BUILDING: CONSTRUCTING AND MANUFACTURING

When your work speaks for itself, don't interrupt.
(Henry J. Kaiser, industrialist)

11.1 The Engineer as Builder

Most engineers and related technically-intensive professionals, while valuing science, are driven by the desire to do something with science—to build something to improve the quality of life. This compulsion may be the primary source of their professional satisfaction and the pleasure of building may have begun during childhood. On learning of a scientific discovery, engineers are likely to say "congratulations!" to the scientists and then immediately ask, primarily themselves, "so what's it good for; what's the application, or what structure, facility, system, product, or process can we now construct or manufacture more effectively or efficiently?" Engineers appreciate science while deriving their principal satisfaction from its people-serving applications.

Engineer and author, Samuel C. Florman (1976) argues that talents and impulses deep within us underlie what we engineer and then build. Our main goal, according to him, is to "understand the stuff of the universe, to consider problems based on human needs, to propose solutions . . . and to follow through to a finished product." Creating useful things for society's welfare gives us "existential delight." The late engineering professor and author Hardy Cross (1952) offered this "bottom line" description of the building, people-serving essence of engineering: "It is not very important whether engineering is called a craft, a profession, or an art; under any name this study of man's needs and of God's gifts that may be brought together is broad enough for a lifetime."

Looking over the span of history, most engineers and other technical professionals, and many non-technical people, marvel at the function and beauty of what our ancestors have built and what we are building. A few representative, highly-varied examples of the fruits of constructing and manufacturing, spanning almost five thousand years and listed in approximate chronological order, are (based, in part, on Fredrich 1989, Hopp and Spearman 2001):

- The Egyptian pyramids
- Tools developed during the Iron Age
- The Great Wall of China
- Athens' Parthenon

- The Roman Pont du Gard in what is now France
- China’s Grand Canal
- Printing press
- Steam engine
- The telegraph system
- Transcontinental railroad in the U.S.
- Powered flight
- Mass production of affordable vehicles and untold other consumer and producer products
- The Panama Canal
- San Francisco’s Golden Gate Bridge
- Digital computer
- Commercial jet aircraft
- The Eurotunnel connecting England and France
- Many electronic devices interconnected via the internet
- Robotic prosthetics
- The International Space Station

11.2 Constructing

11.2.1 Importance of Constructing

A nation’s quality of life is heavily dependent on its infrastructure which includes, but is not limited to, its water supply and wastewater systems, transportation systems (e.g., highways, bridges, tunnels, railroads, airports, and ports), stormwater management and flood control systems, communication systems, power generation and distribution systems, and other structures, facilities, and systems supportive of daily life. The infrastructure is built and maintained by the construction industry.

Speaking from the construction industry perspective, Clifford Schexnayder (2011), one of the authors of a construction management book (Knutson et al 2009), offers this view of construction: “In its simplest terms, construction is about getting work, doing work, and keeping score.” The resulting construction project can be a very complex undertaking. Accordingly, engineers committed to succeeding in constructing need technical competence supplemented with the many non-technical knowledge and skill areas such as, but not limited to marketing, communication, project management, quality, business accounting, law, and ethics.

11.2.2 What Gets Constructed and How?

Given the diversity of what gets constructed and how, the four categories described by Knutson et al (2009) and Clough et al (2005) are useful in gaining insight into the construction industry. These categories are:

Residential construction: This category includes structures built for habitation such as individual homes, that is, tract or custom homes, condominiums, apartments, and assisted living facilities. The need for residential construction is determined largely by the private sector and the structures are typically designed by architects.

Commercial construction: Included here are a wide range of structures, in terms of size and cost, such as office buildings, stores, banks, schools, universities, hospitals, libraries, theaters, sports complexes, and vehicle dealerships. The need for commercial construction is determined by both private and government entities. As with residential construction, commercial facilities are typically designed by architects. However, engineers often provide a support role in areas such as structural; constructability; lighting, security, and other electrical aspects; fire protection; and heating, ventilating, and air conditioning (HVAC).

Industrial construction: Examples of structures and facilities in this category are heavy manufacturing plants, steel mills, refineries, nuclear power plants, pipelines, electric power-generating facilities, ore-handling installations, and other highly-technical projects. Industrial construction is typically initiated and financed by the private sector, engineering firms perform the design, and specialized contractors normally bid for and perform the construction. Sometimes the client or owner may retain a single firm that both designs and constructs the industrial project.

Heavy engineered construction: Included here are projects where the owner is typically a government entity and the publicly-financed structures, facilities, or systems are major public infrastructure elements. Examples are highways, bridges, tunnels, airports, ports, harbors, dams, flood control works, water and wastewater systems, and storm water management systems.

Licensed engineers, who may be government employees or members of consulting engineering firms, direct the designs. Then bidding is used to select a contractor to build the project. This is the common design-bid-build process. Sometimes, because of financial constraints, time limitations, or complexity challenges, a design-build or design-construct approach is used in which the client or owner contracts with one firm that fulfills both the design and construction functions.

11.2.3 Roles of Engineers in Constructing

Project Manager

One of the many diverse roles played by engineers in construction is project management and each organization participating in a construction project will typically have a project manager. Well before construction begins, the firm that is to design the project will designate someone to manage the design process in accordance with the contract between the client or owner and the design firm. This effort will continue to at least delivery of plans, specifications, and other documents, including construction cost estimates. The project manager may also assist the client or owner with selection of the lowest cost, responsible contractor through a publicly-advertised competitive bidding process.

This design firm's project manager, or someone designated by the design firm, may also extend his or her duties into the construction phase in the form of monitoring the effort on behalf of the client or owner, relative to the design requirements. That individual may be required to certify that the project has been substantially completed in accordance with the intent of the design firm's plans and specifications prior to the client or owner accepting and operating the constructed project.

The contractor's project manager, who is sometimes referred to as superintendent, may be an engineer. His or her responsibilities typically include the construction means and methods, schedule, budget, and safety. More specifically, the contractor's project manager is usually responsible for:

- Procuring, marshalling, and allocating labor, equipment, and materials
- Planning the type and sequence of construction activities
- Coordinating the work of subcontractors
- Construction site safety and security

- Informing the client or owner, designer, and the public about a project's status
- Coordinating with local, state, federal, and other regulatory agencies

The owner or client is likely to have a project manager who may be an employee of the owner or client organization or may be on the staff of a professional services firm that specializes in managing construction projects. This project manager's duties may include assisting with selection of an engineering or architecture firm to design the project, providing advice about selection of a contractor, administering the construction contract, monitoring quality control and quality assurance, arranging for review of shop drawings by the design engineer or architect, and working with the design professionals in responding to design changes proposed during construction.

Resident Project Representative or Resident Engineer

The term Resident Project Representative (RPR) is suggested by Fisk (2000) to refer to "an on-site full-time project representative to whom has been delegated the authority and responsibility of administering the field operations of a construction project as the representative of the owner or the design firm." The RPR, often an engineer, may also be referred to by terms such as resident engineer, resident inspector, resident technician, resident manager, project representative, or construction observer. He or she may supervise one or more staff-level, on-site personnel. Fisk (2000) notes that construction inspection, which is one of the RPR's duties, "requires a highly-qualified person with, good working knowledge of construction practices, construction materials, specifications, and construction contract provisions." Other possible RPR duties include survey, layout, and documentation of completed work for payment, and materials inspection and testing to confirm the acceptability of the materials being incorporated into the project. The RPR and/or his or her supervisees do not direct the construction but watch for departures from plans and specifications and, if observed, advise the contractor, owner, and designer and facilitate a resolution.

Project Engineer: An engineer may also be employed by a contractor as project engineer or assistant project manager, especially if the contractor undertakes large and/or complex projects. In that role, he or she may report to one or more of the contractor's project managers or superintendents, or to an executive of the construction company. This technical specialist may be responsible for "tracking requests for information, managing shop drawings, maintaining daily records of the project, calculating pay estimates, updating project schedules, and resolving errors in plans and specifications" (Knutson et al 2009). More broadly, the project engineer may be asked to resolve technical problems that arise on one or more projects and determine ways to optimize use of the company's labor, equipment, and materials.

11.2.4 Trends in Constructing

If constructing interests you, then you may want to learn about some trends in this industry such as the following:

Addressing the shortage of specialty trades personnel: Specialty trades, such as carpenters, electricians, masons, equipment operators, glaziers, painters, plumbers, sheet metal workers, and iron workers are critical, they make up about two-thirds of the construction industry employees. Because of insufficient interest in trades by high school students and because of the high cost of the necessary hands-on training, the construction industry is facing a shortage of trained labor. "Labor and management need to work together to solve this problem." (Knutson et al 2009).

Shift to design-build: Design-bid-build, the traditional project delivery system, is slowly being replaced by the design-build project delivery system (Knutson et al 2009).

Computer-aided earthmoving equipment: Contractors are increasingly requesting digital files that were prepared by the designer to facilitate grading and other earthwork.
Web-based project management: Another trend is document sharing via a common project website. This enables timely sharing of documents such as project plans, meeting agendas and minutes, schedule status, cost summaries, requests for information (RFIs), and change orders with the status of approvals.
Lean construction: According to the Lean Construction Institute (2011), lean construction is "a new way to design and build capital facilities" based on success with lean production management in other engineering disciplines which "caused a revolution in manufacturing design, supply, and assembly." The objectives of lean construction are to "maximize value and minimize waste." This is accomplished, in part, by simultaneously designing a structure, facility, or system and its delivery process and by redefining control "from monitoring results to making things happen."

Improved management: "On the whole, construction contractors have been slow in applying proven management methods to the conduct of their businesses," according to Clough et al

(2005). "Specialists have characterized management in the construction industry as being weak, inefficient, nebulous, backward, and slow to react to changing conditions. This does not mean that all construction companies are poorly managed. Explanation for the management problems in the construction industry include the uniqueness of projects, which complicates standardization, and the small size of most construction companies which means that decisions on a wide variety of complex topics are made by one or a few people. Another explanation is the ease at which an individual or group can enter the construction business in that "nearly anyone with a pickup truck and a cell phone can get into the business" (Knutson et al 2009). Moving forward, the construction industry must improve its management practices.

11.3 Manufacturing

11.3.1 Importance of Manufacturing

Manufacturing can be defined as "organized activities that convert raw materials into salable goods" with those goods being consumer goods or producer goods. Consumer goods are those purchased by the general public whereas producer goods are items purchased by other companies to, in turn, use to manufacture producer or consumer goods. Representative consumer goods are electronic devices, clothes, automobiles, furniture, cosmetics, beverages, and books. Examples of producer goods are machine tools lathes, punch presses, drill presses, milling machines, and printing presses.

Manufacturing is a value-adding process during which the conversion of materials into goods adds value to the original materials and enables the effort (Black and Kohser 2007).

Our lives, from meeting our most basic needs to our most uplifting moments, are impacted by manufactured goods. Essentially omnipresent in developed countries, these goods are often taken for granted. "Every day we come in contact with hundreds of manufactured items, from the bedroom to the kitchen, to the workplace, we use appliances, phones, cars, trains, and planes, TV's, VCRs, DVDs, furniture, clothing, and so on," according to Black and Kohser. They go on to note that "These goods are manufactured in factories all over the world using manufacturing processes." And some of those manufacturing processes, and the manufacturing systems of which they are a part, are engineering marvels.

The selling price of a manufactured product is the sum of engineering, administrative, sales, marketing, and manufacturing costs plus profit. Because the manufacturing component accounts for about 40 percent of the total cost, profitability is most dependent on the manner in which goods are manufactured (Black and Kohser).

A country's standard of living is determined largely by the goods and services available to its citizens.

11.3.2 What Gets Manufactured and How?

The question of what gets manufactured and how is answered by the interaction of the manufacturing organization's marketing, design, and manufacturing personnel who function as an interdisciplinary project team (Ulrich and Eppinger 2008). That project team may be staffed solely by personnel of the manufacturing firm or it may consist of them plus external participants representing business partners, consulting firms, and suppliers and, of course, many team members will be engineers.

As explained in part by Ulrich and Eppinger (2008) who are quoted here, the process is as follows:

Marketing: The marketing activity is part of the "Define need, problem, and/or opportunity"

Marketing personnel facilitate "identification of product opportunities, the definition of market segments, and the identification of customer needs."

Design: This activity "includes engineering design (mechanical, electrical, software, etc.) and industrial design (aesthetics, ergonomics, user interfaces)."

Manufacturing: The manufacturing activity is aligned with both the "Design" function and the "Construct, manufacture, or otherwise implement the process, product, structure, facility, or system". Design is part of the manufacturing activity in that the manufacturing system must be designed, that is, the set of processes and operations that will result in the designed and desired end product. Then the system must be operated to actually produce the product. This manufacturing activity "also often includes purchasing, distribution, and installation.

11.3.3 Roles of Engineers in Manufacturing

As with constructing, engineers fulfill many and varied roles in manufacturing as members of project teams who execute the marketing-design-manufacturing sequence. As explained by Black and Kohser (2008), design engineers design the product and manufacturing or industrial engineers design the manufacturing system and manage its use. Materials engineers focus on developing new and improved materials. Some engineers assist with the initial marketing activity. Other engineers serve the broader project management role. They manage the design, manufacturing, and other functions by attending to the typical competing demands, namely deliverables, schedule, and budget.

In fulfilling these roles as members of project teams, engineers work closely with other experts representing diverse areas such as sales, accounting, finance, and law. Engineers involved in manufacturing also work with technologists, technicians, and other team members such as tool and die makers, machine operators, and computer control programmers.

Your effectiveness as an engineer in manufacturing will be greatly enhanced first by getting and keeping "your personal house in order" and then by enhancing your communication knowledge and skills and striving to develop relationships with others.

11.3.4 Trends in Manufacturing

As a student or young person early in your career who is interested in manufacturing, you may wonder what the future holds. Black and Kohser (2008) offer the following ideas about global trends in manufacturing:

Increased globalization: Manufacturing will continue to be an even more global activity as companies try to optimize availability of low-cost labor, access to suppliers and materials, and location of customers.

Continuous improvement: Factories are being designed or redesigned to more effectively provide quality while functioning faster and cheaper. Efforts to reduce time-to-market for new products will continue. Continuous improvement will be increasingly stressed to meet higher quality expectations of customers.

Increasingly tailored products: The number and variety of products will increase while production quantities will decrease. Existing manufacturing processes must be more flexible and new processes developed.

Reduced time-to-market: Manufacturers will gain a competitive edge by reducing the time needed to design and manufacture products. Tactics include designing products so that they are easier to manufacture and creating even more flexible manufacturing systems.

These challenging trends, coupled with the thrill of building useful products, suggest that manufacturing is an attractive career choice.

11.4 Differences Between Constructing And Manufacturing

Up to now, this chapter has stressed the commonalities between constructing and manufacturing, For example, both involve building to meet human needs and, to the extent they do so, both impact the quality of life. Constructing and manufacturing both have a history of several thousand years and both are heavily dependent on engineering and, as a result, offer many opportunities for aspiring engineers, whether they be students or entry-level practitioners. Constructing and manufacturing also exhibit two differences which may be of interest to students or young practitioners who are contemplating their careers.

As explained by Halpin (2006), the first difference begins with understanding that manufactured products are typically designed and produced without a designated purchaser. "The product is produced on the speculation that a purchaser will be found for the item produced . . . Design and production are done prior to sale." The manufacturer is at risk of not being able to recover the funds invested in design, production, and marketing.

In contrast, as Halpin goes on to explain, with constructing the purchase begins with the client, owner, or customer who has need for a structure, facility, or system and, as a result, often retains an engineering firm to provide design services and later contracts for construction. The risks in this process include the possibility that the one of-a-kind resulting structure, facility, or system will not function as required.

Both manufacturing and constructing require marketing and that some engineers may elect to participate in that process. This leads to the second difference between manufacturing and constructing which is the focus of the related marketing efforts. In the manufacturing arena, marketing is conducted by the manufacturer and targets potential buyers of consumer or producer goods. On the constructing side, marketing is typically carried out by engineering firms who seek to provide design services to organizations that need structures, facilities, or systems and by construction companies desiring to build those items.

Final Word

While design, as discussed in a previous lecture, is the root of engineering, constructing and manufacturing are the fruit of engineering. These two forms of building share some common elements, the most important of which is their people-serving essence. If either constructing or manufacturing intrigue you, explore one or the other further. Depending on whether you are a student or young practitioner, take an exploratory constructing or manufacturing course, arrange summer employment or a cooperative education assignment with a constructor or manufacturer, converse with construction or manufacturing practitioners, visit construction sites and manufacturing plants, and seek constructing or manufacturing assignments.