

Fourth Edition

CONSTRUCTION MATERIALS, METHODS, AND TECHNIQUES

BUILDING FOR A SUSTAINABLE FUTURE

EVA KULTERMANN | WILLIAM P. SPENCE

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INTENT OF THIS BOOK

This book is designed to support introductory courses on construction materials and methods, construction management, and professional programs in architecture at two-year and four-year universities. The text follows the logical progression of the construction sequence, with reference to the 2004 edition of the MasterFormat™, developed by the Construction Specifications Institute and Construction Specifications Canada. Students are able to develop a foundation of knowledge pertaining to individual building components and details, their performance requirements, process of manufacture and assembly, and systematic organization into various building assemblies. The text also gives insight into current best practices in the construction industry.

PREFACE TO THE FOURTH EDITION

This fourth edition of *Construction Materials, Methods and Techniques* has been updated to incorporate the latest advances in materials science, and construction methods and techniques. This revision continues to integrate sustainable construction innovations holistically into the larger construction context. Green, or High-Performance Construction seeks to mitigate the negative impacts of inefficient construction practices by promoting strategies that will conserve natural resources, advance energy and resource efficiency, deal responsibly with waste, and create healthy environments.

Sustainable construction is no longer a unique means of building, but rather an integral part of how the industry is now operating. Cutting-edge building materials, systems, and construction practices have been added to the existing knowledge in each chapter. In addition, new case studies of individual buildings that exemplify sustainable construction materials and technologies have been added. This book has been thoroughly updated and revised to remain current with industry technologies and standards:

- The U.S. Green Building Council and LEED V.4 rating system

- Effective construction planning for efficient material use
- Environmentally friendly building materials with emphasis on recycled content and materials that promote manufacturer, contractor, and occupant health
- Energy-efficient environmental systems
- Sustainable construction operations and practices
- New organizations and resources actively providing metrics and research

HOW TO USE THIS BOOK

This text provides a detailed view of modern construction methods and building systems and the vast array of materials and products provided by manufacturers supplying the construction industry.

The first part of the text gives a brief overview of the basic characteristics and procedures of the construction industry. Pre-construction activities, the role of design professionals, various project delivery methods, and the MasterFormat™ specification system are covered. A discussion of zoning and building codes is followed by information about some of the industry's major professional and technical organizations. A section on sustainable design and construction discusses the environmental impact of the construction industry and provides an introduction of LEED and other sustainable building certification systems.

Early in the book, the physical properties of construction materials are outlined. This overview relates to all of the materials in the remainder of the book. New materials are developed each year, and the architect, contractor, and engineer must be informed of their properties in order to use these materials in the most effective and safe manner.

The remainder of the text is organized following selected divisions of the 2004 Edition of the MasterFormat™.

Division 1 addresses general requirements, including activities such as contractor selection, price and payment procedures, administrative requirements,

and various legal controls and requirements. Additional details are given in Appendix B.

Division 2 outlines the existing conditions present on a project site, their assessment, and technologies available for remediation.

Division 3 presents a detailed study of the manufacture, types, characteristics, and properties of concrete. Consideration of the impact of admixtures, proportions, water, mixing, placing, and curing is included. Emerging technologies, such as smog-eating and bio-concrete, have been added. Drawings and photos are used extensively to illustrate cast-in-place and precast concrete structural systems.

Division 4 includes detailed information on mortar, the key to durable masonry construction. The materials, manufacturing processes, and construction techniques utilized in clay brick, concrete masonry, and stone construction are explained in detail and generously illustrated.

Ferrous and nonferrous metals are presented in Division 5. Their characteristics, mechanical properties, and practical applications are discussed. Steel frame and pre-fabricated construction systems and details are illustrated.

One of the largest divisions in the book, Division 6, covers the vast array of wood and plastic materials that are used in construction. Their properties, characteristics, and recommended applications are explained. Several chapters detail wood structural framing systems, including light wood frame, heavy timber, and innovative new panelized assemblies. The remainder of this division is used to present information on composites and plastic materials that find frequent use in modern construction.

Insulating, waterproofing, and sealing buildings against the weather are covered in Division 7. Structures are exposed to a variety of weather extremes, including temperature swings, driving rain and wind, and subsurface water. Walls, ceilings, and floors must be properly insulated and sealed against moisture penetration. Bituminous materials, bonding agents, sealers, and sealants are covered. Details, components, and materials commonly used for both residential and commercial roofing systems conclude this division.

The types, styles, methods of operation, and materials used for doors and windows are expanding continuously. Many of the products currently employed are illustrated in Division 8, in addition to stock and custom-made storefronts. Glass is

used extensively in façade and window assemblies, so the types, properties, and uses of the numerous glass products available are discussed. New and innovative glass products are increasing the range of uses and applications of the material in modern commercial construction. Finally, an entire chapter is devoted to discussing and illustrating various types of cladding systems that find common use in commercial buildings.

Finishing the interior of a building involves an incredibly diverse range of products in any area of construction. Division 9 includes interior finishes; decorative and protective coatings; gypsum, lime, and plaster products; acoustical finishes and materials; and all types of finish flooring. The construction and finish of interior walls, partitions, and ceilings, and their properties and fire resistance are integrated.

Division 10, 11, and 12 cover the variety of specialty products, equipment, and furnishings that find use both within buildings and on project sites. Examples include visual displays, telephone enclosures, vending equipment, casework and furniture.

A most interesting compilation of special construction assemblies are found in Division 13. Special structural systems refer to innovative long-span structures that are used to provide enclosure for a variety of activities. This division discusses and illustrates a diverse offering, including air-supported and fabric structures, geodesic domes, and other pre-engineered assemblies.

Division 14 discusses and illustrates the range of conveying systems in current use, including conveyors, elevators, escalators, moving walks, and material-handling systems.

Division 21 organizes the many complex factors related to the regulation, operation and maintenance of fire-suppression systems, including installation, instrumentation, and control. Water, carbon dioxide, clean-agent, wet chemical, and dry chemical fire-extinguishing systems are explained.

A basic need for a successful building is a well-functioning plumbing system. Division 22 summarizes the system of pipes and other devices installed in a building for the distribution of potable water and the removal of waterborne wastes. Innovative new technologies and fixtures for a variety of applications are outlined.

Division 23 is a very large division including heating, ventilating, and air-conditioning systems. Basic methods of heat transfer, the fuels employed, and the

types of heating and cooling systems and equipment are explained and illustrated.

Electrical distribution systems inside a building supply electrical power as needed and transmit information through an internal communications system. Division 26, Electrical Systems, carries the discussion from the generation and transmission of electrical power to the service components in both residential and commercial buildings. Renewable power systems are illustrated, and extensive information on lighting technologies is accessible. Equipment for controlling and operating the electrical system, as well as equipment used for communication, such as alarm, television, public address, and other communication systems, is presented.

Division 28 covers the various electronic safety and security systems in buildings and related exterior areas where security is important. Video surveillance and personal protection systems are included, as are electronic detection and alarm systems for fire detection.

Division 31 encompasses the widerange of site construction activities, including soils and subsurface investigations, site preparation, excavations, earthwork, foundations, and the installation of utilities and drainage systems.

At the end of each chapter are materials providing the reader with a means of reviewing what has been read and reinforcing the learning experience. Key terms are listed. Sources of additional information are provided to enable the reader to explore areas in greater depth.

A master glossary at the end of the book provides an additional means of locating definitions. Appendix A provides the MasterFormat numbering system in its entirety. Appendix B provides details concerning the information in Division 1, General Requirements. Appendix C provides an extensive listing of U.S. and Canadian professional and trade organizations. These organizations provide information that is vital to the continual improvement of materials and construction techniques. They develop materials standards and installation specifications, and publish building codes, manuals, and technical reports on an ongoing basis. Readers can reference this information to provide additional insight as the chapters in this book are read. Detailed metric information is available in Appendix D. This information is essential because construction is moving toward using the metric system in the future. Appendix E lists the weights of commonly used construction materials. Appendix F gives the names and atomic symbols of selected chemical elements, and Appendix G provides data on the coefficients of thermal expansion of selected construction materials.

FEATURES OF THIS BOOK

This book includes many features to assist students as they progress through the chapters:

- Correlations to the MasterFormat™ are included at the beginning of each chapter, providing students with a quick reference to this essential manual.
- Individual case studies provide examples of the application of new construction materials and strategies.
- Inserts on Construction Materials, Methods, and Techniques provide detailed information on selected areas of interest.
- Learning Objectives and Review Questions open and close each chapter to provide students with a framework for study to ensure full comprehension of the material.
- Key Terms are in color throughout the text and are listed at the end of each of the chapters, highlighting essential terminology. Complete definitions are provided in the Glossary.
- Activities encourage students to apply what they have learned in the chapter and to build experience for actual on-the-job tasks.
- Additional Resources are listed at the end of each chapter that point students in the direction of organizations, periodicals, Web links, and other references to further learning on selected topics.

NEW TO THIS EDITION

This new edition emphasizes innovative materials and technologies that encourage the student of construction to aggressively deal with the challenges of a changing industry. In light of advances in the field, many topics have been updated whereas others have been reorganized. New topics include:

- An expanded discussion of moisture transfer within assemblies and the technologies available to effectively control it.
- The addition of door and window nomenclature and the hardware associated with their installation.
- Additional information on new cladding technologies, including structural glazing, structural standoff systems, and new metal panel assemblies.
- A new section on fire and smoke management in buildings.

- New information on recent advances in telecommunications and data systems.
- Additional Case Studies, including the Omega Center, The Passive House, and the Lewis Center for Environmental Studies, provide detailed information on the application of emerging sustainable construction technologies.
- The entire text has been updated with extensive new photos and revised detail drawings of the construction process for various assemblies.

SUPPLEMENTS

Instructor Companion Site

Spend less time planning and more time teaching with the **Instructor Companion Site**: Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via www.cengage.com/login. Access and download PowerPoint presentations, images, instructor's manual, and more.

Cengage Learning Testing Powered by Cognero

The Instructor Companion Site features **Cengage Learning Testing Powered by Cognero**. This flexible, online system allows you to:

- author, edit, and manage test bank content from multiple Cengage Learning solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom or wherever you want

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- **Personalized Teaching:** Becomes yours with a Learning Path that is built with key student objectives. Control what students see and when they see it. Use it as-is or match to your syllabus exactly—hide, rearrange, add, and create your own content.
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- **Promote Better Outcomes:** Empower instructors and motivate students with analytics and reports that provide a snapshot of class progress, time in course, engagement and completion rates.

ABOUT THE AUTHORS

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Disclaimer

The information presented in this book was secured from a wide range of manufacturers, professional and trade associations, government agencies, and architectural and engineering consultants. In some cases, generalized or generic examples are used. Every effort was made to provide accurate

presentations. However, the author and publisher assume no liability for the accuracy of applications shown. It is essential that appropriate architectural and engineering staff be consulted and specific information about products be obtained directly from manufacturers.

Procurement and Contracting Requirements CSI Master Format™

- 00 10 00 Solicitation
- 00 20 00 Instructions for Procurement
- 00 30 00 Available Information
- 00 40 00 Procurement Forms and Supplements
- 00 50 00 Contracting Forms and Supplements
- 00 60 00 Project Forms
- 00 70 00 Conditions of the Contract
- 00 90 00 Revisions, Clarifications, and Modifications



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DIVISION 01



General Requirements

- 01 00 00 Summary
- 01 20 00 Price and Payment Procedures
- 01 30 00 Administrative Requirements
- 01 40 00 Quality Requirements
- 01 50 00 Temporary Facilities and Controls
- 01 60 00 Product Requirements
- 01 70 00 Execution and Closeout Requirements
- 01 80 00 Performance Requirements
- 01 90 00 Life Cycle Activities



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The Construction Industry: An Overview

LEARNING OBJECTIVES

Upon completion of this chapter, the student should be able to:

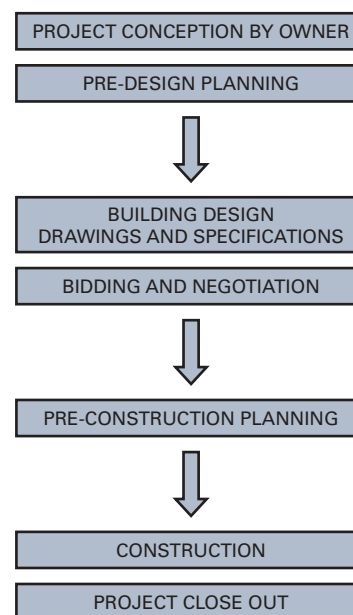
- Gain an understanding of the scope of the construction industry.
- Identify the different phases and activities that make up the building design and construction planning process.
- Recognize the types of drawings and specifications used in a set of construction documents.
- Be familiar with the roles and responsibilities of owners, architects, and contractors.
- Recognize the make-up and organization of construction documents.
- Categorize the types of project delivery methods used in commercial construction and how they are administered.
- Describe the phases and administrative procedures that serve to organize the on-site construction phase.

The construction industry is one of the largest business activities in the United States, encompassing establishments engaged in the construction of buildings and larger engineering projects, such as roadways and utility infrastructure. Construction with all of its related and supporting industries is vital to the economic health of the country, accounting for an annual average of 5 to 10 percent of our gross domestic product.

Compared with other large industries, some characteristics are unique to the planning of buildings and infrastructure. Most new buildings are custom designed and constructed, involving long development schedules. Because each project is site specific, its execution is influenced by physical, social, and regulatory conditions, such as weather, availability of skilled workers, and local building codes. Since the service life of a commercial building can be more than 50 years, future technical requirements must be considered throughout the planning process. Because of the technological complexity of construction, building plans must be flexible enough to allow for changes and adjustments both during construction and after.

The process by which a building or other project is designed and constructed can be divided into four discreet project phases (Figure 1.1). The *pre-design phase* sets the initial objectives and criteria under which a building will be planned. The *design phase* determines the actual geometry, materials, and performance characteristics of the finished structure. The *preconstruction phase* selects the

Figure 1.1 The process by which a building or other project is designed and built can be divided into four discreet project phases.



various project participants and outlines their contractual agreements. Finally, the *construction phase* is involved with the physical realization of the finished building.

CONSTRUCTION: A DYNAMIC INDUSTRY

The construction industry is divided into three major areas: building construction, heavy or infrastructure construction, and industrial construction (Figures 1.2 through 1.4). *Building construction* involves the erection of a building on a piece of property. This includes residential, commercial, civic, educational, religious, and agricultural buildings, among others. While many building projects consist of new construction, a considerable amount of construction activity is concerned with the renovation, repair, or the provision of additional space for existing buildings. *Heavy construction* is the term used for larger infrastructure projects, such as highways, bridges, canals, dams, subways, tunnels, utility piping systems, water control construction, and communications networks. Heavy construction projects are usually financed by governmental agencies and other institutions, or are incorporated into master plans (such as universities) to serve the public good. *Industrial construction* refers to the building of large-scale manufacturing, and processing plants or utility generation installations. Regardless of the type

Figure 1.2 Building construction involves the erection of a building on a piece of property.



Figure 1.3 “Heavy construction” is the term used for larger infrastructure projects, such as highways, bridges, and canals.



Figure 1.4 “Industrial construction” refers to the building of large-scale manufacturing, processing, and other mechanized plants, or utility generation installations.



of construction, each requires planning, financing, and compliance with regulatory constraints.

All construction involves the confluence of skilled workers, architects, engineers, and a vast array of

materials and equipment to execute a carefully conceived plan. Supporting them is a broad range of industries that manufacture the materials and components designated for a project. These can include suppliers of aggregate and cement products, manufacturers of lumber, structural beams, doors and windows, siding, roofing, and finish materials, and dealers of appliances and mechanical equipment (Figure 1.5). Many manufacturing endeavors involve the cutting, shaping, and assembling of various materials into a useful product. Each product area has a tremendous variety of materials and installation methods, requiring extensive technical expertise. Consider just the electrical and mechanical components involved in servicing a building and the procedural knowledge required to design, specify, manufacture, and install them.

Figure 1.5 The construction industry is supported by a broad range of industries that manufacture the materials and components designated for a project.



Construction materials and methods are constantly changing fields with new products and equipment being developed continuously. The people involved in construction must be educated and constantly kept up to date as new materials and methods of construction are introduced. They need to maintain membership in professional organizations, attend conferences, and read professional journals to recognize the value of new technical developments and their proper application.

The industry is currently in the midst of profound changes caused by unprecedented environmental forces that are reshaping all areas of production. The most important challenge of the twenty-first century is to develop strategies of using natural resources in ways that will sustain the natural environment for generations to come. The importance of the construction industry instituting changes that promote both energy and resource efficiency cannot be overstated and will be discussed in detail in Chapter 2.

PRE-CONSTRUCTION ACTIVITIES

Owners, both public and private, plan buildings and other construction projects to accommodate desired functional and spatial needs. The design and construction of a building project is the result of the collective ideas, talents, and services of a large and diverse group of professionals. A vast array of planning decisions must be made at the onset of any construction project. These include an evaluation of the vision for a project, its scope, functional requirements, the determination of a site, budgets and financing, project scheduling, and assurance that regulatory constraints such as zoning and code regulations will be satisfied.

One of the first tasks in commencing larger construction project is in the selection of the project team participants. Members of this multi-disciplinary group are selected based on their professional standing, experience with projects of similar size and scope, and sometimes, previous working collaboration among the various team members (Figure 1.6). The established project team works together in developing a project plan that addresses the roles and responsibilities of each member, and identifies at what point in the process each member will join in the work.

Figure 1.6 The design and construction of a building project is the result of the collective ideas, talents, and services of a large and diverse group of professionals.



Regardless of size, the three main players in any construction team are:

- The owner that initiates the project
- The architect and engineers who design the building
- The general contractor who completes the actual construction

Supporting these main players is a team of other professionals, each involved with particular aspects of the larger project. These include:

- Consultants that provide professional services to the architect, contractor, or owner
- Subcontractors who perform portions of the work under the direction of the general contractor. Product representatives who assist with submittals and furnish field services such as providing consulting and inspecting the installed work
- Manufacturers who produce materials or products, and material suppliers who furnish materials and products of construction
- Testing laboratories and inspection agencies provide quality control services to the owner and contractor
- Financial advisers and institutions that arrange the project financing, and attorneys who coordinate the legal and contractual issues of the project
- Insurance companies that provide risk coverage to the owner, contractor, and design consultants
- Authorities and regulatory agencies that have jurisdiction over the construction and establish standards in the form of codes, ordinances, and permits

Once the project team is established, it begins the investigation of the multitude of project parameters required for the development of project definition and feasibility, referred to as the pre-design phase.

Pre-Design and Design Development

Owners most often procure the services of an architect or an architect/engineering/contracting firm (AEC) to help in the development of project definition and feasibility. Once an architect or AEC firm has been identified, the pre-design portion of the work can begin. In this phase, the architect, other design consultants, and the owner mutually determine the goals and objectives of the project. Most projects begin with a thorough examination of the existing needs, goals, and constraints that will influence a design. **Programming** is the research and decision-making process that determines the specific set of needs that a building is expected to fulfill, and identifies the scope of work to be designed.

Design sketches and feasibility studies are developed as a series of alternatives for approval by the owner. Early design efforts focus on establishing what is known as the design intent. **Design intent** is a statement that defines the anticipated aesthetic, functional, and performance characteristics of the finished building or project.

Functional and spatial requirements, including sizes and adjacencies of spaces, are defined and tabulated. The architect will conduct initial checks that zoning and building code requirements can be met within the design concept. Surveys and drawings of existing conditions are obtained or prepared. The result of pre-design work will be a written program. A program is a written document that explains design intentions, controls, and standards for a project, including detailed space requirements and the types of equipment and systems to be used. This phase is complete when the owner and architect agree that the scope of work, anticipated construction cost, and time schedule are well defined.

During design development, initial design ideas are further developed into detailed drawings of the building, indicating exact sizes and relationships between building elements. Architects use a system of orthographic drawings of a building or structure to simplify the graphic understanding of complex forms. The **floor plan** is a representation of a building looking down after a horizontal plane has been cut through it and the top portion removed (**Figure 1.7**). A **building section** gives a view of a building after a vertical plane has been cut through it and the front portion removed (**Figure 1.8**). An **elevation** drawing shows the exterior façade of a building, delineating geometries and the materials of construction (**Figure 1.9**).

Since plans, sections, and elevations cannot show all the specific aspects of the construction, larger-scale detail drawings are used to explain the joining of materials, elements, and components of the various building assemblies. Detail drawings are keyed into plans and sections drawings to give more information on the specific means of assembly. Other information included in the drawings are schedules that reduce the amount of information that must be placed directly on the drawings themselves. Door and window schedules, for instance, use graphic symbols on the plan drawings that are keyed into a schedule, a table format that lists the type, size, and operating characteristics of each element. Schedules are also used for interior finishes, partition types, and structural elements of a building.

Most architectural drawings generated today use a system of **computer-aided drafting**, known as CAD. Before the advent of CAD, drawings were painstakingly generated by hand, and making significant changes to the drawings was difficult and time consuming. CAD software enables the design team to efficiently create and manage modifications to the architectural drawing set. The use of the software also facilitates effective communication between the various consultants on a project through digital file sharing.

Figure 1.7 The floor plan is the most-often-referred-to drawing in a set of construction documents showing the relationship of spaces and overall building dimensions.

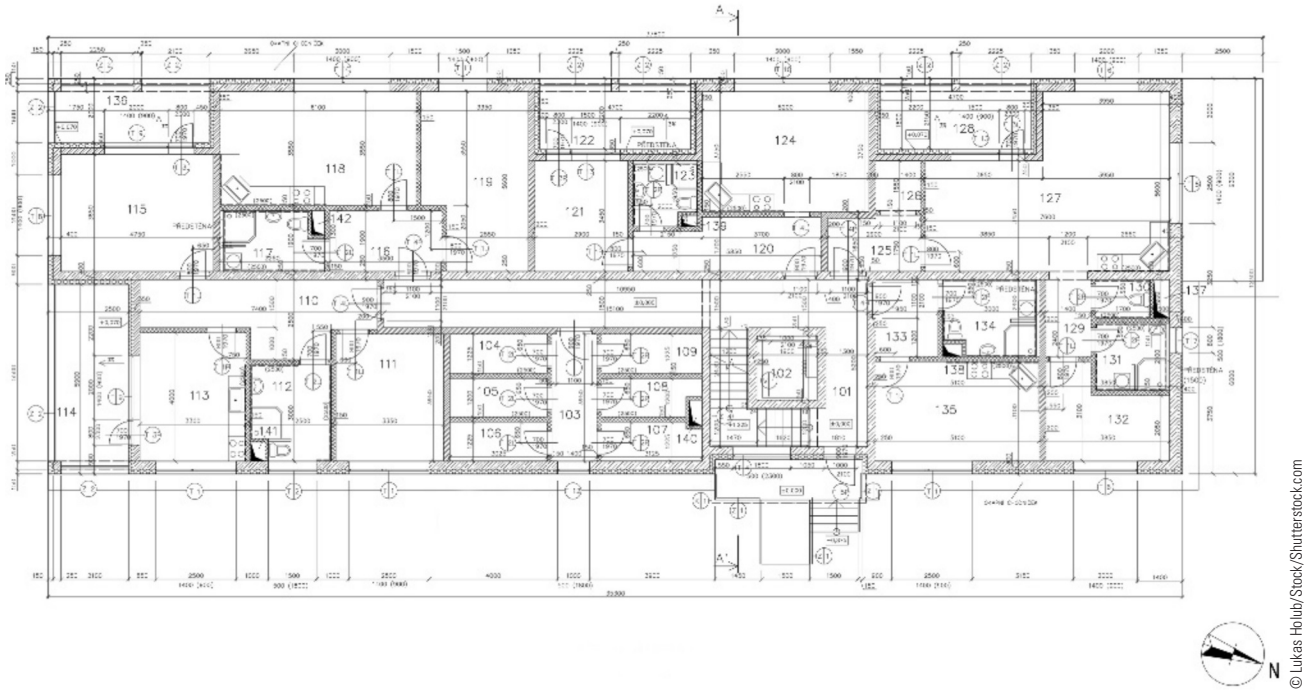


Figure 1.8 A building section graphically illustrates a cut through the building from foundation to roof, showing interior spaces and the materials of construction.

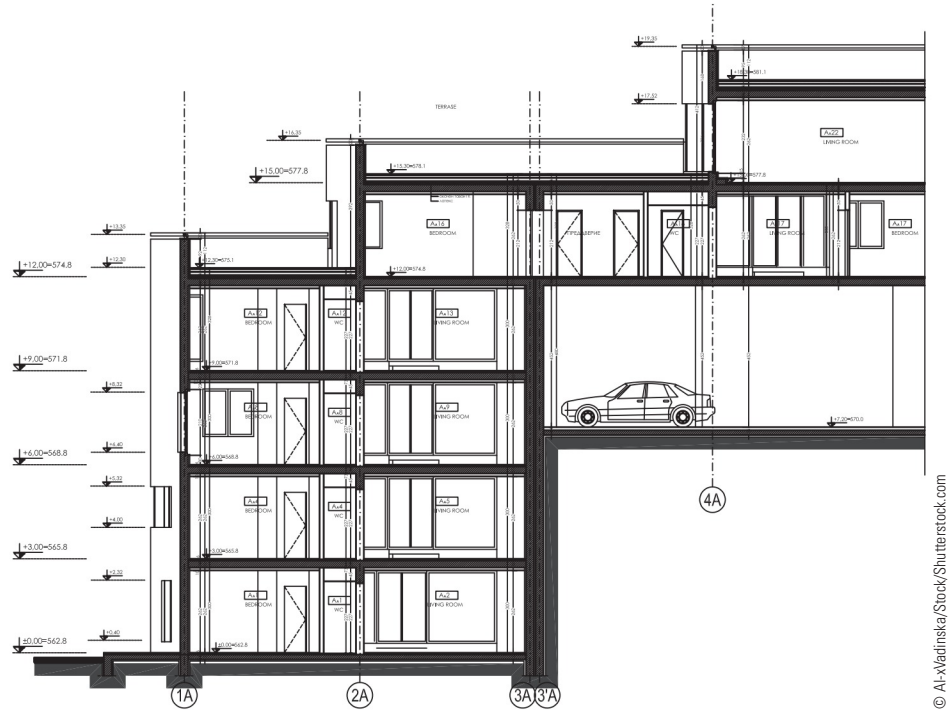
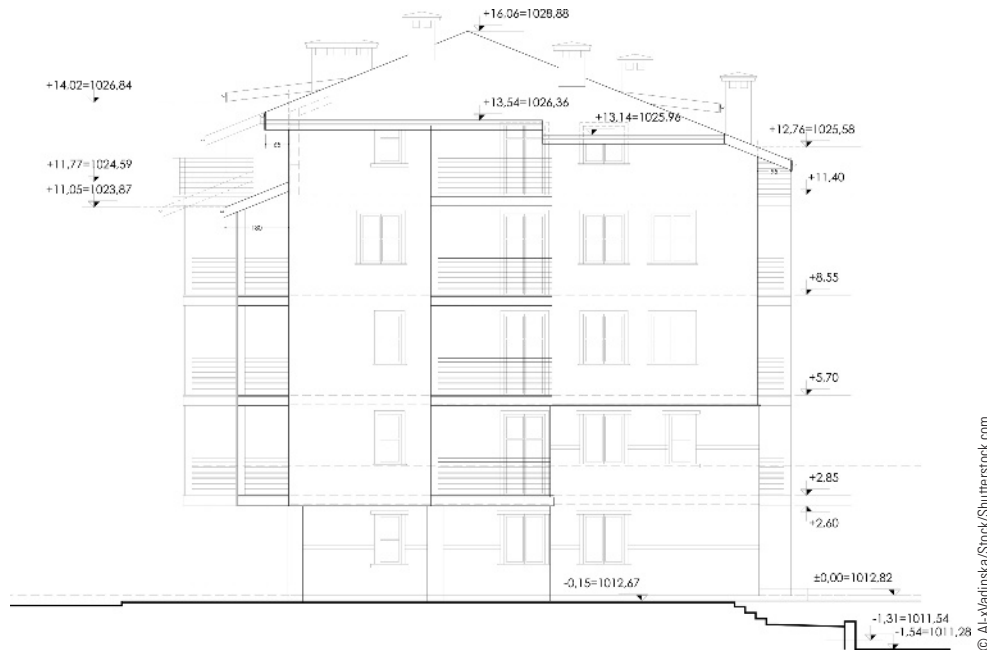


Figure 1.9 An elevation drawing shows the exterior façade of a building, delineating geometries, building heights, and the materials of construction.



Because of the multitude of systems under consideration at this stage, the architect will normally hire the services of other design consultants in the development of systems. Structural, mechanical, electrical, plumbing and civil engineers, fire protection consultants, interior and landscape designers, and cost-estimating consultants are common on most projects of larger scale. Depending on the type of building being designed, other specialty consultants, such as traffic and parking consultants, lighting designers, or acoustical specialists, may be brought into work with the team. During this stage of the work, most substantive decisions regarding the structural frame, mechanical systems, materials, and construction methods are determined. If a contractor for the project has been selected, it is advisable to include them in the development of solutions for constructability and other technical aspect of the construction.

Building Information Modeling

Efforts are currently under way to develop new ways of managing the complexity of the interdisciplinary information that goes into the design and construction phase activities of a building. The National Institute of Building Sciences (NIBS) has formed the buildingSMART alliance, whose aim is to optimize a computer software system that standardizes the design, construction,

operation, and maintenance process for buildings by compiling all of the related information in a single electronic format. The software, known as **Building Information Modeling (BIM)**, has revolutionized the way buildings are designed, constructed, and maintained. Architects and engineers use BIM to generate a three-dimensional model of a building with embedded links to other project information. In its current state, BIM has a range of capabilities, including drawing, construction estimating and scheduling, interdisciplinary coordination, and generating fabrication protocols. BIM also runs analysis of structural design solutions, building code compliance, projected energy performance and consumption models, and daylight penetration (Figure 1.10).

The buildingSMART alliance publishes the National BIM Standard – United States® which consists of nineteen reference standards, terms, and definitions; nine information exchange standards; and eight practice guidelines to support users in their implementation of BIM.

The use of the Building Information Modeling system results in enhanced efficiencies during the construction process itself. Construction methods, sequences, and details can be studied using the modeling process, resulting in fewer mistakes, fewer changes, and, ultimately, shorter construction schedules. The software allows for complete material takeoffs to be generated, eliminating the painstaking process of calculating material quantities

Figure 1.10 A BIM model illustrating the capability of visualization and analysis of various building systems.

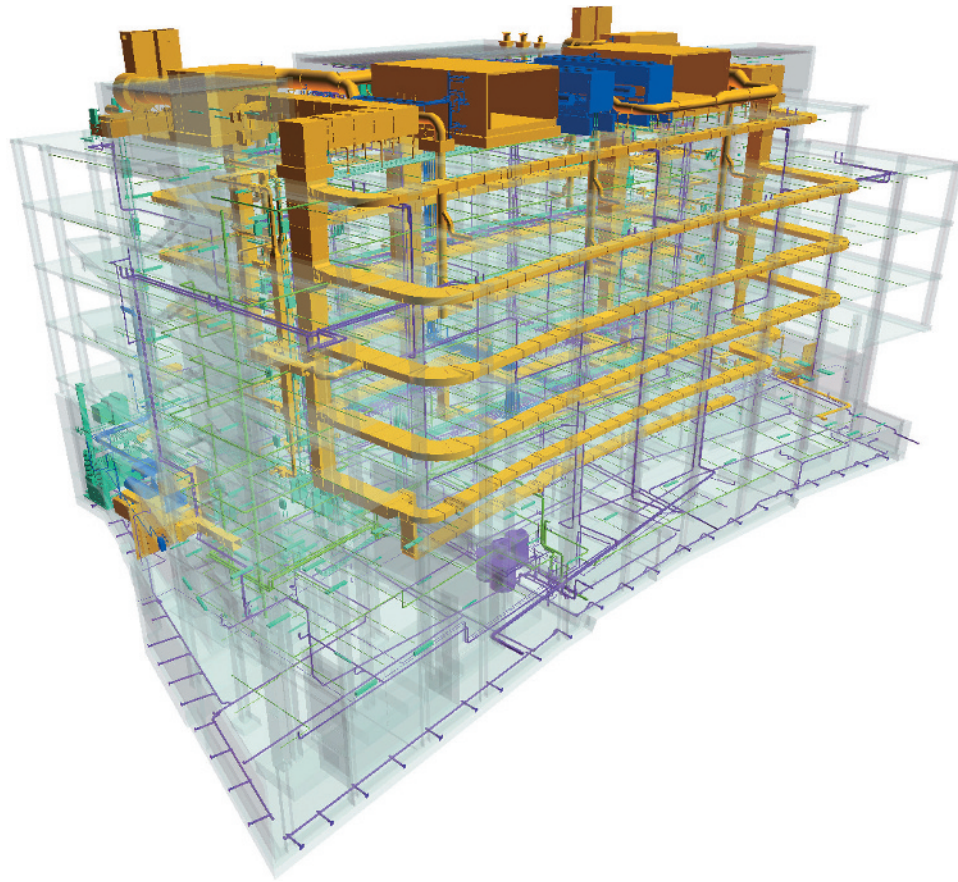


Image courtesy of Mortenson Construction and McKinstry Company

by hand. By designing in a three-dimensional model systems, integration can be visualized and better coordination realized. Information from models can be fed directly to material fabricators, eliminating the need for shop drawings and ensuring tight dimensional tolerances. Students of construction should become familiar with the BIM software, because its use in the construction industry is becoming widespread.

Construction Documents

Once all basic decisions have been approved by the owner, the architect and consultants will commence with the final phase of the design process, the preparation of construction documents. *Construction documents (CD)* consist of two interdependent components: the drawings and the specifications.

Construction drawings, sometimes referred to as working drawings, visually outline the dimensional relationships between all aspects of the building including their location, form, size, and quantities, as well as the materials used, and their colors and textures. Working

drawing sets are organized from the general overall building plans, sections, and elevations, down to the level of the detail, indicating fasteners and connections. Full drawing sets are collated according to discipline and include civil, architectural, structural, mechanical, electrical, and plumbing (MEP), and fire protection sheets, among others (Figure 1.11). The drawings are the basis on which the contractor generates cost estimates, and are used to guide the actual construction of the building on the site.

Since working drawings cannot give all of the details involved in describing the quality and performance characteristics of specific materials, construction methods, and project procedures, the construction documents include a written manual called the specifications. The *specifications* describe in writing more detailed information on the exact types of materials to be used and the ways in which construction processes are conducted. The drawings graphically indicate the relationship between elements, while the specifications spell out the specific types, qualities, and properties of those materials; their installation; and other information not shown in the drawings.