling isolation hangers isolate ceilings from noise traveling through the building. The hanger wire is then attached to this and to a t-section for a perforated metal ceiling, to a carrier for a linear metal ceiling or furring channel, and to a main runner for a metal pan ceiling. Sound absorption will depend on the amount of batt insulation used above the metal ceiling. More common grid systems will have a hanger attached to a cross T or T-spline and main runner. Then the 2′x2′ or 2′x4′ acoustical panels are slid into the grid system.

Acoustical ceiling tiles are made from soft, sound absorbing materials like cork, wood fibers, sugarcane fibers, mineral wool, gypsum, and fiberglass. Most ceiling tiles are perforated to allow more sound absorption and less deflection. Another type of ceiling panel is known as a baffle. Baffles are acoustical panels hung from the ceiling to reduce airborne noise that can be generated in a school gymnasium, auditorium or restaurant. Other ceiling tiles may be glued, nailed, or stapled directly to a gypsum board ceiling or to furring strips attached to the ceiling joists.

Suspended ceilings using a grid system are the most common form of installing an acoustical ceiling. Common suspended ceilings fall into three types; the exposed grid, semi-exposed grid and concealed grid. Exposed grids have the main runner and cross runner exposed. This type of grid can enhance the ceiling design depending on the finish applied to the grid system. The semi-exposed system has the main runner exposed but the cross runner is concealed giving the finished ceiling a very linear look with all the parallel lines. The concealed system has no runners exposed giving the impression that the ceiling is attached to rather than suspended from the roof or ceiling joists.

**Acoustical Wall Treatment**

The sound absorbing materials and placement of walls within an area help control the effects of sound waves. Acoustical plaster, used to finish walls, is made with perlite or vermiculite aggregate that is most often sprayed onto the walls rather than applied by hand. Another spray-on material is a bonding agent composed of cellulosic fibers. The advantage of these two materials is that they can reach and completely seal a wall surface that is curved or one that is irregularly shaped.

Another product that is available in many sound-absorbing materials is a wall panel. Many are made from molded mineral fibers and covered in fabric that is attached to a standard wall surface. These panels can also be fire-resistant and may be seen in gymnasiums, indoor swimming pools and offices, in the form of cubicles or pre-fabricated walls, or restaurants as dividers and backdrops, to name just a few of their uses. Sculptured acoustical wall units, made from high-density molded fiberglass bonded to a sound-absorbing glass fiber blanket is used as decorative sound-absorbing units and can typically be found in many shapes.
Special Wall Surfaces

Interior walls and partitions in commercial and residential buildings are usually non-load bearing and are there to meet the needs and requirements of the owner and the occupants needs. Interior walls and partitions may be load bearing as well and can be constructed with wood, metal or masonry. Many types of finishes can be applied to the framing and that surface may be finished with another more decorative finish.

Walls and partitions function to divide a building into different areas of use according to its occupancy and to hide mechanical and electrical equipment that may run through the cavity. In addition, walls and partitions provide sound-control, fire, and smoke protection, insulation, privacy, and protection.

Specialty walls include firewalls that are built to restrict the spread of fire. They must extend continuously from the foundation to or through the roof. This height will be specified by code. Smoke barriers are fire resistant continuous membranes that run from one exterior wall to the next, and from the floor slab to either the roof or the floor slab above. Doors in these walls must meet special code requirements and have automatic closers when smoke is detected.

Paints, Coatings, and Stains

Many types of paints, coatings, and stains exist including oil based and water based paints, varnishes, lacquers, and special purpose coatings, and oil based and water based stains. There are opaque finishes, transparent finishes, and special purpose coatings that include high-performance coatings, graffiti resistant coatings, fire-retardant coatings, and elastomeric coatings.

Paint is an opaque coating made from a mixture of solid pigment and a liquid medium. The liquid medium consists of a volatile solvent (thinner) and a binder that bonds it all together during the drying process. Applying an opaque coating will hide the grain and texture of the substrate. Roll, brush or spray paint onto the substrate. For decorative purposes, there are other application methods to apply paint such as rags, burlap and sponges for special techniques and finishes.

Primer is an opaque coating that must be applied to the bare surfaces of the substrate (wood, drywall, plaster, etc.). The primer soaks into the substrate so that subsequent coatings will bind to its surface allowing for better coverage and durability. The intermediate coat is applied over the primer and the top coat finishes the three-step application of paint. Depending on the color, the condition of the substrate and the amount of pigment in the paint that is chosen, more than one top coat may be required. In the case of smoke or water damage to the substrate, a sealer that will eliminate the odor from the smoke or the stain that water damage creates can be used before or after the primer coat is applied, thereby keeping the odor and stain from bleeding through the final top coat.

Paint and other coatings are regulated by the 1992 Residential Lead-Based Paint Hazard Reduction Act and the 1970 Clean Air Act. Lead, found to be hazardous to children and animals, is no longer used in paints. Homes must be inspected for lead paint and contractors who are exposed to lead paint must wear respiratory protection and protective clothes. The 1970 Clean Air Act regulates the emissions from products that produce volatile organic compounds (VOCs), which include paint and other coatings. VOCs are any substance that evaporates from paint or other coatings as they dry, except for water.
To have consistency in a coating, the paint must be applied at a uniform thickness called the minimum wet film (MWF). The MWF varies due to the spreading rate per gallon of paint. On the other side, the minimum dry film (MDF) determines how much protection will be provided to the substrate.

When choosing paint or another coating to finish a substrate, several factors affecting the coatings need to be considered. Water and high humidity should be considered when choosing a coating for a bathroom, kitchen, basement, or garage. Solar radiation streaming through windows and doors can cause the paint to fade, expand, and contract. Dust and dirt around the baseboard, door or windows may cause exposure to abrasion in these areas. Sometimes chemical reactions like efflorescence can come through the mortar and concrete causing paint to bubble and become soft until it flakes off the substrate. If the substrate is too hard or smooth, the paint and other coatings may not absorb into it enough to adhere and protect it without the proper preparation. To paint over old coatings, the new paint must be compatible with the old. Water based coatings can be used over an oil based or water based coating, but an oil based coating can only be used over another oil based product. The old coating must have all loose paint removed; cracks and holes repaired, and substrates must be in good condition to have a new paint applied.

Many paints can be selected when determining the conditions of the substrate:

- Oil based paints that harden to form a tough elastic film
- Alkyd paints that have an alkyd resin added to them
- Latex paints that have a binder of acrylic resin
- Epoxy paints that have an epoxy resin that acts as a resistor to chemicals, corrosion, or abrasion
- Rust inhibiting paints with anticorrosion pigments
- Fire retardant paints with silicone, polyvinyl chloride, or other substance
- Intumescent coatings that when heated turns into a thick layer of inert foam that slows the spread of flame and silicone resin used in areas exposed to high temperatures

Another coating is varnish made from a natural resin dissolved in alcohol (spirit varnish) or oil (oil varnish). New varnishes available are made from synthetic resins (plastic) like alkyds, polyurethane, silicone, epoxy, acrylics, and phenolics. Natural varnishes fall into three basic types: linseed oil varnishes, tung oil varnishes, and spirit varnishes or shellac. Turpentine, mineral spirits, naphtha and benzene are used as a solvent for varnish.

Varnishes are usually dark in color and can be brushed, rolled or hand-rubbed onto a wood substrate. Caution needs to be used when overlapping because each coat darkens the wood more but still allows the natural grain to show. The synthetic resin varnishes are used where a hard, durable finish is required. These varnishes have excellent resistance to yellowing with age, ultraviolet rays and oxidation. They are also resistant to many caustic materials and abrasive situations as well as high heat and water.

Lacquer is another synthetic coating that dries with a very high gloss finish. Most lacquers are sprayed on and many coats are required. It is widely used on cabinets, casework and furniture as a finish.
Special purpose coatings are those formulated to meet a special need such as bituminous, asphalt, reflective, and fire retardant coatings. Bituminous coatings mix up natural bitumens in an organic solvent that can be used to coat roofs because it is water resistant. Asphalt coatings, made from petroleum, have good water resistance and are often used on driveways and exterior foundation walls. Coatings on signage, stairs and walkways use reflective coatings that absorb light and reflect it back. Pigmented and intumescent fire retardant coatings are applied to any type of wood based substrates and delays contact between the flames and the substrate, giving occupants more time to evacuate.

Stains provide color to wood substrates. They are blends of oil, driers, resins, a wood preservative, mildewcide, water repellant, and coloring pigment. Stains are available as oil based or water based. Stains can be applied with brushes, rollers, or hand rubbed. Stains do not raise the wood grain.

Wall Coverings

Wall coverings may include different styles of paneling finished in wood veneer, natural finishes, like marble and granite, leather, or synthetic finishes designed to be used in a variety of usages. Water-resistant panels can be used in commercial and residential situations.

Wallpaper is another type of wall covering used in both commercial and residential applications. Wallpaper can be applied to practically any substrate when properly prepared. Rolls of wallpaper come with the pattern preprinted on one side and are prepasted on the other side. It is made from many different grades of paper or cloth and the finishes can be anything from a single pattern that does not need to be matched to extremely detailed finishes using natural materials like leaves or dried flowers.

Conclusion

Residential and commercial architecture has evolved through the centuries by trial and error, ever improving upon the materials and substrates that create the environment in which people live and work. As manufacturing methods have improved, products continued to be available and affordable. Our environment will continue to improve as these and newer products are put to the test of working toward a “greener” earth.

Suggested Links

- http://www.wishihadthat.com/
- http://floorfacts.com/
- http://www.bobvila.com/
- http://greenbuilder.com/
- http://americanclay.com/
- http://artisanash.com/
• http://bellaandbirch.com/
• http://variancefinishes.com/
• http://www.servicemagic.com/
• http://reedconstruction.com/
• http://gefsconstruction.com/
• http://www.constructionway.com/
• http://products.construction.com/
• http://arcat.com/
• http://www.aecinfo.com/
• http://www.tileusa.com/profile_main.htm
• http://wrcla.org/
• http://www.simplefloors.com/
• http://floorfacts.com/
• http://improvementweb.com/
• http://www.thelaminateflooringsite.com/
• http://seemydesign.com/
• http://woodfloors.com/
• http://naturestonefloors.com/
• http://www.wikipedia.org/
• http://www.youtube.com/results?search_query=finishes&search_type=&aq=f
Chapter 20

Furnishings

Furnishings are specified as decorative items that reflect the personal taste of the occupants. Whether it is residential or commercial furnishings, good design can be recognized because it displays a quality that is both permanent and tasteful. It does not have to be in style or out, popular or not. Nor does it have to be to the liking of the observer. If the furnishing serves the purpose it is intended to, it is easily recognized by all as good design.

Furnishings include several areas of design:

- Fabrics, art and sculpture
- Casework and countertops
- Floor, wall, and window treatments
- Furniture and seating
- Lighting, interior plants, and exterior furnishings

These items are used as accessories, storage, workspaces, security, privacy, acoustical control, comfort, and aesthetics. Furnishings are designed and utilized to reflect what has been learned from the environment. It allows a feeling of rightness when surrounded by objects that reflect the occupants’ requirements and personal tastes.

Fabrics

Any material that is made through bonding, crocheting, knitting, or weaving is considered fabric. Fabric is chosen for its fiber content, weave, and pattern. Fabrics are made from either natural fibers like cotton, linen, silk, and wool, or from synthetic fibers like fiberglass, acetate, acrylic, modacrylic, nylon, and polyester.

Weaving is an ancient art that uses fiber to create fabric through handlooms or power looms. Weaves are classified into three types:

- Plain weaves: plain and basket weaves
- Floating weaves: twill and satin weaves
- Pile weaves: cut and uncut weaves

Patterns are created by the weave of the fabric. Artistic patterns have been developed for many centuries in an endless array of color.

Stability of color, as well as soil and fire resistance are also important factors to be considered with fabrics. If poorly made, colors will fade quickly, so textile manufacturers must choose dyes and
chemicals that produce a product that is known to be colorfast. Standard tests specified by the Bureau of Standards help assure that the fabric is truly colorfast and certified against color fading. New processes have made fabric more resistant to soil and fire. Although no fabric can last forever, finishes used to protect it from everyday soil will help extend its life because it will require fewer cleanings and be handled less.

Art

Art began as rock painting in prehistoric times. As civilization grew, the means to produce art objects improved, creating art that has been preserved and passed down through generations. To our generation it seems natural that wall, floor, and ceiling surfaces invite some form of art to accent or draw attention to the space.

Art is a meaningful, aesthetic piece that complements and shares its surroundings. It is a desire to show or feature a picture, sculpture, or other piece of artwork in a way that highlights the object. Art should be chosen not only for its content or sentimental value, but also for its suitability in size, scale, and location.

Paintings and sculptures may be from any period and be entirely appropriate as long as they are suitable in scale and character with the rest of their surroundings. Just because a painting or sculpture is an antique, or by the latest artist, does not mean that it will be a good fit with the rest of the furnishings. Major paintings or sculptures become permanent parts of a building so it is important that they reflect the important and successful elements of the piece. The cost, visual importance and permanent display of good art can be a very successful element in the residential or commercial building.

Other pieces of artwork may include fabric wall coverings and murals, made from either natural or synthetic materials. Stained glass, windows of colored translucent glass that are cut into shapes that are then held in place with H-shaped lead strips, can be mounted in wood or metal frames and used as room dividers, windows or doors treatments. Whatever form of art is chosen it is important to keep in mind the form, scale, style, texture, color and light that will create a good fit within the space whether residential or commercial.

Manufactured Casework

Manufactured casework includes stock cabinets made from metal, wood, or plastic laminates, as well as countertops, sinks, and any fixtures or accessories mounted to the countertop. Cabinets can be found in many styles, sizes and finishes. Adequate storage provides space for possessions that are not for public viewing and open spaces to display objects that the occupants want to share.

Casework may be freestanding storage as in a chest of drawers, china cabinets, filing cabinets, hutches, and wardrobes. It can also be built-in storage units. These units have the advantage of maximizing storage space in small areas. Casework may be used in many spaces in residences as well as in commercial applications.
Specialty Casework

Specialty casework is used in educational facilities and includes file cabinets, overhead storage, lab counters, under-counter storage, supply cabinets, and trophy cases, etc. Offices may require display cabinets and presentation cabinets. Retail facilities require showcases, and hospitality facilities require full kitchens and countertops to meet the demands of their customers. Recreation facilities require cabinetry to store equipment, and medical facilities need counter space, storage files, and an assortment of casework to store supplies to meet the needs of their patients. In personal service facilities, casework and countertops are needed to mix chemicals, keep equipment within reach, and to store products safely and also needed are display cases for products and magazine storage for the entertainment of their clients.

There are many manufacturers of casework specializing in cabinets made from metal, wood, or plastic laminates. Many of these manufacturers specialize in making casework for industry or specialized facilities. Some of these specialty areas include:

- Child care
- Museums
- Airports
- Health care
- Ecclesiastical
- Arenas or stadiums
- Animal care
- Greenhouses
- Residential
- Waste management
- Distribution warehouses
- Storage facilities
- Processing plants
- Commercial
- Laboratory

Countertops

Countertops are workspaces that are mounted to the top of base cabinetry, to walls, or freestanding with a support system. They are made from natural and synthetic materials to resist chemicals, heat,
and cold. Metal countertops, especially stainless steel, are used extensively in the medical, hospitality, and food manufacturing facilities because it can easily be sterilized to protect against disease. Wood countertops can often be found in residential kitchens, workshops and garages. Plastic laminate countertops can be used in retail facilities, residential and commercial facilities, and any area that does not require cutting or use of chemicals. They are strong, durable and easy to maintain. Stone, solid surfacing and quartz countertops add quality to any application.

Office Accessories

Office accessories or similar public objects are not the home-style accessories that may come to mind but are necessary pieces that are highly functional. For example, clocks need to be where they can easily be seen, but must fit into the style and design of the space. Desk accessories, lighting, trash receptacles, floor easels, projection screens, multimedia carts, and coat racks are all necessary office accessories. Neutral accessories are provided for offices that have more than one occupant. Executive offices, having only one occupant, may have some personal accessories as well. A tastefully framed photograph of family is one common accessory. Paintings, sculpture, and plants can be designed to fit the individual taste and interests of the occupant.

Furnishing Accessories

The list of furnishing accessories in residential and commercial applications is nearly endless. Without accessories, a home would be no different from a hotel, designed to be neutral and each decorated exactly like the next. Furnishing accessories in the home reflect the passion and personality of its occupants in the objects that are collected and the hobbies they pursue. In this case, accessories can be anything with which the occupant wants to be surrounded. Functional accessories may include the screens, andirons and tools needed for a fireplace; towel bars, soap dishes and tissue holders in the bathroom; and the huge amount of accessories required to operate a kitchen.

Accessories are a unique addition to the home. When choosing them, consider their contribution to the space. Think of them in terms of mood, texture, color, size, and shape before placement. The most pleasing accessories are those that act as an extension of the space and enhance the décor.

Rugs and Mats

Entrance floor coverings include mats, grills, gratings, grids and tile. Each is used as a transition from the exterior to the interior space. The grills, gratings and grids are made from metal, rubber or synthetic materials. Tiles are usually slate, quarry or a synthetic material like vinyl. All but mats are permanent flooring. Mats are most often made from carpeting with a rubber or synthetic backing to keep it from skidding on the floor surface.

Rugs and runners are made from the same materials and the same process as carpeting, but on a smaller scale. They are used to define an area, unify seating arrangements or add drama to a space. Rugs and runners do not cover the entire floor space. Unlike floor finishes, rugs and runners cover areas of space on the floor over top of other floor finishes, including carpeting. Rugs and runners are economical, long wearing, and can easily be moved for cleaning.
Window Treatments

Window treatments are one of the most versatile of all furnishings. With window treatments a view can be emphasized or disguised, dominate a wall or blend into it with style. They can help insulate, give privacy, and control light that enters into the space. There is really no limit to the originality of what can be done with window treatments.

Window treatments include curtains, draperies, and their hardware and accessories. It also includes blinds, interior shutters, and shades. Since there are many types and styles of windows that operate in different ways, there is no single solution when it comes to window treatments.

Blinds

Venetian and other blinds have long been accepted as a functional window treatment. Venetian blinds are traditionally wood slats supported by tapes and maneuvered by cords. The Egyptians started using them in ancient times and they have been used as a window treatment ever since, as popular today as then. In today’s market, Venetian blinds are made with a variety of woods, plastics, and metals in widths from 1/2” to 2” wide.

Other blinds may include woven wood or aluminum blinds. Woven blinds are made with thin strips rolled from the bottom with cords allowing some light to penetrate. The thin strips are usually colored or the thick strips of cloth that are woven into the blinds are colored. Split bamboo blinds hang vertically and operate like draw draperies. Other vertical blinds operate as movable louvered, similar to a Venetian blind on its side. These blinds are made of wide strips of translucent plastic or fabric and are installed so they can be drawn to one side of the window. Vertical blinds are very popular in commercial application because of the large expanses of window to cover in curtain walls. They are also used in residential applications to cover large windows and doors.

Shutters and Hinged Panels

Shutters are difficult to install and although they come ready-made, the shutters or panels will more often have to be custom made to fit the many different sizes and styles of windows. Shutters have fixed or louvered slats or space for shirred fabric panels. Some shutters have inserts backed with fabric. Panels are similar to shutters in that they can open and close. Panels are usually plain and can extend from floor to ceiling, from windowsill to window top or to any length, the occupant desires. Advantages of shutters and panels are that they provide privacy and if louvered, allow ventilation.

Shades

Shades have been a decorating accessory for centuries. They control light from filtering it to blocking it out. Shades can be hung with other window treatments and practically disappear when open. Their insulating powers and thermal control make them environmentally friendly and prove to be a major factor in energy conservation.
There are three basic types of shades:

- Roller shades
- Roman shades
- Austrian shades

Roller shades are a strip of material that hangs from a spring-loaded rod placed at the top of the window frame. They are made from many types of materials. Translucent ones will allow some light to come through while opaque ones will completely block the light. Both are durable, washable by hand, and resistant to tearing, water, and fire. Pull-downs, attached to a wood slat sewn into the bottom hem of the shade allow for decorative finishes to the shade.

Roman shades are usually made from rich, heavy fabrics that are used as the sole window treatment. They are on pulls, much like the Venetian blinds. The fabrics lay flat when extended and pleats into horizontal layers when the shade is raised. Roman shades have Velcro or snap-tape attached to back of the shade that is then attached to either a spring tension rod or board that is mounted onto the window frames.

Austrian shades or balloon shades operate on the same principle as the Roman shades. Vertical cords are threaded through rings that are attached to the back of the shade at equal spacing across the width and height of the shade. The cords are attached to the bottom ring and then pulled through each ring above it until the cord reaches the top ring in each column. When each cord has reached the top ring, all cords are threaded through the top ring horizontally from right to left for a right hand pull down or vice-versa for a left-hand pull down. When the cords are pulled down together, the fabric lifts elegantly up into graceful scallops of beautiful fabrics.

Curtains and Draperies

Curtains and draperies are available in floor length, sill length and apron length unless custom-made. They can be used alone or with an assortment of accessories like sheers, swags, valances and cornices. Curtains and draperies can be hung straight from a curtain rod or with drapery hardware and pulled back with decorative holders or fabric tiebacks. Curtains are designed with pockets in them at the top to allow a curtain rod to be inserted through it so that they can be hung. Draperies are most often designed with accordion pleated tops. Drapery pins are inserted into these pleats and then hooked into the drapery hardware where they can be opened and closed either manually with cords or electronically by remote control.

Formal curtains and draperies include glass curtains (sheers), draw draperies and drapery panels. Glass curtains or sheers hang straight down from a rod behind the formal curtains or draperies next to the glass. They provide some privacy during the daytime and soften daylight. Draw curtains are designed for privacy and can be opened or closed using drapery hardware. Drapery panels are narrow panels of fabric that cannot be drawn. They are for decorative purposes only.

Informal curtains include shirred, ruffled and café curtains. Shirred curtains hang directly on rods that are installed at both the top and bottom of the window inside the frame. The curtains are wider than the window by two or more times and are gathered onto both rods then shirred (aligning the curtains in
a pleasing pattern). Ruffled curtains usually have ruffled hems and some have ruffled inside edges. They have ruffled valances and tiebacks as accessories to finish the effect. Café curtains are straight curtains hung from rings or tabs that slide along café curtain rods. They can be tiered to cover an entire window or hung only on the bottom half of the window with a valance hung at the top.

**Commercial Furnishings**

Commercial furniture includes any furniture needed for privacy, storage, work surfaces, shelving and lighting. This includes furniture needed in educational facilities, offices, retail, hospitality, recreational, medical, personal services and exhibition facilities to name but a few. When thinking about a facility’s needs, imagine all the different area that need furniture and what the furniture requirement may mean.

For example, an entry to any business may need a desk with locked storage, shelves for books and rosters, an ergonomic stool or chair, and a bulletin board for important information. In a waiting room, seating for fifty people means multiple chairs and sofas, side tables and lamps, magazine and bookracks, a serving table for coffee and water, seating and a play area for children, artwork, plants and many more accessories. An administrator’s office may need a computer ready desk, file cabinets, overhead storage, an executive chair, guest chairs, task lighting, and a conference table with chairs.

Each facility requires furniture suited to its function. Some require kitchens and commercial appliances, lockers, mail distribution centers, and specialty furniture for music rooms, art classes, shop classes, detention rooms, libraries, and multimedia rooms.

Healthcare facilities need furniture like hospital beds, visitor seating, nightstands, consoles, wastebaskets, and dispensers for paper boots, latex gloves, and eyewash. Architectural facilities need drafting boards, CAD stations, plotters, printers, drafting chairs and glare free lighting. Retail facilities offer customer comforts like sofa, coffee tables, chairs, bars and seating, clothes hooks and mirrors in dressing rooms. The retail store may need clothing racks, heavy-duty shelving, shoe racks, and furniture for the employees lounge area. Each commercial facility requires furniture that meets both the need of its employees and its clients.

Character, comfort, and scale should determine how a piece of furniture fits into any situation. An understanding or working knowledge of materials and finishes are an asset when choosing furniture for any facility. When choosing furniture make sure it is comfortable, sturdy, of good quality, and fits into the space and style of the facility.

**System Furniture**

System furniture consists of panels and components that include work surfaces, shelves, drawer units, flipper doors, file units, task lighting, tack surfaces, pencil drawers, file pedestals and box pedestals, to name a few of the options available. The panels are acoustically designed and most are hardwired for electricity, cable, and phone lines. They can be arranged in many different styles, come in several heights and lengths, and can be matched to any décor.
Multiple Seating

Multiple seating is furniture that is required to accommodate audiences. It includes fixed seating used in theaters, schools, auditoriums, restaurants, and the pews and benches used in churches, to name a few. Another type of multiple seating is stadium and arena seating that includes both bench seating and individual seating. Restaurant style booths and tables, multiple use fixed seating, and telescoping bleachers and chair platforms, often found in school gymnasiums are included.

Residential Furniture

Furniture is the nucleus around which all other accessories revolve. A major purchase such as furniture is one that the owner will have to live with for a long time. Furniture is a personal product that is loved or hated and potentially passed on from one generation to the next.

Although crude forms of furniture have been around since there have been tools, the first known development of freestanding furniture lasted from about 1100 to 1500 CE and is called Gothic. As tools improved and fabrics became more available, furniture making prospered, becoming a respected craft throughout the civilized world. Even then, most of the ornate furniture found in our museums was made for royalty or nobility rather than the common person. That is why so much furniture is named after the reigning monarch of the period. Most of the furniture we are familiar with today became known in the early 1600s with English furniture and the mid 1600s with French and American furniture.

Residential furniture has increasingly become an important part of our lifestyle. The Industrial Revolution made it possible to mass produce furniture at the same time more of the world was moving into a middle-class status. Furniture was provided at reasonable cost, but it put an end to the traditional artisan.

Furniture is not made such that one size fits all. Human beings vary so much in size and weight that it is difficult to design manufactured furniture that will fit everyone. Finding comfortable furniture is a major priority when selecting it for the residence. Comfort, scale and character influence the end decision.

The many various furniture styles fall into three main groups:

- Traditional
- Country
- Contemporary

Traditional or classical styles mostly come from early European designers, specifically the French and English. Cabinetmakers built furniture designed to please those who commissioned them. Traditional styles are sometimes identified by the cabinetmaker that built the furniture or the reigning monarch of the time. Country styles are similar to traditional but more simplified. The furniture is considered more casual and less ornate although its function is the same.

Country styles were more often named for their geographical region such as American Colonial, English Country, American, Italian and French provincial. Folk styles included Shaker and Pennsylvania Dutch.
Contemporary or modern styles evolved from Scandinavian designs and German Bauhaus designs. The Scandinavian designs reflect the bold style that emphasizes the single sculpted lines of natural wood. The German Bauhaus style was more interested in producing furniture that could be mass produced. Designs evolved around modular steel and laminated woods. Today’s modern furniture styles are developed with modern needs and technology in mind.

There are many popular styles of furniture. Taking the time to study the characteristics, quality, and manufacturer of any style ensures that a good solid choice is made when selecting pieces for any room in a residence.

**Interior Planters and Artificial Plants**

Live and artificial plants are used extensively in commercial and residential buildings. They assist in the process of air exchange, add humidity to the area and are aesthetically pleasing. For example, it can be quite pleasing to walk into a mall in Minnesota, in the middle of winter, and be greeted by palm trees from Florida. With interior landscaping, summer or winter can be brought inside all year long.

Interior landscaping has grown in acceptance as much as interior design. It requires knowledge of plants, planters, landscaping tools and maintenance of the plants. Interior landscapes can be designed to help cool atrium spaces, improve aesthetics throughout any interior space, and brighten small areas. Because live plants require light they are always found where they could receive lots of natural light or in an environment where artificial light can enhance the décor of the area.

Live plants must be replaced at the end of their life cycle. In large commercial buildings such as hotels and restaurants, it can be a full time job replacing or replanting live plants. Because of this, many companies and homeowners have opted to have artificial plants instead. With all the fabrics that are available, it has become difficult to distinguish between live and artificial plants. Maintenance is still required but those who suffer from allergies can still enjoy the beauty that plants bring to an environment.

Keep in mind that just any plant may not create the effect or drama that the owner wants to create; therefore it is important to make sure that the scale, texture, size, and form of the plant complements the rest of the décor.
Chapter 21

Exterior Improvements

In addition to a building being placed on a site, several other features and structures will be included. The designer and the construction manager must be familiar with these. The following is a list of the major categories:

- Parking lots
- Walkways
- Vegetation
- Irrigation Systems
- Athletic Fields
- Parking Lots

Building sites are required to provide off-street parking spaces for automobiles. The number of parking spaces is specified by zoning codes. For example, a doctor’s office requires a different number of spaces as compared to a small retail store. Large campuses such as hospitals or colleges may have enclosed parking structures. Paved surface parking lots are common for midsized uses. New single family homes are required to provide one or two parking spaces. Commercial and institutional buildings are required to develop parking spaces reserved for the handicapped. These spaces must be located near building entrances for ease of accessibility.

In designing parking facilities, lighting for night time security must be considered.

The materials used to build lots can be simple crushed stone, asphalt concrete; or Portland cement concrete. Since containment of rainfall runoff is an important consideration in site design, new paving materials are being designed that allows adsorption of water. LEED certification points can be generated with these new innovative approaches to paved surface design. More information can be found at www.usgbc.org.

Walkways

The location and size of walkways should not be overlooked. Their purpose is to provide a path to connect points of interest for pedestrians. These are generally constructed of hard surface material so that pedestrians have a permanent surface upon which to walk, regardless of weather conditions. Walkways might be as simple as connecting a residential driveway to the front door, or as complex as including fitness walking trails on large campuses.
Vegetation

Buildings can be beautiful works of art, taking a variety of sizes and shapes, with an endless variety of exterior claddings. Intelligent, well designed landscaping can complement a building while poor landscaping can be a detriment to the final appearance.

Irrigation Systems

Good landscaping designs include trees, shrubs, and ground cover that will thrive well in the particular environment. The site designer must consider the amount of water needed for plants to survive and thrive. When necessary, irrigation systems must be provided. Collection and storage of rainwater for use during dry spells can help in the overall control of rainfall runoff. Grey water, the waste water from a building other than toilet waste, can be a source for irrigation. Excellent discussions of this topic are available at www.greywater.com and www.usgbc.org.

Site furnishings

The interior of a building is not the only place that requires furnishings. At the residential level there are patio sets, deck furnishings, pool accessories and garden seating to name a few. Commercial buildings require much more to accommodate a large number of occupants expecting security and a pleasant experience when soliciting a business or simply coming to work. Commercial buildings may add park benches, picnic tables, bike racks, and trash receptacles. Others may add shelters, message centers and pet waste systems if they are near a park or residential area. In the parking area, owners may want to put down some speed bumps and add planters throughout the site. Site furnishings, like interior furnishings, must be scaled to the site and be a complementary style that fit well into the overall plan.

Athletic Fields

Owners of large sites may have many reasons to include athletic fields into their site design. In some cases these uses may be the main reason for the site development (for example, a golf course where clubhouses are secondary to the athletic activity). In other cases athletic fields can be complementary to the site’s main function (a baseball field on a high school site, for example). Examples of such athletic fields include:

- Baseball and softball
- Football and soccer
- Track
- Tennis

In all cases, grading is important. Outdoor athletic fields must be designed so that they shed water as quickly as possible. Spectator seating and restroom facilities may be a consideration. Use of athletic
fields can be increased by lighting. The ground cover must be a material that will stand up to the intended use. Many synthetic materials are being developed so that grass is no longer the only surface for athletic fields.

**Streets**

Public streets may be needed to provide access to the site. Civil Engineers are responsible for design. Factors to be considered are the width of the street (dependent on the expected traffic), grade or steepness of the street and the collection and disposal of the increased storm water runoff created by the additional hard surface.

Street surface materials can be rigid pavements or flexible pavements. Both can be excellent pavement surfaces but care must be exercised during construction in order to insure long life.

Portland cement concrete is normally the material considered as rigid pavement. Concrete has high compressive strength, which means it can support heavy loads, but it has little or no flexural strength. If the soil base under the concrete surface is not properly prepared to support the heavy loads transferred from traffic to the pavement, structural failure will occur. Pavement will crack and settle, creating a rough surface. Therefore care must be used in preparing the soil (or base material).

Asphalt concrete is the material generally associated with flexible pavements. Since the cementing material is liquid asphalt that has some flexibility and give, the pavement will bend but not break when loads are applied. The soil and bases under asphalt pavement should be compacted just as much as that under Portland cement concrete, but due to its characteristics, it will not immediately break as the rigid surface will. More information can be found at [http://www.flexiblepavements.org/](http://www.flexiblepavements.org/) and [http://www.hotmix.org/index.php?option=com_content&task=view&id=330&Itemid=1](http://www.hotmix.org/index.php?option=com_content&task=view&id=330&Itemid=1).

The critical component of structural strength of pavements is the strength of the underlying soil (subgrade). This should be extended to parking lots, walkways and any other hard surfaces constructed on a site.

**Driveways**

Any site must have access to public streets. Streets may have to be constructed to give access to a site, or they may already exist. In either case, there must be vehicular access from the public street to the site and parking areas. These too can be made of rigid or flexible pavement. They can be as simple as a driveway to a single family home or a very elaborate entry to a large complex.
Traffic Control

Traffic control devices may be needed to direct traffic around large commercial sites, from electric traffic control to regulatory signs. See http://mutcd.fhwa.dot.gov/Signs/.

Waterway and Marine Construction

Construction around large bodies of water creates a unique discipline of construction. Buildings and the other structures on a marine site must be protected from the power of water, both during construction and after. While this text will not go into detail on this subject, topics that can be explored are:

- Cofferdams
- Dredging
- Waterway bank protection
- Revetments
- Seawalls

Conclusion

This section has introduced a wide range of information that is part of developing the land on which a building is to be located. Many subjects are introduced and all should be explored further beyond this text. Several links to websites have been listed here, but the research possibilities are unlimited.

Suggested Links

- http://greatmats.com/
- http://greenbuilder.com/
- http://homeownernet.com/
- http://www.servicemagic.com/
- http://gcfinish.com/
- http://www.constructionway.com/
- http://products.construction.com/
- http://www.art.com/
• http://housefabric.com/defaultproduct.asp
• http://arcat.com/
• http://arcat.com/
• http://sysfurniture.com/
• http://furniturequest.com/
• http://www.everythingfurniture.com/encen.html
• http://www.furnituremanufacturers.net/
• http://improvementweb.com/
• http://countertop.com/