

CONSTRUCTION GRAPHICS



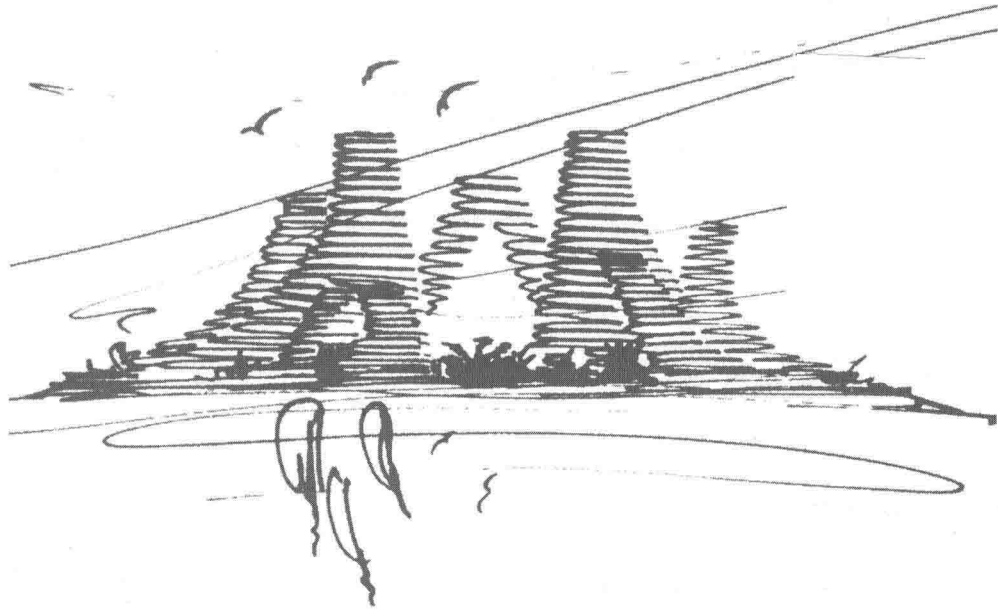
A PRACTICAL GUIDE TO INTERPRETING WORKING DRAWINGS



KEITH A. BISHARAT

Construction Graphics

A Practical Guide to Interpreting Working Drawings



Keith A. Bisharat

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Construction Graphics

Preface

This textbook is the product of 10 years of facilitating the educations of numerous construction graphics students in the construction management program at California State University, Sacramento. Helping these students understand how constructors use construction drawings was an involved task requiring a wide variety of references and assignments. Architects and engineers write many of the references used by construction management students, and their product orientation is reflected in their work (e.g., will the structure serve its intended purpose, will it add value to its environment, will it protect its users during all sorts of natural events?). While this helps construction students understand the interests and concerns of the design professional—useful information to know—it sheds little light on what drawings mean to constructors, who are process-oriented (what does the project consist of; how much time and money will I need to construct it; what kind of equipment, materials, and personnel are required; where do I start, and so forth?). This book is designed to bridge the gap between what the design professional conceives and depicts and what the construction professional—and construction management students—must see in terms of the materials and processes required to produce the product.

The book was written primarily for freshman and sophomore construction management or building technology students who have had some technical drawing experience, although anyone whose experience with construction drawings is limited may also benefit from using it. Design professional students may also derive a benefit from using the text, since it reveals the value system of a contractor as it relates to construction drawings. The text focuses mainly on building construction projects.

Throughout the production of this text, I kept the following hypothetical conversation with the reader in mind: “Here is a basic construction system. Here is how the system is designed to function. The design professional depicts the system this way. These symbols mean this; these lines mean that, this is how big it is and this is where it fits. This, however, is a picture of what the builder has to consider: here is the access to and staging on the site; here is the hole in the ground that we have to create. Here is the temporary structure (formwork, for example) that we have to build in order to give workers reasonable, safe access to their work and to hold the concrete in the desired shape. Here are the parts that must be installed after the temporary structure is in place, but before the concrete is placed and finished. Here is how we’ll transport, place, and cure the concrete. And this is what we must consider when we take this temporary structure down. This is what these drawings mean to us.”

Chapters 1 through 5 consist of an overview of graphic communication, the construction business environment, the design professional’s work product, and drawing fundamentals, with an emphasis on sketching. Chapters 6 through 13 cover eight basic categories: site construction; foundations; framing systems; cladding, glazing and exterior doors; roof systems; interior construction; mechanical systems; and electrical systems. These basic categories include virtually all of the tasks involved in constructing a building, and for the most part follow the Construction Specifications Institute’s (CSI) UniFormat™ classification system. Chapter 14 addresses shop drawings.

All the chapters follow the same format. Each begins with a list of key terms and concepts, followed by a description of the role that the subject system plays in the

overall context of the project. Comments on what to anticipate in the drawings and the typical projections, lines, symbols, and other graphic conventions used to describe the system are next, followed by illustrations of the processes used to construct a system (where it was practical to include them). Fundamental quantity surveys of the system, or portions of it, as well as exercises conclude each chapter. Selected references follow at the end of the book. Requiring students to develop simple plans for constructing parts of systems and to perform quantity surveys while they are studying graphic depictions of them serves to integrate project planning, graphics, construction materials and processes, structural design, the fundamentals of estimating and, to some extent, scheduling; and it immediately gives students something to sink their teeth into

that is undeniably construction-oriented. For younger CM students who have several years to go before they will actually practice their discipline, this approach can be engaging.

In the creation of this book, it was my intention to show the respect and appreciation that I genuinely feel for all of the participants in the construction process, from the owners who develop the projects and the designers who conceive and describe them to the remarkable people who construct them, including the laborers on the project site.

This textbook is a work in progress; the publisher and the author welcome input from readers as to how the material might be more effectively organized and presented, as well as how it might be supplemented or reduced in size.

Acknowledgments

A wise old Sacramento contractor once said to me, “There’s no such thing as a self-made millionaire; somebody had to help.” That humble statement certainly applies to my work on this book, too. Thanks to the many people who supported me, including Bob Christenson, Chief Operating Officer of Panattoni Construction Company; Dr. Braja Das, Dean of the College of Engineering and Computer Science at California State University, Sacramento; and Dr. Joan Al-Kazily, Chair of the Civil Engineering Department, who felt strongly enough about this work to commit resources toward it. Without their investment, I wouldn’t have undertaken the project. Thanks, also, to Rovane Younger, Bruce Yoakum, and Mike Borzage (colleagues of mine at California State University, Chico), and to Hal Johnston at California Polytechnic State University, San Luis Obispo, who were good enough to review my initial proposal and offer their insights as to the content and structure of the book. Ruth Younger contributed her thoughtful, thorough, and effective editing of early chapters of the book. Professor Donald Nostrant, my remarkable colleague at CSUS, is a terrific sounding board for all manner of topics.

*The project that is the subject of the drawings reproduced in this text under Comstock Johnson Architects’ name was a design collaboration between Comstock Johnson Architects serving as the architect of record and LPA Sacramento, Inc., which acted as the design architect.

My friends Ron Nurss, Chuck Smith, Rob Cacioppo, Jerry Cova, and Sean Riley of Blueline Construction, and Irv and Brian Ballance, of Ballance Construction, were generous with their time and insights into the construction process and construction graphics. Kevin Wilcox and Don Comstock of Comstock Johnson Architects,* Ron Miglori of Buehler and Buehler Structural Engineers, Stan Gibbons of Entelechy, and the folks at the HLA Group, Landscape Architects, were enthusiastic contributors of their graphic work. A long line of construction management students—a hardy bunch all in all—have wrestled with my classes for over a decade and have helped me understand and appreciate the challenges they face in assimilating the information related to construction graphics—there is a lot to know on this subject.

Rob Garber and Joel Stein at John Wiley & Sons, Inc., encouraged me early on in the project, and Jim Harper and Mike Olivo did a fine job keeping me on task as the project progressed.

I owe special thanks to my parents, who encouraged my siblings and me to wonder, and I am particularly indebted to my wife, Patti, who bore the lion’s share of the domestic workload while managing her own busy career, and to my wonderful children, Adrienne and Ian, who tolerated my absence from family activities for months.

KEITH BISHARAT
Sacramento, California

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1 Construction Graphics: An Overview

Key Terms

American Institute of Architects (AIA)
Architect/engineer (AE)
As-built drawings
Building codes
Computer-aided design and drafting (CADD)
Construction Specifications Institute (CSI)
Dead load
Design-build
Dynamic load
Engineering contractor
General building contractor
Geotechnical report
Hydrostatic load
Integrated services delivery
Live load
National Cad Standard (NCS)
Planning codes
Shop drawings
Specialty contractors
Static load
Substructure
Superstructure
Temporary structures
Value engineering
Work breakdown structure
Zoning codes

Key Concepts

- The probability of differences arising between people engaged in an endeavor rises exponentially with the number involved, as demonstrated by the following formula: 2^{n-1} , where n is the number of participants and 1 is the single circumstance in which all participants agree.

Objectives

- Describe many of the challenges that design professionals face in their work.
- List the principal participants in a construction project, and identify their roles.
- List and describe the principal categories of construction project.
- Describe the typical educational path of architects, engineers, and contractors.
- Differentiate the design professional's and constructor's responsibilities.

■ Introduction

Graphics are indispensable to anyone trying to communicate a vision or describe an object to an audience. Ideas commonly originate as pictures, which their creators then translate into words or words and pictures when they want to share them with others (see Figures 1.1a and 1.1b).

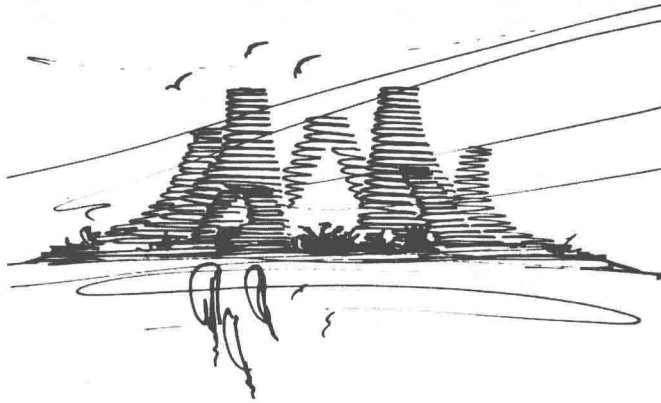


Figure 1.1a Graphics are used to give life to a design concept, which may grow out of simple sketches such as this. (Sketch courtesy of the estate of Victor H. Bisharat.)

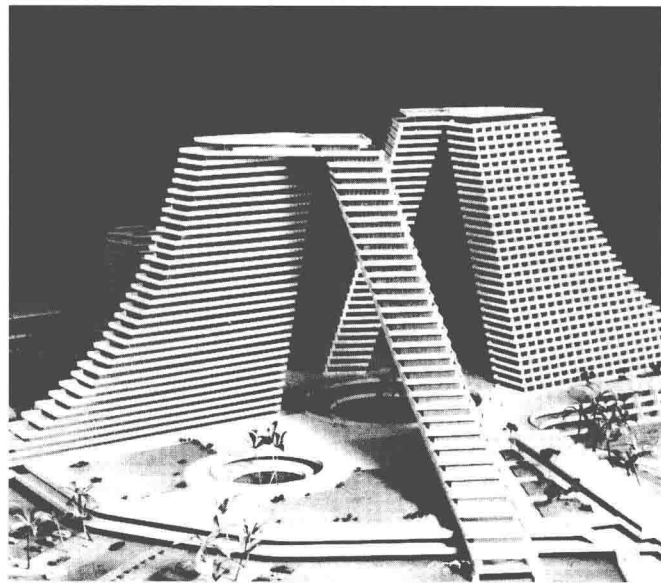


Figure 1.1b The sketch takes model form after considerable design work has been executed. (Photograph courtesy of the estate of Victor H. Bisharat.)

Indeed, combining pictures with words is the only reliable way to describe some objects, particularly complex ones such as machines, buildings, and other structures. Because professionals involved in designing construction projects must communicate particularly complex ideas, they typically do so through graphics. Therefore builders—whose responsibilities include interpreting the plans that design professionals create, determining the means and methods of construction, and executing construction work in a safe and profitable manner—must have a thorough understanding of the graphics commonly used in construction projects.

■ Graphics and Builders

In the course of executing their work, contractors use drawings, specifications, and other documents extensively, and are responsible for producing shop drawings, as-built drawings, and drawings for temporary structures. They are responsible for effectively communicating work requirements to their employees and subcontractors. Constructors who fully understand the project they are planning to build and can effectively communicate the processes required to build it, orally, graphically, and in other ways, dramatically reduce the risk in the undertaking. Those who are alert to what the design professional is trying to achieve in a project and can offer less costly solutions to the design without compromising its integrity—a process known as *value engineering*—give themselves a significant edge over their competitors. Additionally, the increasing popularity of the design-build project delivery system (*integrated services delivery*), which requires the design professional and constructor to collaborate on the design from the inception of a project, suggests that the constructor who is attuned to the interests and concerns of the design professional will be a sought-after partner.

■ Challenges Facing the Design Professional: Telling a Complicated Story

Architects and engineers have the very challenging task of conceiving solutions to the complex design problems their clients have, then communicating them to the people who bring the project to reality. They face a staggering number of issues in the course of their work. Every client has a unique set of requirements to identify, evaluate, and accommodate. Although they often borrow ideas from other projects, many architects develop solutions from “out of the blue,” that is, from their imaginations. Their concepts are usually a melding of the owner’s needs and their own artistic proclivities. Architects are well aware of the publicity associated with their work—after all, build-

ings are the most visible art—and this awareness frequently affects their decision making. Indeed, the principal criterion for selecting a particular architect is often the architect's design "signature."

During the design development stage, in addition to the owner, myriad permitting authorities and community groups have the opportunity to influence a project's design. For example, a project located on a major waterway within a large city might involve 10 or more public organizations—federal, state, and local agencies—that have jurisdiction over various aspects of it. In some jurisdictions, this means that the architect must develop a photograph of a prospective building design and insert it in a digitized photo of the neighborhood, so that planners can evaluate its visual impact prior to approving it. The context of a project requires the design professional to consider, for example, the effects that weather and surrounding buildings will have on a building project—or, in the case of a bridge, such considerations as traffic flow, kinesthetic effect, and safety. The size and configuration of a site, access and egress to it, and even the nature of its soil play a significant role in the project design. The single greatest influences on projects are the time and money that owners allocate to them. And construction as an industry is unique—tens of thousands of parts must be transported to and assembled on the site by armies of skilled workers, directed and supervised by management teams that change with every project. Consequently, no two projects are exactly alike; all are prototypes.

Recent developments in computer technology enable architects to develop highly unusual designs—projects so unique as to be impossible to draw using conventional board drafting methods (see Figure 1.2).

Although computer-aided design and drafting (CADD), when employed to take advantage of its strengths, has contributed significantly to document production, it is commonly used to produce the conventional two-dimensional depictions of the project (the drawings). The full capabilities of existing software, including its potential to produce dimensionally sound pictorial representations of the project, have yet to be widely used.

Computer software companies are currently developing and refining programs that potentially will give designers and builders much more effective control over the design and construction processes. So-called "intelligent building models" (variously dubbed "parametric modeling" or "object-oriented" programs) and "object linking and embedding technology" (OLE) enable the user to define and store detailed parameters of building assemblies (such as foundations, walls, ceilings, and equipment) within the drawings. This makes retrieving many kinds of information quick and easy. The form that construction drawings will take in the future—and the medium used during construction—remains to be seen. For the time being, however, architects and engineers contin-

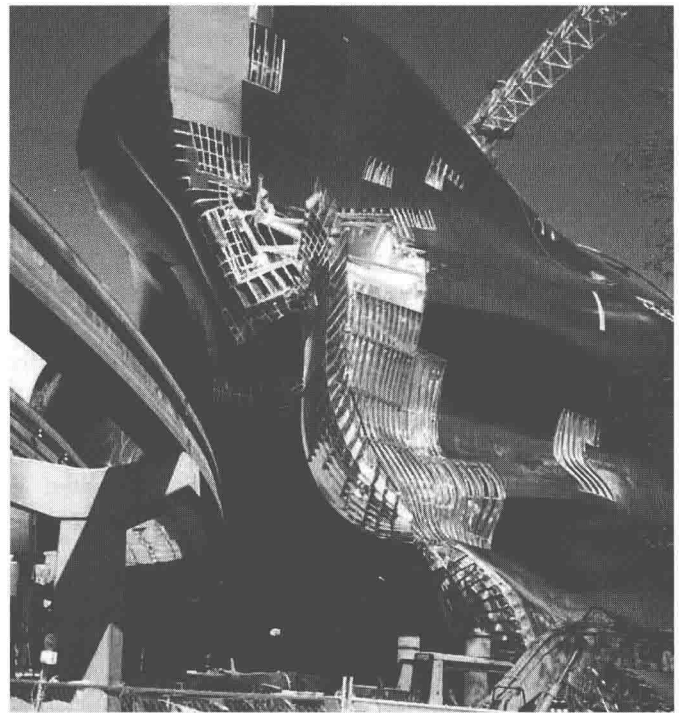


Figure 1.2 The Experience Music Project in Seattle, Washington, represents a growing genre of projects that will test the ingenuity and skill of the construction community. (Frank Gehry, Architect; Hoffman Construction, Contractor; photo by the author.)

ue to produce, on paper, two-dimensional depictions of the projects they design.

These influences make it easy to understand why the design and construction professions are error-prone and why they will remain lively fields of practice in the future.

■ Dialects and the Standardization of Drawings

It is useful to think of construction graphics as a language that participants in the construction process must "speak" fluently, even if with varying "accents." As oral communication varies with the individual using it, so does graphic communication. Consequently, we see considerable variation in how drawing sets are organized, how each sheet is formatted and annotated, and how graphic symbols are used. This lack of consistency adds difficulty to an already complicated process and increases the potential for misunderstandings between builder, owner, and design professional.

The publication of the first *Architectural Graphic Standards (AGS)*, written by Charles George Ramsey and Harold Reeve Sleeper in 1932*, was an early effort to standardize graphics for construction projects. Today,

*Ramsey and Sleeper (2000).

AGS is a widely used compendium of planning, design, construction, graphic, and other reference information that focuses primarily on design data. *ConDoc*, developed by Onkal Guzey and James Freehof of the American Institute of Architects (AIA), the principal professional organization of the architectural community, is a design presentation standard that offers a uniform drawing set organization, sheet format and numbering methodology, and a keynote system that facilitates the prompt communication of graphic and specification information. Though *ConDoc* has contributed significantly to better quality control and drawing productivity, it is not universally employed. Many design offices insist on using their own formats and drawing set organization.

As recently as 1990, the Construction Specifications Institute (CSI) discovered that few standards related to construction drawings actually exist. Having had considerable success with its MasterFormat indexing system (a widely used list of construction products and activities oriented toward how parts are specified, purchased, and installed), CSI turned its attention in 1994 to developing a single construction drawing standard, which it named the *Uniform Drawing System (UDS)*. The *UDS* has become a fundamental part of the *National Cad Standard (NCS)*, an evolving collaboration of CSI, AIA, the U.S. Department of Defense Tri-Service CADD/GIS Technology Center and the United States Coast Guard, the Facility Information Council of the National Institute of Building Sciences (NIBS), the U.S. General Services Administration (GSA), and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA). These organizations signed a memorandum of understanding in 1997 to develop and promulgate the use of the NCS. The Facility Information Council of NIBS provides the forum for the effort; CSI is contributing its *UDS*, the AIA its CAD layering guidelines, and the Tri-Service CADD/GIS Technology Center its plotting standards. The NCS is a much-needed single standard for the organization and presentation of drawing sets; a format for individual sheets, schedules, and diagrams; and standards for color, keynotes, material symbols, and CAD layering.[†] Though not yet widely used, the NCS is a work in progress that is gaining acceptance.

■ Participants in the Design Process: Owners, Design Professionals, and Contractors

Designing and constructing projects frequently involves hundreds of participants; however, there are three principal players in every project: the owner, the design professional, and the contractor.

[†]National Institute of Building Sciences/American Institute of Architects/Construction Specifications Institute/Tri-Service and the U.S. Coast Guard (2001).

Owners

Although the list of potential construction project owners is nearly infinite, the short list includes governments (federal, state, and local), districts (school, irrigation, and reclamation), for-profit and nonprofit corporations, partnerships, and individuals. Construction projects occur when a representative of one of these groups seeks to mitigate a need or realize an idea. The owner's role generally is to provide the site; finance both the design and construction of the improvements; give timely, accurate feedback to the design professional; and operate the facility. Owners commonly engage the services of a design professional to conceive the design and produce the construction documents. Owners place contractors under contract to execute the work described in the construction documents.

The Design Professional and Design Consultants

Design professionals—primarily architects and engineers—offer a wide variety of services to project owners. Traditionally, they have created projects and produced construction documents and contract administration on behalf of owners, under service agreements called *design contracts*. The tumult in the design profession in the last decade has prompted architects and engineers to diversify the services they offer for a fee. Many now include facility life-cycle analysis, recycling and management, as well as practice management in the range of services they provide.

The number of different design professionals involved in producing construction drawings varies according to the type and complexity of the project. Individuals or very small organizations generate most drawings for homes. In some states, laypersons may design homes and duplexes without a design professional's license. Developing the design for a hospital, performance center, or a manufacturing facility, in contrast, may require many highly specialized design professionals who, after rigorous examination, have been licensed by the states in which they do business.

The core participants commonly responsible for the design of building construction projects include architects and landscape architects, and geotechnical, civil, structural, mechanical, and electrical engineers.

Architects, whose authority to design projects derives from state licensing boards, conceive the physical attributes of a project and incorporate local land-use ordinances and applicable building code requirements into their designs. Their interests and professional responsibilities are focused primarily on how a project looks (esthetics) and how it works as a product (that is, will it protect its users from the elements and from injury during catastrophic events such as earthquake and fire? Does it fit effectively into its environment? Does it fulfill the owner's needs?).

The number of specialists and the variety of services that design consultants offer is substantial; however, architects

commonly hire structural, mechanical, and electrical engineers for significant portions of building design work—areas of specialty for which they frequently do not have the training, license, or personnel. Large design firms, however, frequently have in-house engineering capability, which gives them more market share, greater efficiency, and more control over the design process. Such organizations are commonly referred to as *architect/engineer* (AE) firms. Regardless of the size and organizational structure of the office, the overall responsibility and liability for the design of a project reside with the architect, who becomes known as the *prime design professional* (the “prime” designer or contractor is the term given to the entity that signs a contract with the project owner).

Geotechnical engineers are registered professional engineers who are required to devote several more years to practice and/or additional education after becoming licensed civil engineers before they can legally call themselves geotechnical engineer. They are hired by owners to investigate a project site and produce a comprehensive evaluation of its soil conditions, which are recorded in a geotechnical report. Geotechnical engineers commonly investigate the past uses of a site and its hydrology, identify its soil types, determine whether and to what extent a site is contaminated, and delineate any procedures that the contractor must follow to prepare the soil for its intended role. For example, soils must be made stable and competent to bear the weight of structures and vehicular traffic for years, and soils may be used to encapsulate solid waste and to line excavations and earthen structures that will contain water.

A host of participants in the design and building process use the geotechnical report. The structural engineer uses the report to design the foundation of a structure; the landscape architect uses the report to develop the specifications for the planting and irrigation of landscaped areas; and the contractor and subcontractors use the report to determine the costs of earthwork (such as excavation, soil preparation, pile-driving, and foundation work) and evaluate the risk associated with it.

The principal concern of geotechnical engineers is how the soil will perform over time with the planned activities imposed on it. Their contracts with the owner normally require them to prepare the geotechnical report, and monitor, inspect, and approve earthwork while it is being performed. Additionally, the geotechnical engineer resolves issues that arise in the course of construction, such as the mitigation of contaminated soil that might not have been apparent during the site investigation. Beyond these functions, they do not typically get involved in design.

Civil engineers typically produce most of the construction documents related to engineering construction (streets and highways, sewer and water treatment plants, harbors, dams, bridges, and utilities). They must be licensed by the state in which they perform design work. On commercial building projects, the civil engineer plays

“It is generally recognized that an architect is a combination of artist and engineer, with the ‘art’ aspect emphasized . . . most architects have an initial and abiding concern about a project’s aesthetic appeal, impact, and propriety.

– RALPH LIEBING, *Architectural Working Drawings*, 4th edition (Wiley, 1999)

a relatively limited design role, normally taking responsibility for on-site grading, drainage, and paving plans and specifications; for off-site improvements (driveways, gutters, curbs, and sidewalks along a public thoroughfare); and for the design of certain on-site underground utilities (sewer lines, fire system supply, storm drainage, domestic water supply). Civil engineers often cite the standard specifications of the city, county, or state in which the project is located, particularly in the design of off-site improvements. These specifications are frequently tried-and-true specifications that are developed by state departments of transportation (which invest considerable funding in research) and are often wholly adopted by public works departments at the local level.

Structural engineers specialize in the design of foundations (piles, caissons), substructures (habitable portions of a structure that are below ground, such as basements), and superstructures (the portion of the project above grade, or above water in the case of bridges built across bays, lakes, and rivers). Like civil engineers, structural engineers are licensed by the states in which they do business, but they are frequently required to have specialized education and training beyond that of the civil engineer. Structural engineers—frequently hired by architectural firms for their expertise—are focused on the performance of the structural system under various loading conditions that fall under two classifications—static and dynamic loading. Static loading comprises dead loads (gravitationally imposed loads resulting from the weight of the struc-

“The qualities that most clearly set architecture apart from other established professions are its close ties to the arts and its similarities to artistic endeavors. Creativity is crucial to all professions, but for the architect it is of the highest priority. Moreover, architects produce objects that are fixed in space, highly public, and generally long lasting.

– DANA CUFF, PH.D., *Architect’s Handbook of Professional Practice*, 12th edition (American Institute of Architects, 1994)

ture and its permanent equipment) and live loads (mobile loads that are not necessarily present at all times). Furniture, snow, hydrostatic pressure (the pressure at any point exerted on a surface by a liquid at rest), and a building's occupants are examples of live loads. Dynamic loads, such as seismic activity and wind can occur suddenly, and they vary in intensity, duration, and location.

Structural engineers are responsible for protecting the lives and property of project users in a cost-effective way. Although their focus is on the performance of a structure under the loading conditions just mentioned, they should also be aware of the esthetics of the project.

Mechanical engineers involved in building project design are responsible for plumbing, sewerage and piping systems, and for heating, ventilating, and air conditioning systems (HVAC). Mechanical engineers commonly form consultant agreements with the A/E to develop and describe the plumbing and HVAC systems in buildings, which are designed to ensure the comfort and health of building occupants. Plumbing and sewerage systems provide an adequate source of water for human consumption and sanitation, and effectively dispose of wastes generated in the building. The heating, cooling, ventilating, and air conditioning equipment is used to control environmental comfort factors such as the temperature of the ambient air in a building, the mean radiant temperature of the surrounding surfaces, the relative humidity of the air, pureness of the air, and air motion. HVAC and plumbing systems in building projects present a significant design challenge, particularly in the distribution of conditioned air and piping through the structure. The involvement of mechanical engineers in the design process increases dramatically when they are involved in industrial construction projects, such as refineries, manufacturing facilities, chemical plants, waste and water treatment plants. Indeed, they may hold the prime design professional role on these projects. Mechanical engineers concentrate on the performance of the systems they design.

Electrical engineers are involved in the design of a variety of construction projects, including massive power generation and distribution systems for state and federal governments, cogeneration power plants, and building construction projects, to name a few. As with the other engineers, electrical engineers must be licensed by the state in which they conduct business. In building construction projects, these engineers design the electrical service and communications systems on the site, as well as the site lighting, usually at the request of the A/E. They also design the service and distribution systems inside the structures. In addition, electrical engineers must design and clearly spell out the type and location of electrical equipment and cabinetry and the means of distributing and controlling the power. Those engineers who work for the local utility company frequently control the design of the off-site system (the portion found in public utility easements). Electrical engineers focus on the proper sizing of

the system, the location of the equipment, the distribution of the power, and the safety of the end user.

Landscape architects, also licensed by the state, specialize in developing ornamental landscaping plans, which includes selecting trees, shrubs, ground cover, and grasses, and designing the irrigation system required to support them. The landscape architect's work may also include some site improvements (such as walkways, garden structures, screens, fencing, and water features, all of which are referred to generally as *hardscape*). Landscaping plays an important role—not only for the visual beauty it brings to a project, but for the beneficial effects that a well-conceived and -executed design can have on the energy consumption of a building, as well as on air and water pollution.

Contractors

Although the term “contractor” is loosely applied to anyone who earns income from constructing things, sole proprietorships, partnerships, corporations, and joint ventures are the common legal entities that assume responsibility and liability for constructing projects under contract with the owner. Many states regulate contractors through licensing boards, which assure the health, welfare, and safety of the public through education, testing, and, where applicable, the enforcement of state license laws.

There are distinct categories of contractor:

- **Engineering contractors** construct engineering projects such as highways, bridges, and industrial construction projects.
- **General building contractors** produce residences, multiple-family projects, commercial and civic buildings, and/or retail spaces.
- **Specialty contractors** focus on one portion of a project, such as plumbing, sheet metal and air conditioning, roofing, insulation, tile, floor coverings, or elevators.

The contractor who signs a construction contract with an owner is called the *prime contractor*. The prime contractor, for a variety of reasons, frequently hires specialty contractors for portions of the work, who become subcontractors under the construction contract. Plumbing, mechanical, and electrical specialty contractors are commonly hired in this fashion.

■ Varying Professional Viewpoints: Legal Responsibilities, Education, Training, and the Consequences of Diversity

The term “professional” has numerous definitions, among them “engaged in a specific activity as a source of livelihood,” “performed by persons receiving pay,” “and having great skill or experience in a particular field or