History and Basic Concepts

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1.1 Bridges and History

Water crossings have always been seen as great engineering achievements. Since Roman times, bridges and various river crossings have played a major role in history. Apollodorus was chief engineer for the Roman Emperor Trajan and built a bridge across the Danube River in the second century AD. This bridge allowed Trajan and the Roman Empire to invade Dacia and annex the territory of modern-day Romania.

The length of clear span bridging was greatly increased by the development of the cable-supported suspension bridge. The world’s oldest vehicular steel cable bridge in continuous use (without failure) was built by John A. Roebling in Cincinnati, Ohio, during the Civil War. It is still one of the major arteries connecting Cincinnati with Covington, Kentucky.

When construction started in 1856, the charter authorizing the construction required a clear span of 1,000 feet between two towers, with the deck located a minimum of 100 feet above the water’s surface. The bridge was completed in 1866. The 1,057-foot main span was, at the time, the longest in the world. It was one of the first suspension bridges to use both vertical suspenders to support the deck and diagonal cable stays that radiated from the top of each tower. This innovative use of cable stays gave the bridge great rigidity and resistance to movement during high winds. Roebling used this same concept later in the design of the Brooklyn Bridge.
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The bridge was upgraded to its present configuration in 1894 (Figure 1.1). A second set of 10.5-inch cables was added to carry heavier decks. The reconstruction increased the carrying capacity of the bridge to a 30-ton limit. As a native of Covington, one of the authors rode both trolley (street) cars and electrically powered buses hundreds of times to the transit terminal in Cincinnati located at the north end of the bridge. In 1984, the bridge was named the John A. Roebling Bridge.

World famous bridges have become a symbol of civil engineering. The Golden Gate Bridge in San Francisco has not only been hailed as a tremendous engineering achievement but also a beautifully balanced aesthetic achievement. Plans are now underway to bridge the famous Straits of Messina between the toe of Italy and the island of Sicily. This bridge will have a clear span of almost 2 miles, approximately 10 times the span of the Roebling Bridge in Cincinnati. It will also be designed to resist hurricane-force winds. Construction of this bridge will rival the construction of the Channel Tunnel connecting England and France.

1.2 The Historical Impact of Construction

Construction and the ability to build things is one of the most ancient of human skills. In prehistoric times, it was one of the talents that set Homo sapiens apart from other species. Humans struggled to survive and sought shelter from the elements and the hostile environment that surrounded them by building protective structures. Using natural materials such as earth, stone, wood, and animal skins, humans were able to fabricate housing that provided both shelter and a degree of protection.

As society became more organized, the ability to build things became a hallmark of the sophistication of ancient civilizations. The wonders of the ancient world reflect an astounding ability to build not only structures for shelter but also monuments of gigantic scale. The pyramids and Greek temples, such as the Parthenon (Figure 1.2), are impressive testimony to the building skills of the civilizations of antiquity. Great structures punctuate the march of time, and many of the structures of ancient times are impressive even by modern standards. The great Hagia Sophia in Constantinople, constructed during the sixth century, was the greatest domed structure in the
world for nine centuries. It is an impressive example of the ingenuity of the builders of that time and their mastery of how forces can be carried to the ground using arches in one dimension and in three dimensions as domes.

In modern times, the Brooklyn Bridge and the Panama Canal stand as legendary feats of engineering achievement. They are also testimonies to the fact that realizing a construction project involves solving a multitude of problems, many of which are not technical. In both the Brooklyn Bridge and Panama Canal projects, people-centered problems requiring great innovation and leadership were just as formidable as the technical problems encountered. To solve them, the engineers involved accomplished “heroic” feats. The stories of these two construction projects are told in the following sections.

1.3 Great Captains of Construction

The Roebling family as a group can be credited with building the Brooklyn Bridge during the period 1869 to 1883. It was the greatest project of its time and required the use of technology at a scale never before tried. The concept of a cable-supported suspension bridge was perfected by John A. Roebling (Figure 1.3). Roebling was born in Germany and was the favorite student of the famous philosopher Hegel. Roebling was a man of tremendous energy and powerful intellect. He built a number of suspension bridges, notably the John A. Roebling Bridge in Cincinnati (which is still in daily use), that demonstrated the cable-supported concept prior to designing the Brooklyn Bridge. Upon his death (precipitated by an accident that occurred during the initial survey of the centerline of the bridge) his son, Washington, took charge.

Washington Roebling (Figure 1.4) was a decorated hero of the Civil War who had received his training in civil engineering at Rensselaer Polytechnic Institute. Like his father, he was a man of great vision and courage. He refined the concepts of caisson construction and solved numerous problems as the great towers of the bridge rose above New York City. Because he would not
require anyone to work under unsafe conditions, he entered the caissons and supervised the work personally. He ultimately suffered from a mysterious illness related to the fact that the work was carried out under elevated air pressure in the caissons. We now know that this illness, called “the bends,” was caused by the absorption and rapid exit of nitrogen from the bloodstream when workers entered and exited the pressurized caissons.
Although incapacitated, Washington continued to supervise the work from an apartment that overlooked the site. At this point, Emily, Washington’s wife and the sister of a Civil War general, entered the picture (Figure 1.5). Emily carried information to Roebling’s supervising engineers on the site. She became the surrogate chief engineer and gave directives in the name of her husband. She was able to gain the confidence and respect of the site engineers and was instrumental in carrying the project through to successful accomplishment. The tale of the building of the great bridge (see The Great Bridge by David McCullough, 1972) is one of the most extraordinary stories of technical innovation and personal achievement in the annals of American history.

1.4 Panama Canal

The end of the 19th century was a time of visionaries who conceived of projects that would change the history of humankind. Since the time Balboa crossed Panama and discovered the Pacific, planners had conceived of the idea of a water link between the Atlantic and the Pacific oceans. Having successfully connected the Mediterranean with the Red Sea at Suez, in 1882 the French began work on a canal across the narrow Isthmus of Panama, which at that time was part of Colombia. After struggling for nine years, the French were ultimately defeated by the formidable technical difficulties as well as the hostile climate and the scourge of yellow fever.

Theodore Roosevelt had become president during this period, and his administration decided to take up the canal project and carry it to completion. Using what he would refer to as “gun-boat” diplomacy, Roosevelt precipitated a revolution that led to the formation of the Republic of Panama. Having clarified the political situation with this stratagem, the famous “Teddy” then looked for the best person to actually construct the canal. That person turned out to be John F. Stevens, a railroad engineer who had made his reputation building the Great Northern Railroad (Figure 1.6). Stevens proved to be the right man at the right time.
Stevens understood the organizational aspects of large projects. He immediately realized that the working conditions of the laborers had to be improved. He also understood that measures had to be taken to eradicate the fear of yellow fever. To address the first problem, he constructed large and functional camps for the workers in which good food was available. To deal with the problem of yellow fever he enlisted the help of an army doctor named William C. Gorgas. Prior to being assigned to Panama, Dr. Gorgas had worked with Dr. Walter Reed to wipe out yellow fever in Havana, Cuba. He had come to understand that the key to controlling and eliminating this disease was, as Dr. Reed had shown, the control of the mosquitoes that carried the dreaded infection and the elimination of their breeding places (see *The Microbe Hunters* by Paul de Kruif).

Dr. Gorgas was successful in effectively controlling the threat of yellow fever, but his success would not have been possible without the total commitment and support of John Stevens. Having established an organizational framework for the project and provided a safe and reasonably comfortable environment for the workers, Stevens addressed the technical problems presented by the project. The French had initially conceived of a canal built at sea level and similar to the Suez Canal. That is, the initial technical concept was to build a canal at one elevation. Due to the high ground and low mountains of the interior portion of the isthmus, it became apparent that this approach would not work. To solve the problem of moving ships over the “hump” of the interior, it was decided that a set of water steps, or locks, would be needed to lift the ships transiting the canal up and over the high ground of Central Panama and down to the elevation of the opposite side. The construction of this system of locks presented a formidable challenge. Particularly on the Atlantic side of the canal, the situation was complicated by the presence of the wild Chagres River, which flowed in torrents during the rainy season and dropped to a much lower elevation during the dry season.

The decision was made to control the Chagres by constructing a great dam that would impound its water and allow for control of its flow. The dam would create a large lake that would become one of the levels in the set of steps used to move ships through the canal. The damming of the Chagres and the creation of Lake Gatun itself was a project of immense proportions requiring concrete and earthwork structures of unprecedented size (Figure 1.7).

The other major problem had to do with the excavation of a great cut through the highest area of the canal. The Culebra Cut, as this part of the canal was called, required the excavation of earthwork quantities that even by today’s standards stretch the imagination. Stevens viewed this
FIGURE 1.7  Construction of a lock at the Panama Canal

part of the project as the construction of a gigantic railroad system that would operate continuously (24 hours a day) moving earth from the area of the cut to the Chagres dam construction site. The material removed from the cut would provide the fill for the dam. It was an ingenious idea.

To realize this system, Stevens built one of the great rail systems of the world at that time. Steam-driven excavators (shovel fronts) worked continuously loading railcars. The excavators worked on flexible rail spurs that could be repositioned by labor crews to maintain contact with the work face. In effect, the shovels worked on sidings that could be moved many times each day to facilitate access to the work face. The railcars passed continuously under these shovels on parallel rail lines.
Stevens’ qualities as a great engineer and leader were on a level with those of the Roeblings’. As an engineer, he understood that planning must be done to provide a climate and environment for success. Based on his railroading experience, he knew that a project of this magnitude could not be accomplished by committing resources in a piecemeal fashion. He took the required time to organize and mass his forces. He also intuitively understood that the problem of disease had to be confronted and conquered. Some credit for Stevens’ success must go to Theodore Roosevelt and his Secretary of War, William Howard Taft. Taft gave Stevens a free hand to make decisions on the spot and, in effect, gave him total control of the project. Stevens was able to be decisive and was not held in check by a committee of bureaucrats located in Washington (i.e., the situation present prior to his taking charge of the job).

Having set the course that would ultimately lead to successful completion of the canal, Stevens abruptly resigned. It is not clear why he decided not to carry the project through to completion. President Roosevelt reacted to his resignation by appointing a man who, as Roosevelt would say, “could not resign.” Roosevelt selected an army colonel named George Washington Goethals to succeed Stevens. Goethals had the managerial and organizational skills needed to push the job to successful completion. Rightfully so, General Goethals received a great deal of credit for the construction of the Panama Canal. However, primary credit for pulling the job “out of the mud,” getting it on track, and developing the technical concept of the canal that ultimately led to success must be given to Stevens—a great engineer and a great construction manager.

1.5 Other Historic Projects

Much can be learned from reading about and understanding projects such as the Brooklyn Bridge and the Panama Canal. David McCullough’s books The Great Bridge and The Path Between the Seas are as exciting and gripping as any spy novel. They also reflect the many dimensions of great and small construction projects. Other projects such as the building of the Hoover Dam on the Colorado River have the same sweep of adventure and challenge as the construction of the Panama Canal. The construction of the Golden Gate Bridge in San Francisco was just as challenging a project as the construction of the Brooklyn Bridge in its time.

The construction of the Empire State Building in less than 14 months is another example of a heroic engineering accomplishment. Realization of great skyscrapers such as the Empire State Building and the Chrysler Building in New York was made possible by the development of technologies and techniques in the construction of earlier projects. The construction of the Eiffel Tower in Paris and the towers of the “miracle mile” in Chicago in the early 1900s demonstrated the feasibility of building tall steel-frame-supported structures. Until the advent of the steel frame with its enclosing “curtain” walls, the height of buildings had been limited based on the strength of materials used in the bearing walls, which carried loads to the ground.

The perfection of the concept of steel-frame-supported structures and the development of the elevator as a means of moving people vertically in tall buildings provided the necessary technologies for the construction of the tall buildings that we take for granted today. Modern-day city skylines would not have been possible without these engineering innovations.

More recently, a project of historical proportions was realized with the completion of the Eurotunnel connecting the British Isles and France. This project has been dreamed of for many centuries. Through the skill and leadership of a large team of engineers and managers, it has now become a reality. Great projects are still being proposed and constructed. For the interested reader, brief coverage of many historical projects is given in The Builders: Marvels of Engineering published by the National Geographic Society (editor: Elizabeth L. Newhouse, 1992).
Construction versus Manufacturing Processes

Construction is the largest product based (as opposed to service oriented) industry in the United States. The dollar volume of the industry is on the order of $700 billion annually. The process of realizing a constructed facility such as a road, bridge, or building, however, is quite different from that involved in manufacturing an automobile or a computer.

Manufactured products are typically designed and first produced without a designated purchaser. In other words, products (e.g., automobiles or computers) are produced and then presented for sale to any potential purchaser. The product is made on the speculation that a purchaser will be found for the item. A manufacturer of bicycles, for instance, must determine the size of the market, design a bicycle that appeals to the potential purchaser, and then manufacture the number of units that market studies indicate can be sold. Design and production are done prior to sale. In order to attract possible buyers, advertising is required and is an important cost center.

Many variables exist in this undertaking and the manufacturer is “at risk” of failing to recover the money invested once a decision is made to proceed with design and production of the end item. The market may not respond to the product at the price offered. Units may remain unsold or sell at or below the cost of production (i.e., yielding no profit). If the product cannot be sold so as to recover the cost of manufacture, a loss is incurred and the enterprise is unprofitable. When pricing a given product, the manufacturer must not only recover the direct cost (labor, materials, etc.) of manufacturing, but also the so-called indirect and General and Administrative (G&A) costs such as the cost of management and implementation of the production process (e.g., legal costs, marketing costs, supervisory costs, etc.). Finally, unless the enterprise is a “nonprofit,” the desire of the manufacturer is to increase the value of the firm. Therefore, profit must be added to the direct, indirect, and G&A costs of manufacturing.

Manufacturers offer their products for sale either directly to individuals (e.g., by mail order or directly over the Web), to wholesalers who purchase in quantity and provide units to specific sales outlets, or to retailers who sell directly to the public. This sales network approach has developed as the framework for moving products to the eventual purchaser. (See if you can think of some manufacturers who sell products directly to the end user, sell to wholesalers, and/or sell to retail stores.)

In construction, projects are sold to the client in a different way. The process of purchase begins with a client who has need for a facility. The purchaser typically approaches a design professional to more specifically define the nature of the project. This leads to a conceptual definition of the scope of work required to build the desired facility. Prior to the age of mass production, purchasers presented plans of the end object (e.g., a piece of furniture) to a craftsman for manufacture. The craftsman then proceeded to produce the desired object. If King Louis XIV desired a desk at which he could work, an artisan would design the object, and a craftsman would be selected to complete the construction of the desk. In this situation, the purchaser (King Louis) contracts with a specialist to construct a unique object. The end item is not available for inspection until it is fabricated. That is, since the object is unique it is not sitting on the show room floor and must be specially fabricated.

Due to the “one-of-a-kind” unique nature of constructed facilities, this is still the method used for building construction projects. The purchaser approaches a set of potential contractors. Once agreement is reached among the parties (client, designer, etc.) as to the scope of work to be performed, the details of the project or end item are designed and constructed. Purchase is made based on a graphical and verbal description of the end item, rather than the completed item itself. This is the opposite of the speculative process where design and manufacture of the product is done prior to identifying specific purchasers. A constructed facility is not commenced until the purchaser has been identified. It would be hard to imagine, for instance, building a bridge without...
having identified the potential buyer. (Can you think of a construction situation where the construction is completed prior to identifying the buyer?)

The nature of risk is influenced by this process of purchasing construction. For the manufacturer of a refrigerator, risk relates primarily to being able to produce units at a competitive price. For the purchaser of the refrigerator, the risk involves mainly whether the appliance operates as advertised.

In construction, since the item purchased is to be produced (rather than being in a finished state), there are many complex issues that can lead to failure to complete the project in a functional and/or timely manner. The number of stakeholders and issues that must be dealt with prior to project completion lead to a complex level of risk for all parties involved (e.g., designer, constructor, government authorities, real estate brokers, etc.). A manufactured product is, so to say, “a bird in the hand.” A construction project is “a bird in the bush.”

The risks of the manufacturing process to the consumer are somewhat like those incurred when a person goes to the store and buys a music CD. If the recording is good and the disk is serviceable, the risk is reduced to whether the customer is satisfied with the musical group’s performance. The client in a construction project is more like a musical director who must assemble an orchestra and do a live performance hoping that the recording will be acceptable. The risks of a failure in this case are infinitely greater. A chronological diagram of the events involved in the manufacturing process versus those in the project construction project process is shown schematically in Figure 1.8.

1.7 Project Format

In contrast to other manufacturing industries that fabricate large numbers of units such as automobiles or computers, the construction industry is generally focused on the production of a single and unique end product. That is, the product of the construction industry is a facility that is usually unique in design and method of fabrication. It is a single “one-off” item that is stylized in terms of its function, appearance, and location. In certain cases, basically similar units are
constructed as in the case of town houses or fast-food restaurants. But even in this case, the units must be site adapted and stylized to some degree.

Mass production is typical of most manufacturing activities. Some manufacturing sectors make large numbers of similar units or batches of units that are exactly the same. A single item is designed to be fabricated many times. Firms manufacture many repetitions of the same item (e.g., smartphones, thermos bottles, etc.) and sell large numbers to achieve a profit. In certain cases, a limited number or batch of units of a product is required. For instance, a specially designed transformer or hydropower turbine may be fabricated in limited numbers (e.g., 2, 3, or 10) to meet the special requirements of a specific client. This production of a limited number of similar units is referred to as batch production.

Mass production and batch production are not typical of the construction industry (Figure 1.9). Because the industry is oriented to the production of single unique units, the format in which these one-off units are achieved is called the project format. Both the design and production of constructed facilities are realized in the framework of a project. That is, one speaks of a project that addresses the realization of a single constructed facility.

The focus of construction management is the planning and control of resources within the framework of a project. This is in contrast to other manufacturing sectors that are interested in the application of resources over the life of an extended production run of many units.

1.8 Project Development

Construction projects develop in a clearly sequential or linear fashion. The general steps involved are as follows

1. A need for a facility is identified by the owner.
2. Initial feasibility and cost projections are developed.
3. The decision to proceed with conceptual design is made and a design professional is retained.
4. The conceptual design and scope of work is developed to include an approximate estimate of cost.
5. The decision is made to proceed with the development of final design documents, which fully define the project for purposes of construction.
6. Based on the final design documents, the project is advertised and proposals to include quotations for construction of the work are solicited.
7. Based on proposals received, a constructor is selected and a notice to the constructor to proceed with the work is given. The proposal and the acceptance of the proposal on the part of the owner constitute the formation of a contract for the work.

8. The process of constructing the facility is initiated. Work is completed and the facility is available for acceptance and occupancy/utilization.

9. In complex projects, a period of testing decides if the facility operates as designed and planned. This period is typical of industrial projects and is referred to as project start-up.

10. The facility operates and is maintained during a specified service life.

11. The facility is disposed of if appropriate or maintained in perpetuity.

These steps must be modified on a case-by-case basis to address the special aspects of a given project. Topics relating to items 1 through 8 will be discussed in detail in Chapters 2 and 3. The key players in this developmental sequence are:

1. The owner

2. The designer or design professional

3. The constructor

The interaction of these three major entities is shown in Figure 1.10. Although other entities such as regulators, subcontractors, materials vendors, and so forth are important supporting players in this sequence, the major development of the project revolves about these three major entities. The legal definition of this interaction is established in the general conditions of the contract. This interaction will be described in detail in the following chapters.

1.9 Construction Technology and Construction Management

The study of construction as a discipline can be broadly structured into two general themes:

1. Construction technology

2. Construction management

As the name implies, “construction technology” relates to the methods or techniques used to place the physical materials and elements of construction at the job site. The word technology...
can be broken into two subwords—technical from “techno” and logic. Logic addresses the concept of sequence or procedure. That is, logic addresses the order of things: something is done first, another thing second, and so on until a result is achieved. Adding technical to this leads to the idea that technology has to do with the technical sequence in which something is done to produce an end result. It is possible to talk about a technology that applies to placing concrete, cladding a building, boring a tunnel, and so on.

Once a project has been defined, one of the most critical questions facing the construction manager is “What construction technique or method should be selected?” The types of methods for placing construction are diverse. New methods are continuously being perfected and a construction manager must weigh the advantages and disadvantages of a given method or technique.

In contrast to construction technology, construction management addresses how the resources available to the manager can be best applied. Typically, when speaking of resources for construction, we think of the four Ms of construction: manpower, machines, materials, and money. Management involves the timely and efficient application of the four Ms to construct a project. Many issues must be considered when managing a project and successfully applying the four Ms. Some are technical (e.g., design of formwork, capacities of excavators, weather tightness of exterior finishes, etc.). Many issues, however, are more qualitative in nature and deal with the motivation of workers, labor relations, the form of contracts, legal liability, and safety on the job site. As noted in discussing the Panama Canal, organizational issues can be very critical to the success of any project. This book will focus mainly on the topic of construction management. Therefore, we will be talking about the four Ms and subjects that relate to management and the timely and cost-effective realization of a project.

1.10 Construction Management Is Resource Driven

The job of a construction manager is to efficiently and economically apply the required resources to realize a constructed facility of acceptable quality within the time frame and budgeted cost specified. Among the many watch words within the construction industry is the expression “on time and within budget.” More recently, the concept of quality as a requirement has become an increasingly important aspect of the construction process. So this old adage can be expanded to say “a quality facility on time and within budget.”

The construction manager is provided with resources such as labor, equipment, and materials and is expected to build a facility that meets the specifications and is consistent with the drawings provided for the project. The mission of construction is constrained in terms of the available time and amount of money available. The challenge faced by the construction manager is to apply the resources of workers, machines, and materials within the limited funding (money) and time available. This is the essence of construction.

The manager must be clever and innovative in the utilization of resources available. Somewhat like a general in battle, the manager must develop a plan of action and then direct and control forces (resources) in a coordinated and timely fashion so that the objective is achieved.

This requires a variety of skills. A high level of competency is needed in a broad range of qualitative and quantitative subjects. A manager must be like a decathlon athlete. A strong ability in many areas is a necessity. Being outstanding in one area (e.g., engineering) but weak in a number of others (e.g., interpersonal relationships, contract law, labor relations, etc.) is not enough to be a successful construction manager. A strong performance across the board is required.
1.11 Construction Industry

The construction industry has been referred to as the engine that drives the overall economy. It represents one of the largest economic sectors in the United States. Until the early 1980s, the construction industry accounted for the largest percent of the gross domestic product (GDP) and had the highest dollar turnover of any U.S. industry. Since the recession of the second half of the 2000s, construction accounts for approximately 4% of the GDP (Bureau of Economic Analysis, NIPA Table 1.1.5). As noted above, the total annual volume of activity in the construction sector is estimated to be well in excess of $700 billion (Bureau of Economic Analysis, NIPA Table 1.1.5). More than 650,000 firms operate in the construction sector (Bureau of the Census, SUBS), and the number of people employed in construction is estimated to be almost 6.7 million (Bureau of Labor Statistics, NAICS 23).

The industry consists of very large and very small firms. The largest firms sign contracts in excess of $20 billion annually and consist of thousands of employees. Many of the largest firms work both domestically and in the international market. In contrast to the large companies, statistics indicate that over two-thirds of the firms have fewer than five employees (Bureau of the Census, SUBS). The spectrum of work ranges from the construction of large power plants and interstate highways costing billions of dollars to the construction of single-family houses and the paving of driveways and sidewalks. The high quality of life available in the United States is possible in large part because of the highly developed infrastructure. The American infrastructure, which consists of the roads, tunnels, bridges, communications systems, power plants and distribution networks, water treatment systems, and all of the structures and facilities that support daily life, is without peer. The infrastructure is constructed and maintained by the construction industry. Without it, the country would not be able to function.

1.12 Structure of the Construction Industry

Because the construction sector is so diverse, it is helpful to look at the major types of projects typical of construction in order to understand the structure of the industry. Construction projects can be broadly classified as (1) building construction, (2) engineered construction, and (3) industrial construction, depending on whether they are associated with housing, public works, or manufacturing processes.

The building construction category includes facilities commonly built for habitational, institutional, educational, light industrial (e.g., warehousing, etc.), commercial, social, and recreational purposes. Typical building construction projects include office buildings, shopping centers, sports complexes, banks, and automobile dealerships. Building construction projects are usually designed by architects or architect/engineers (A/Es). The materials required for the construction emphasize the architectural aspects of the construction (e.g., interior and exterior finishes).

Engineered construction usually involves structures that are planned and designed primarily by trained professional engineers (in contrast to architects). Normally, engineered construction projects provide facilities that have a public function relating to the infrastructure and, therefore, public or semipublic (e.g., utilities) owners generate the requirements for such projects. This category of construction is commonly subdivided into two major subcategories; thus, engineered construction is also referred to as (1) highway construction and (2) heavy construction.

Highway projects are generally designed by state or local highway departments. These projects commonly require excavation, fill, paving, and the construction of bridges and drainage structures. Consequently, highway construction differs from building construction in terms of the division of activity between owner, designer, and constructor. In highway construction, owners
may use in-house designers and design teams to perform the design so that both owner and designer are public entities. Heavy construction projects are also typically funded by public or quasi-public agencies and include sewage plants, flood protection projects, dams, transportation projects (other than highways), pipelines, and waterways. The owner and design firm can be either public or private depending on the situation. In the United States, for instance, the U.S. Army Corps of Engineers (public agency) has, in the past, used its in-house design force to engineer public flood protection structures (dams, dikes) and waterway navigational structures (river dams, locks, etc.). Due to the trend toward downsizing government agencies, more design work is now being subcontracted to private design engineering firms. Public electrical power companies use private engineering firms to design their power plants. Public mass-transit authorities also call on private design firms (design professional) for assistance in the engineering of rapid-transit projects.

Industrial construction usually involves highly technical projects in manufacturing and processing of products. Private clients retain engineering firms to design such facilities. In some cases, specialty firms perform both design and construction under a single contract for the owner/client.

### 1.13 Differing Approaches to Industry Breakdown

Figure 1.11 represents one of many ways in which the industry can be divided into a number of sectors. This breakdown includes single-family houses within the residential construction sector. In some breakdowns, one- and two-family houses are considered to be a separate industry, and this residential activity is not reported as part of the construction industry. As can be seen from the pie chart, residential and building construction account for between 70 and 75% of the industry. Industrial construction and heavy engineering construction (which are more closely related to the infrastructure) account for 25 to 30% of industry activity.
A slightly different approach to project classification is used by the Construction Market Trends Section of the *Engineering News Record* (ENR) magazine, which reflects the weekly dynamics of the construction industry in the United States. This breakdown of construction identifies three major construction categories:

1. Heavy and highway
2. Nonresidential building
3. Multiunit housing

The nonresidential building category includes building and industrial construction as defined above. These overall categories are further dissected as shown, to reflect the major areas of specialization within the construction industry.

ENR publishes an update of information based on this set of construction categories each week. In addition to this information regarding individual project categories, the ENR indexes derived from a 20-city base are also reported. These indexes indicate industry trends and provide the construction manager with a nationwide view of the construction industry.

### 1.14 Management Levels of Construction

Organizational considerations lead to a number of hierarchical levels that can be identified in construction. This derives from the project format. Decision making at levels above the project relate to company management considerations. Decisions within the project relate to operational considerations (e.g., selection of production methods) as well as the application of resources to the various construction production processes and work tasks selected to realize the constructed facility. Specifically, four levels of hierarchy can be identified as follows:

1. **Organizational** The organizational level is concerned with the legal and business structure of a firm, the various functional areas of management, and the interaction between head office and field managers performing these management functions.

2. **Project** Project-level vocabulary is dominated by terms relating to the breakdown of the project for the purpose of time and cost control (e.g., the project activity and the project cost account). Also, the concept of resources is defined and related to the activity as either an added descriptive attribute of the activity or for resource scheduling purposes.

3. **Operation (and Process)** The construction operation and process level is concerned with the technology and details of how construction is performed. It focuses on work at the field level. Usually a construction operation is so complex that it encompasses several distinct processes, each having its own technology and work task sequences. However, for simple situations involving a single process, the terms are synonymous.

4. **Task** The task level is concerned with the identification and assignment of elemental portions of work to field units and work crews.

The relative hierarchical breakout and description of these levels in construction management are shown in Figure 1.12. It is clear that the organizational, project, and activity levels have a basic project and top management focus, while the operation, process, and work task levels have a basic work focus.

To illustrate the definitions given above, consider a glazing subcontract for the installation of glass and exterior opaque panels on the four concourses of Hartsfield International Airport in Atlanta, Georgia. This was a project requiring the installation of five panels per bay on 72 bays of each of the four concourses. Figure 1.13 shows a schematic diagram of the project. A breakout of typical items of activity at each level of hierarchy is given in Table 1.1. At the project level, activities within the schedule relate to the glass and panel installation in certain areas of the concourses. At the work task level, unloading, stripping, and other crew-related activity is required.
1.14 Management Levels of Construction

**FIGURE 1.12** Management levels in construction

- **Hierarchical Level**
  - Organizational
  - Project
  - Activity
  - Operation
  - Process
  - Work Task

- **Description and Basic Focus**
  - Company structure and business focus
  - Head office and field functions
  - Portfolio of projects
  - Gross project attributes: total cost, duration, profit, cash flow, percent complete
  - Project definition, contract, drawings, specifications
  - Product definition and breakdown into project activities
  - Cost, time, and resource control focus
  - Attainment of physical segment of project equaled tooling and cost control
  - Current cost, time, resource use
  - Status focus
  - Construction method focus
  - Means of achieving construction
  - Complete itemized resource list
  - Synthesis of work processes
  - Basic technological, sequence focus
  - Logical collection of work tasks
  - Individual and mixed trade actions
  - Recognizable portion of construction operation
  - Fundamental field action and work unit focus
  - Intrinsic knowedge and skill at crew member level
  - Basis of work assignment to labor

**FIGURE 1.13** Schematic of concourse building
### Table 1.1 Example of Hierarchical Terms

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Installation of all exterior glass and panel wall construction on the Concourses of the Hartsfield International Airport, Atlanta, GA</td>
</tr>
<tr>
<td>Activity</td>
<td>Glass and panel installation on Concourse A, Bays 65–72</td>
</tr>
<tr>
<td>Operation</td>
<td>Frame installation to include preparation and installation of five panel frames in each concourse bay; column cover plate installation</td>
</tr>
<tr>
<td>Process</td>
<td>Sill clip placement; mullion strips installation</td>
</tr>
<tr>
<td></td>
<td>Glass placement in frame; move and adjust hanging scaffold</td>
</tr>
<tr>
<td>Work task</td>
<td>Locate and drill clip fastener; unload and position mullion strips; strip protective cover from glass panel; secure scaffold in travel position</td>
</tr>
</tbody>
</table>

### REVIEW QUESTIONS AND EXERCISES

1.1 Look up the names of the largest contractors reported by ENR in its three main categories: Heavy and highway, nonresidential building, and multiunit housing. Notice that the list also includes their ranking for the previous years. Were they the largest the previous year?

1.2 There have been many construction marvels in human history, of which this chapter mentioned only a few. Comment on three historical projects of your choosing not included here. Examples include the Great Wall of China, the pyramids, the Suez Canal, the Eiffel Tower, and the Golden Gate Bridge, among many others. Why were they built? What makes them unique? How were they built? Who paid for them?

1.3 What advantages do you see in consolidating the roles of owner, designer, and constructor shown in Figure 1.10?

1.4 Give examples of the management levels in construction shown in Figure 1.12.