FUNDAMENTALS OF RESIDENTIAL CONSTRUCTION

FOURTH EDITION

4

EDWARD ALLEN · ROB THALLON
ALEXANDER SCHREYER

WILEY

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Fourth Edition

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Edward Allen
Rob Thallon
Alexander C. Schreyer

Featuring the Drawings *of*
Joseph Iano

WILEY

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Contents

Chapter 6
Masonry 141

Chapter 7
Concrete 179

PART THREE
Wood Light Frame House Construction 199

Chapter 8
Rough Site Work 201

Chapter 9
Foundations 221

Chapter 10
Floor and Wall Framing 251

Chapter 11
Roof Framing 281

PREFACE

Preface to the Fourth Edition

The book that you hold in your hands is the fourth edition of what has since its first publication in 2002 become the standard textbook on residential construction. When its preceding book, *Fundamentals of Building Construction, Materials and Methods*, was first published more than 30 years ago, it filled a void and quickly was adopted by hundreds of colleges and universities as a text for general courses in construction technology. It also precipitated immediately the first of a growing stream of requests from teachers for a companion volume that would concentrate on residential construction while retaining the qualities of the parent book. The authors were pleased to respond to those requests with Fundamentals of Residential Construction. This book has since grown steadily over the previous three editions and now—in its fourth edition—provides even more improvements, both in terms of content as well as its delivery. All chapters have been edited to reflect the latest in construction technology and describe traditional but also emerging methods. Content has been reorganized in a more logical fashion and the chapter on multifamily construction has been significantly expanded.

This fourth edition inherits several important traits from its predecessors: It is straightforward and readable, and it contains extensive drawings and photographs. These elements are blended on attractive pages, and, for the reader's convenience, each illustration appears on the same two-page spread as its referencing text. Retained, too, is the concern for both technical and aesthetic matters, because the authors believe that those are important for the quality of buildings and the lives of the people who inhabit them.

New to the fourth edition is a chapter on sustainability aspects of construction. Green building and sustainability have over the past years grown from an add-on to traditional design and construction practices to an integral requirement for good construction. Customers now demand high-performance houses and building codes put more stringent energy-efficiency requirements on every construction project, large and small. The chapter on sustainability provides the reader with a thorough background on the topic, which is strengthened through updated "Green building with…" features in each chapter of the book.

With much of today's construction planning and execution based on the computer, this fourth edition features not only new Web Links sections for each chapter, but also a thorough set of digital 3D exercises. Those exercises allow the reader to virtually practice the presented construction topics and their assemblies without "getting their hands too dirty" (or wasting material). The exercises, which are linked to many locations in the chapters through sidebar icons, are easy to accomplish practices for individual or classroom use.

This fourth edition also has Alex Schreyer joining the team of the original authors, Edward Allen and Rob Thallon. Alex Schreyer, Senior Lecturer and Director of the Building and Construction Technology Program at the University of Massachusetts, is extraordinarily grateful to have been chosen by the original authors as well as the editorial team at John Wiley & Sons, to carry on the educational legacy of this book. Having this well-written, beautifully illustrated, and comprehensive tome on residential construction as a resource has allowed many students, practitioners, and laypeople to learn about our dwellings and explore in an approachable and easily comprehensible manner how they are produced. Alex intends to continue this tradition with reverence to the original intent of this book and a keen eye for current tendencies in construction.

Although all three authors teach in schools of architecture and construction, they are not mere ivory-tower academicians. Between Edward Allen and Rob Thallon, they are the architects of well over 200 constructed houses and innumerable remodeling projects. They have spent countless hours on construction sites, working with residential builders, developers, contractors, and craftspeople on the day-to-day minutiae of getting houses built.

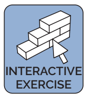
They have both constructed houses with their own hands, from excavation to finishes. In addition, both have authored books on construction that have found enthusiastic acceptance in the building professions. Alex Schreyer adds to this a background in construction, engineering, wood science, and digital design. He is the author of "Architectural Design with SketchUp," the main reference on this popular 3D modeling software. He is also a researcher and sought-after speaker on various aspects of wood structural design and digital planning in construction.

The team of authors brings to the table a broad regional background that includes wintry New England, the damp but mild Pacific Northwest, as well as Canada. To extend the boundaries of their own experiences, the authors also have consulted frequently with colleagues in other regions of the United States and Canada.

Online Resources

This fourth edition of Fundamentals of Residential Construction comes with online resources for instructors and students, which can be found by going to www.wiley.com/go/resconstruction4e.

A set of interactive exercises that are new to this fourth edition are linked to specific locations in the text via an icon (shown as a sample next to this paragraph). The reader is encouraged to seek those exercises out and practice constructing specific building details virtually in 3D on the computer when this would allow for a better understanding of the presented content.



As an example, in a section about window framing, there is an exercise where the framing around a window (including studs and headers) needs to be assembled by copying, placing (moving and rotating), and cutting (stretching) provided pre-modeled items.

These exercises require only minimal understanding of 3D modeling software and all of the necessary knowledge to complete them can be acquired easily by watching an introductory video (provided on the companion website). For the instructor, they provide pre-made, "hands-on" exercises that can be assigned to even large classes or as part of an online course.

Acknowledgments

Together, Edward Allen, Rob Thallon, and Alexander C. Schreyer are very grateful to all the people at John Wiley & Sons, Inc., who have given so much of themselves to producing this book. We thank especially Publisher Amanda Miller, Editor Margaret Cummins, Developmental Editor Lauren Olesky, and Senior Production Editor Doug Salvemini. Like the quality of a house, the quality of a book is proportional to the skill and dedication of the individuals on the production team.

For Edward Allen

Edward Allen is grateful to be teamed with Rob Thallon, a gifted teacher, accomplished author, and award-winning architect of some of the loveliest, most livable houses ever constructed. He offers apologies to Dee Etzwiler and Carter and Claire Thallon for involving their husband and father, respectively, in an enterprise that kept him holed up in his office for many hours over a period of several years. He thanks Rob for sharing his vision of excellence and making this book so special. He is grateful to Joseph Iano, whose ideas and innovations for the parent book still shine in this book. And he thanks Mary M. Allen for her support and encouragement.

For Rob Thallon

Rob Thallon is especially thankful to Edward Allen, his mentor and friend, for selecting him to work on this important project. He also thanks his coauthor for having been his keenest critic and most fervent champion during his previous writing projects, and he notes that their collaboration on this book has deepened his appreciation for the clarity of Edward Allen's vision and his language. He wishes to thank the talented illustrators Mu-Yun Chang, Lisa Ferretto, Laura Houston, and Dave Bloom, who helped develop and render drawings for the original edition; and Ben Rippe and John Arnold, who contributed illustrations and organizational brilliance to the second edition. Finally, thanks and a deep appreciation to Jesse Crupper, Dee Etzwiler, and Hank Warneck, whose research, photography, and illustrations were instrumental to the quality of this third edition.

For Alexander Schreyer

Alex thanks former Wiley editor Paul Drougas for originally championing this project and his joining of the original team of authors. He also thanks his colleagues Ben Weil and Ho-Sung Kim for their technical reviews and very helpful feedback on the manuscript. He also thanks his wife, Dr. Peggi Clouston, for her encouragement, support, love, and the many discussions about building, which they both feel highly passionate about. Finally, he thanks his two beautiful girls, Sophia and Mackenzie, for their patience when the manuscript was due and he had to choose to work at his computer rather than playing with them in the garden.

Alex dedicates his contributions to this book to his wife, Peggi.

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FUNDAMENTALS OF RESIDENTIAL CONSTRUCTION

Fourth Edition

PART ONE

Context for Building


DEWALT

THE CONTEXT FOR RESIDENTIAL CONSTRUCTION

1

1.1 History

People have been building houses for thousands of years. These houses have provided shelter, afforded privacy, defined territory, enhanced status, and, in some cases, provided defense. The earliest houses were opportunistic uses of naturally sheltered places like caves and were more like nests than houses. As time passed, people learned to assemble materials collected from nature to make simple freestanding structures. In many cultures, these structures have evolved into highly crafted houses that are elegant expressions of cultural patterns and values (Figures 1.1 and 1.2). In the past 150 years, technology has afforded us conveniences such as electricity, plumbing, and automatic heating and air conditioning that have made houses, in the words of the famous architect Le Corbusier, "machines for living." Most recently, housing in the industrialized world has

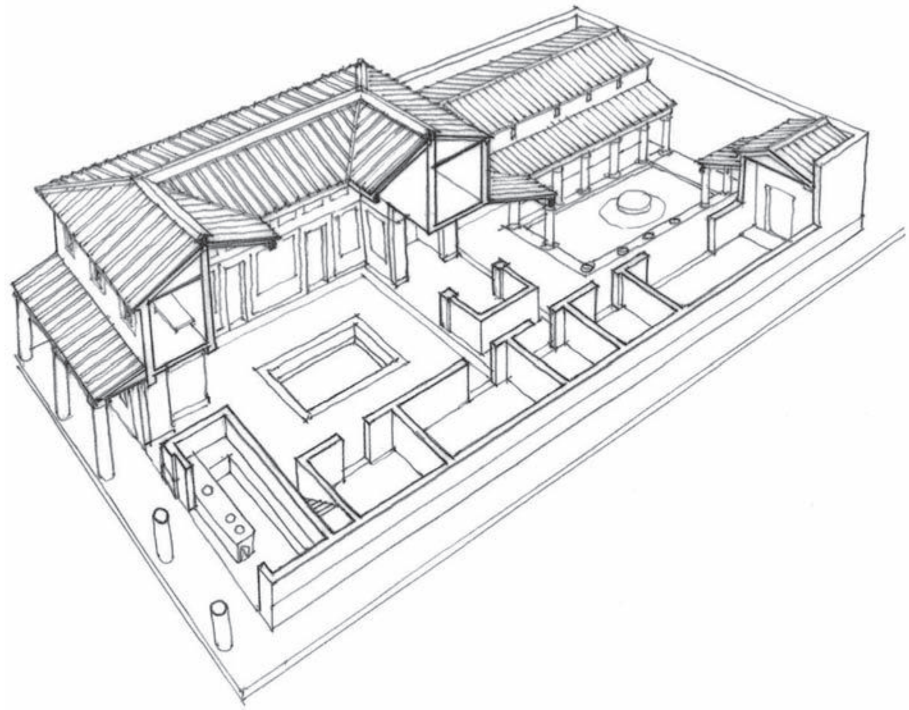

FIGURE 1.1
The Roman domus, developed more than 2000 years ago, had individual rooms for common daily functions and was built around a central courtyard that helped to cool the rooms naturally.
Source: Reproduced with permission of John Wiley & Sons, Inc.

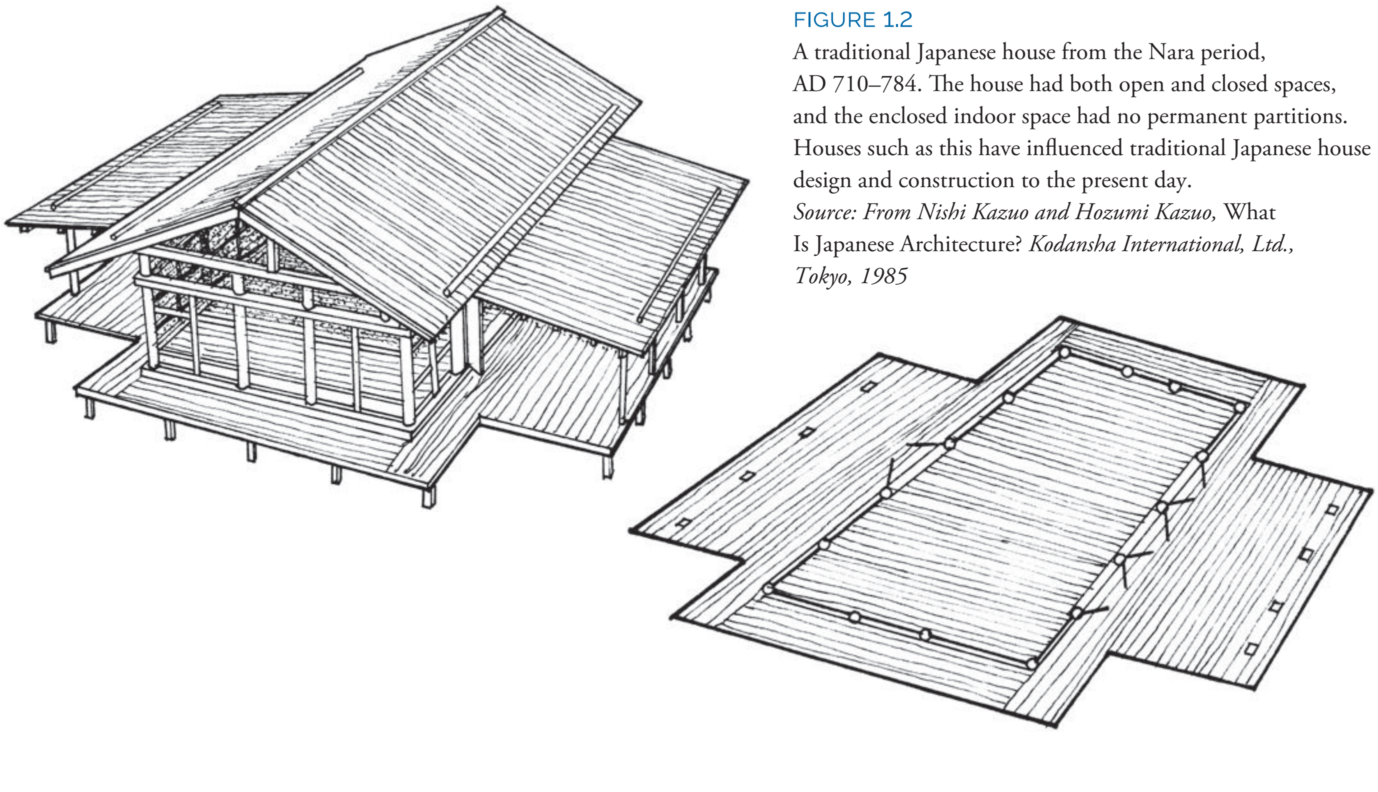

FIGURE 1.2
A traditional Japanese house from the Nara period, AD 710–784. The house had both open and closed spaces, and the enclosed indoor space had no permanent partitions. Houses such as this have influenced traditional Japanese house design and construction to the present day.
Source: From Nishi Kazuo and Hozumi Kazuo, What Is Japanese Architecture? *Kodansha International, Ltd., Tokyo, 1985*

emphasized energy conservation and efficient production. Today, residential designers have a rich history from which to draw, and residential builders have the best tools and most complete palette of quality materials with which to build that have ever existed. The challenge for this new generation of designers and builders is to sustain and improve the built environment in the face of decreasing natural resources and increasing population.

Throughout history, the forms of houses have differed from region to region. House form varies primarily in relation to climate, to available building materials and tools, and to the culture of the people being housed. The influence of climate on house form is dramatically demonstrated by the comparison of the igloo in polar regions with the open-sided palm-thatched structure in tropical zones. The forms of houses in the same climate can vary also, however, because of the use of different building materials. In Mexico, for example, the introduction of reinforced concrete has spawned a collection of flat-roofed houses that contrast sharply with the traditional sloped roof made of timber covered with clay tiles. The culture of the people being housed also has considerable influence on house form. Native American tribes who were nomadic built dwellings such as tepees that were easily folded and transported, while rooted tribes from the same region built stationary houses of earth, stone, and wood.

The modern North American house has evolved largely from 16th-century timber-framed houses that had been developed in response to the climate, materials, and culture of northern and central Europe (Figure 1.3). Early pioneers landing on the eastern shores of North America found a new homeland rich with timber that had to be cleared to make way for development, so it was logical to use wood for the construction of new houses. The settlers soon discovered, however, that the European tradition of exposed timber frame was inadequate in the harsher climate of the New World, so they developed an exterior skin of clapboards to protect the frame (Figure 1.4). This wooden structure and its details evolved over the years in response to changes in tools, transportation, and social norms. Other building materials and systems such as brick and stone masonry developed simultaneously but were never as prevalent in North America as the clapboard-clad, timber-framed building.

Then, in the 1840s, after more than 300 years of development, the heavy timber frame yielded its preeminence almost overnight to a new system of construction, the *wood light frame.* The emergence of the light frame was made possible by two technological developments: mass production of the inexpensive wire nail and the ability of water-powered sawmills to cut large quantities of consistently dimensioned lumber. These developments allowed the large timbers and complicated connections of the traditional timber-framed buildings to be replaced

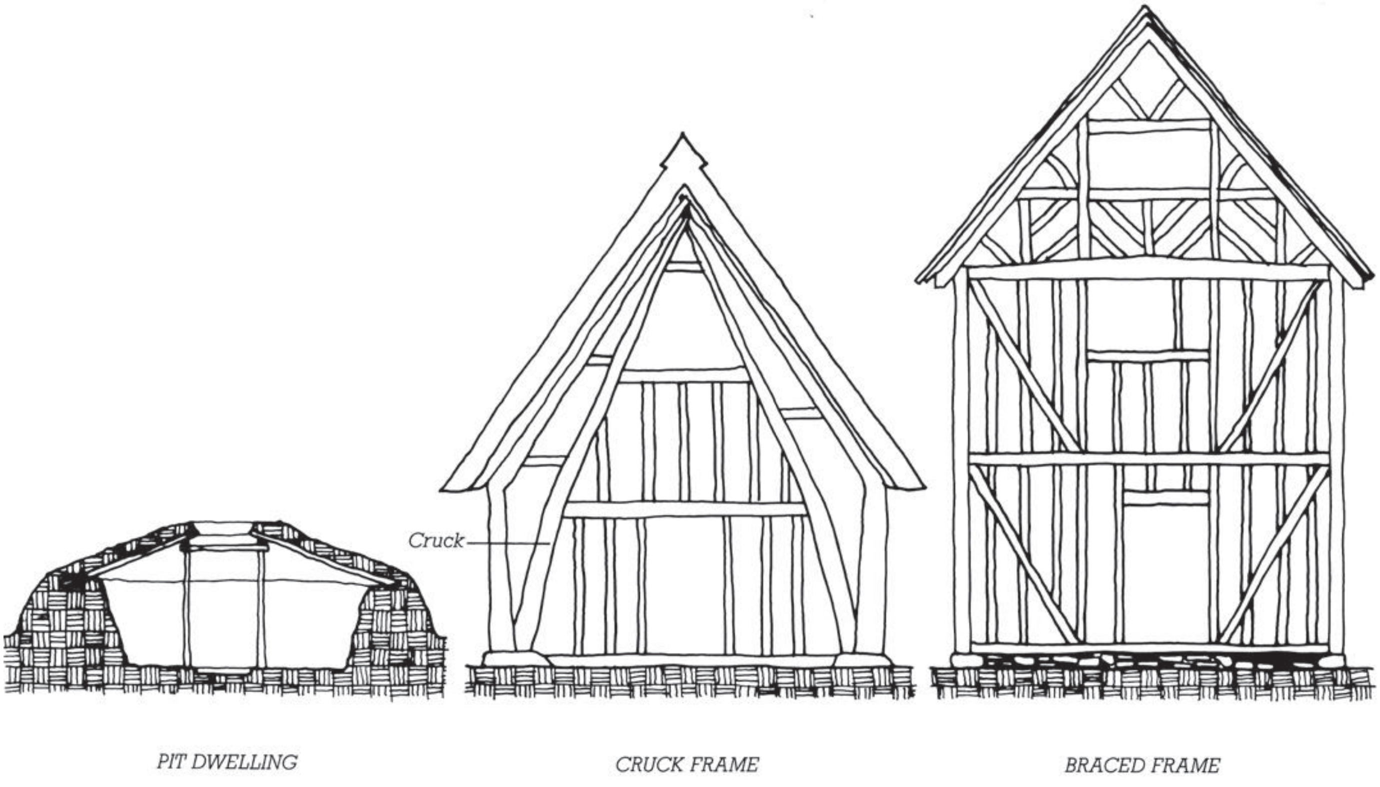

FIGURE 1.3
European timber house forms generally followed a progression of development from crude pit dwellings, made of earth and tree trunks, to cruck frames to braced frames.

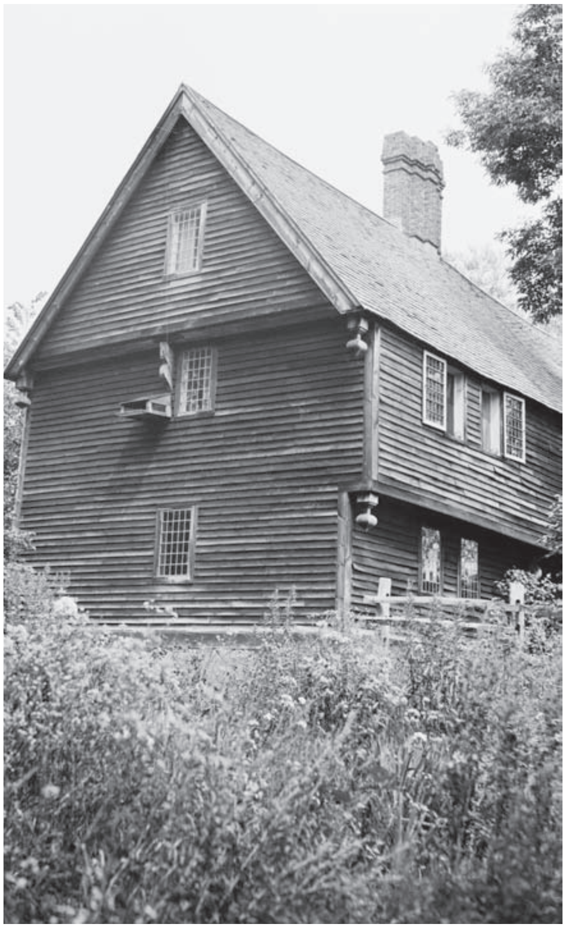

FIGURE 1.4
The North American climate was more severe than the European climate, so early pioneers found a way to wrap the wooden frame with cladding, protecting it more securely from the weather than the exposed half-timbers of European houses. This example, built in Essex County, Massachusetts, is still standing.
Source: Photo courtesy Library of Congress, Prints and Photographs Division, Historic American Buildings Survey, Reproduction Number, HABS, MASS, 5-TOP, 1–6

with numerous small structural pieces, simply connected (Figure 1.5). The advantages of the wood light frame over its predecessor are so numerous and compelling that it has dominated residential and other small-scale construction for the 150 years since its introduction, and it still shows no sign of giving way to other systems. Today, the wood light frame accounts for over 90 percent of all new site-built residential construction and is the basis for most factory-built housing as well.

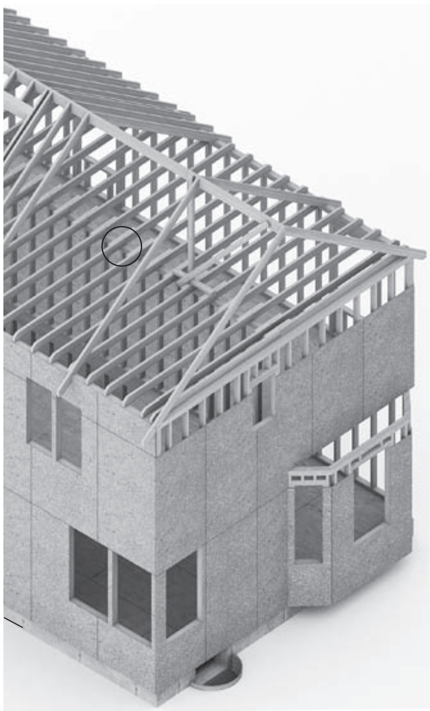

FIGURE 1.5
The wood light frame uses less material and less labor to construct than does its predecessor, the timber frame. For lateral stability, light framing relies on sheathing such as plywood applied to the exterior of the frame.

1.2 A Culture of Building

Houses are built within the context of the many individuals and institutions that affect their design and construction. In primitive and vernacular societies, the context was relatively local and involved few people. The head of a household might acquire a piece of land through the family, formulate a simple design based on local traditions, consult with a local builder about schedule and cost, arrange for the purchase of local building materials, and work together with the builder using traditional methods to build the house. The building of a house today in North America involves a much more complex process and many more participants. Nonetheless, all these participants are instrumental to the success of the project, and all are connected to what can be called a residential building culture—a network of people and institutions, which we will call "subcultures," that are directly or indirectly dedicated to the production of houses. The principal subcultures are discussed in the following paragraphs and in later chapters of this book.

1.2.1 Contractors and Subcontractors

At the center of today's residential building culture are the *contractors* and *subcontractors* whose job it is to construct houses. These people—carpenters, plumbers, masons, electricians, and myriad others—devote their professional lives to assembling materials in concert with one another to make houses. Their work depends on direct contributions from many other sectors of the building culture such as designers, material suppliers, and code enforcement agencies. Indirect contributions from realtors, financial institutions, educators, and publishers also play an important role in their work. Contractors and subcontractors are discussed extensively in Chapter 3.

1.2.2 Builders and Developers

Builders bring together and coordinate the numerous parts of an entire building project for the purpose of offering it for sale or rent. The builder purchases a building lot, obtains financing, hires the designers and other consultants to produce plans, hires the contractor to do the construction, markets the project, and sells or rents it. Builders can work on one house at a time or can build large tracts of houses or large multifamily structures.

Whereas builders are the entrepreneurs who produce houses for sale, *developers* are entrepreneurs who produce building lots. Developers purchase large tracts of land, contract for the design of roads and utilities, obtain the necessary governmental permissions to develop the land, contract for the installation of roads and utilities, and sell the divided land as building lots. Developers often expand their operation to become builder/developers, and builders likewise can expand in the other direction. Nonprofit builder/developers produce affordable housing for rent or sale to low-income families or individuals. Builders and developers are discussed further in Chapter 3.

FIGURE 1.7
Large retail outlets such as this one provide one-stop shopping for professional builders and homeowners alike. Because of the large volume of building materials, tools, and books sold at these outlets, prices are usually competitive, and building professionals receive an additional discount.
Source: Photo by Rob Thallon

FIGURE 1.6
The North American wood light frame building system is now used extensively in Japan, where its resistance to earthquakes makes it most practical.
Source: Photo by Rob Thallon

FIGURE 1.8
Lumberyards play an important role in residential construction. Based on a set of building plans, an employee of the yard will estimate the quantity of lumber that is required to build a project and will furnish a competitive bid for the entire package of lumber, delivered to the building site. Yards prefer doing business with contractors who organize their work so that deliveries can be concentrated into five or six truckloads for an average-sized house.
Source: Photo by Rob Thallon

1.2.3 Designers and Consultants

The members of the building culture most responsible for creative solutions and communication are the *designers.* This group includes architects, building designers, engineers of several kinds, landscape architects, landscape designers, and interior designers. They are responsible for being knowledgeable about current building practices, understanding and interpreting the various codes and laws that regulate building design, having a current understanding of the availability and performance of building materials, and integrating all these factors into designs that are appreciated by their clients.

Whenever a higher degree of specialization is sought than a primary designer can provide, *consultants* are engaged who perform services for the designer in a certain specialty, such as structure, building systems and performance, code and environmental compliance, and others. The number of consultants on a project typically increases with the size of the project.

These various participants in the role of residential design are discussed further in Chapter 4.

1.2.4 Material Manufacturers and Distributors

There are thousands of companies, large and small, many of which operate internationally, that manufacture and sell the materials and assemblies used to construct houses. The *manufacturers* generally sell their goods wholesale to retail stores, which, in turn, sell to contractors and to the general public. Contractors, because they are frequent customers who often buy in volume, usually are offered a discount at retail outlets. Product information in both printed and electronic form is distributed to contractors and designers and is disseminated to the general public via commercial advertising in periodicals.

Building material manufacturers have also formed a large number of organizations that work toward the development of technical standards and the dissemination of information in relation to their respective products. The Western Wood Products Association (WWPA), for example, is made up of producers of lumber and wood products. It carries out programs of research on wood products, establishes uniform standards of product quality, certifies mills and products that conform to its standards, and publishes authoritative technical literature concerning the use of lumber and related products. Associations with a similar range of activities exist for virtually every material and product used in building. All of them publish technical data relating to their fields of interest, and many of these publications are indispensable references for the architect or engineer. A considerable number are incorporated by reference into various building codes and standards.

Each upcoming chapter features the relevant associations in the Web Links section at the end of the chapter. The reader is encouraged to browse websites and download relevant information and thereby build up a reference library.

1.2.5 Realtors

Realtors are the salespeople of the building culture and play a critical role in marketing houses built for sale. They are responsible for knowing what the buying public wants in a house and for selling or renting houses as they are built. Because realtors have direct contact with consumers and are in a position to learn their desires, they are frequently queried by resourceful builders who are trying to discover new design features that will make their houses more marketable.

New speculative houses are typically advertised and sold by realtors via a *listing agreement* under which realtors assume numerous responsibilities, including negotiating the price of the house, the terms of the sale, and the conditions of the contract, with particular attention paid to the aspect of financing. For this service, realtors are generally paid a percentage of the cost of each house sold. Large builder/developers will often create their own real estate company for the purpose of marketing and selling their own houses.

1.2.6 Regulatory Agencies

Building design and construction are regulated by zoning ordinances and building codes written for the purpose of providing safe and healthy built environments. *Zoning ordinances* are local laws that divide the locality into zones and regulate such things as what kinds of buildings may be built in each zone and to what uses these buildings may be put. For example, these regulations restrict the use of buildings within residential zones so that dangerous or obnoxious activities do not get mixed in with houses. Within residential zones, the minimum size of lots, the distance a house must be from the property line, requirements for off-street parking, and maximum fence heights are typically regulated. *Building codes* are designed to ensure structural and fire safety and a healthy living environment within the house itself. The sizes of structural members, minimum standards for plumbing and wiring, minimum ceiling heights, the design of stairs and handrails, and provision for emergency escape are all examples of the regulations found in building codes. Zoning ordinances and building codes are further discussed later in this chapter.

1.2.7 Financial Institutions

Most residential construction projects require financial resources beyond the immediate means of the owner. Banks and other financial institutions provide capital for the projects in the form of long-term loans to qualified owners. The ability to resell a house if the owner defaults on payments is a primary concern of lending institutions, which results in them being rather risk-averse and conservative. As a result, banks may be less inclined to loan money for the purchase of houses that appear to be very different from the norm. Financial institutions are further discussed later in this chapter.

1.2.8 Educational and Research Institutions

Most designers and builders have some formal training from a technical school or university. Architects are required to have at least a 5-year professional degree, and most plan service drafters have taken courses in drafting and residential construction. Many courses in both the business and the physical skills required in their specialties are offered to contractors and subcontractors. Some contractors and subcontractors are required to be licensed, and there are sanctioned courses offered by different institutions for this purpose.

In addition to providing education for the building community, universities also commonly engage in building-related research. Examples of such research are new materials and structural systems, performance of existing building methods, energetic performance of materials and systems, construction management practices, and cost of building. Often, outcomes of this research provide the market with new materials and solutions, and can inform the regulatory community about more adequate guidelines, which then make their way into building codes.

The training of residential designers is explored in Chapter 4, and that of builders and contractors is discussed in Chapter 3.

1.2.9 Associations

There are many associations that relate to the design and construction of houses. The *American Institute of Architects (AIA)* and the *National Association of Home Builders (NAHB)* are two of the largest such associations, and there are numerous other organizations of manufacturers, building trades, and other groups within the building culture. Their Canadian equivalents are the *Royal Architectural Institute of Canada (RAIC)* and the *Canadian Home Builders' Association (CHBA).* Hybrid groups that include members from several disciplines also exist. For example, the International Code Council (ICC), which is responsible for writing building codes, includes architects, builders, and building code officials.

1.2.10 Publishers and Media

The publishing industry has long been an integral part of the residential building culture. For hundreds of years, periodicals have advertised the latest building materials, tools, and other products (Figure 1.9). Popular magazines such as *Better Homes and Gardens, Sunset,* and *Home* have carried articles about design, while others such as *Builder* and *Fine Homebuilding* have focused on construction. Books and journals are devoted to a variety of related topics. Recently, there has been a proliferation of how-to books for the do-it-yourself (DIY) market, which is mirrored online and on TV. Shows like PBS's *This Old House* and cable channels like the *DIY Network* and *HGTV* deliver not only housing ideas and built examples but also education in the involved techniques to the broader public and builders alike.

Whether the motive is advertising or education, the most successful published materials come from sources with strong connections to the building culture and especially to the design and construction processes.

FIGURE 1.9

Ads such as this one from the year 1882 have appeared in popular journals for as long as the journals have existed. Many modern ads refer to Web pages and/or offer free demonstration videos and downloadable material.

Source: From Builder and Wood-Worker, *Vol. XVIII, Chas. D. Lakey, New York, 1882*

1.3 Construction Systems

For the past 150 years, most houses in North America have been built using wood light frame construction, which is the most flexible of all building systems. There is scarcely a shape it cannot be used to construct, from a plain rectilinear box to cylindrical towers to complex roofs with dormers of every description (Figure 1.10). Since it first came into use, wood light framing has served to construct buildings in styles ranging from reinterpretations of nearly all the historical fashions to uncompromising expressions of every architectural philosophy of the last 100 years. It has assimilated without difficulty a succession of technical improvements in building: gas lighting, electricity, indoor plumbing, central heating, air conditioning, thermal insulation, prefabricated components, and electronic communications.

Wood light frame buildings are easily and swiftly constructed with a minimal investment in tools. Many observers of the building industry have criticized the supposed inefficiency of wood light frame construction, which is carried out largely by hand methods on the building site, yet it has successfully fought off competition from industrialized building systems of every sort, partly by incorporating their best features, to remain the least expensive form of durable construction for houses and even multistory, multifamily buildings.

However, wood light frame construction has its deficiencies: If ignited, the unprotected frame burns rapidly; if exposed to dampness, it can decay. It expands and contracts by significant amounts in response to changes in humidity, sometimes causing chronic difficulties such as cracking plaster, sticking doors, and buckling floors. The framing itself is so unattractive to the eye that it is seldom left exposed in a building. These problems can be controlled, however, by appropriate design (e.g., with a covering of gypsum board that increases fire resistance), using adequate materials (e.g., using engineered wood products instead of solid wood to reduce swelling) and careful workmanship. There is no arguing with success: Frames made by the monotonous repetition of wooden joists, studs, and rafters are likely to

FIGURE 1.10

The Carson House, built in 1885 in the Queen Anne style for a lumber baron in Eureka, California, is one of the most elaborate residential forms ever built and stands as a testament to the versatility of the wood light frame.
Source: Courtesy of University of Oregon Visual Resources Collection. Original photography by Michael Shellenbarger

remain the number one system of building in North America for a long time to come. The wood light frame system is described in detail in Chapters 8 to 22.

If 90 percent of all site-built residential construction consists of light wood frame, the remaining 10 percent is divided among several other residential construction systems. In some regions of the South, loadbearing masonry is the dominant system. Throughout the continent, other systems such as timber frame, light-gauge steel frame, insulating concrete forms, insulated masonry, and panelized construction are used in significant numbers of dwellings. These systems are important for their roles in developing new materials and building methods and for inducing innovation in the dominant wood light frame system. These less common systems are discussed in Chapters 23 to 27.

The *manufactured housing* industry factory-builds entire houses as finished boxes, often complete with furnishings, and trucks them to prepared foundations where they are set in place and made ready for occupancy in a matter of hours (Figures 1.11, 1.12, and Chapter 23). If the house is 14 feet (4.27 m) or less in width, is constructed on a rubber-tired frame, and is completely finished in the factory, it is known as a *mobile home.* If the house is wider than this or is more than one story high, it is built in two or more completed sections that are joined at the site and is known as a *sectional home* or *modular home.* Some manufacturers employ hybrid approaches where, for example, the utility-heavy bathrooms and kitchens are produced as boxes and all other walls are panelized single-wall segments, complete with windows, finishes, and siding.

Modular and mobile homes are sold at a fraction of the price of conventionally constructed houses. This is due in part to the economies of factory production and mass marketing, and in part to the use of components that are lighter and less costly and, therefore, of substantially shorter life expectancy. At prices that more closely approach the cost of conventional on-site construction, however, many companies manufacture modular housing to the same standards as conventional construction. Manufactured housing is an important component of the housing industry but is highly specialized. Because the units are made in a factory rather than at the site, the designs are strongly driven by considerations of production and transport, and their construction process is somewhat different from that of site-built housing.

FIGURE 1.11
This manufactured house was trucked to the site in sections, which were joined together as they were placed on the site-built concrete foundation. The garage will be built at the site because garages, having no framed floors, are difficult to transport and are economical to frame on-site. Manufactured houses account for approximately 25 percent of all new housing in the United States.
Source: Photo by Rob Thallon

1.4 Types of Residential Development

At the present time, single-family houses are built in the United States at a rate of about 620,000 new units per year—less than half of the totals reached in recent peak years. Those single-family detached (freestanding) dwellings comprise approximately 70 percent of all residential buildings. An additional 28 percent are units within large multifamily structures (5 and more units), and the remaining 1 percent are in buildings with 2 to 4 units (2014 data, see Figure 1.13). Most new housing is built at the site, but about 60,000 manufactured houses (representing about 10 percent of the total, in 2013 figures) are built in factories and shipped to the site each year (Figure 1.14). Remodeling of existing houses is more difficult to quantify because it includes projects that range in scope from a new window to an addition larger than the original house. However, it is clear that remodeling is a substantial component of the residential construction industry. The U.S. Census Bureau estimates that residential remodeling in the United States in 2014 accounted for $135 billion in economic activity, about 36 percent of the value of all new residential construction (Figure 1.15).

In Canada in the year 2014, more than 189,000 units were built, 40 percent of which were single-family detached houses.

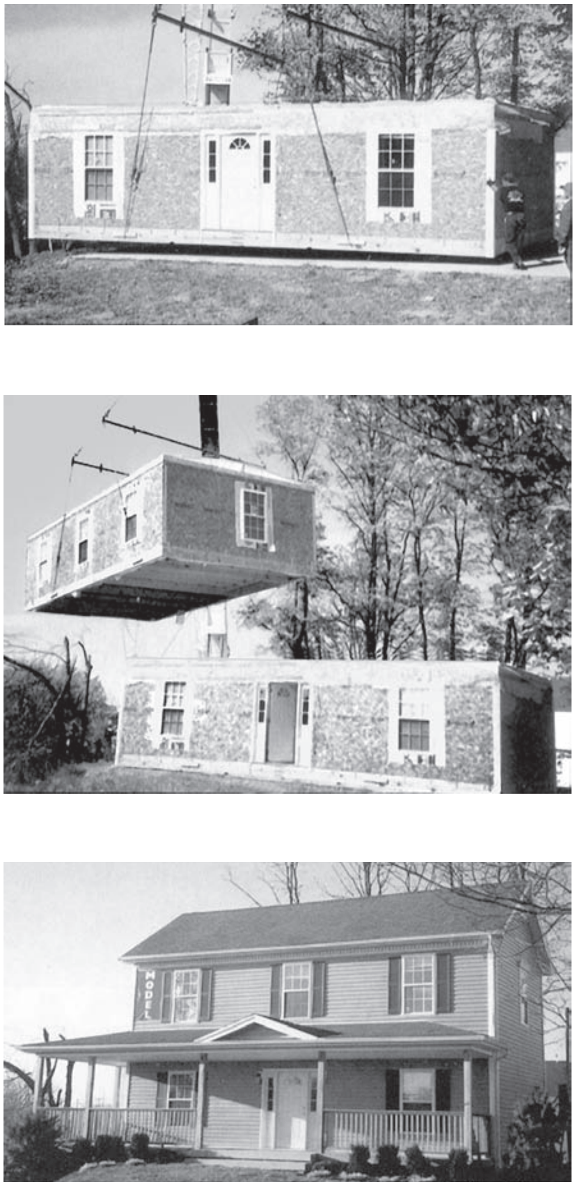

FIGURE 1.12
Manufactured housing is typically single-story construction, but some companies produce two-story models. This house was set on the foundation within a matter of hours, but it took weeks for the site crew to add the porch, finish the trim, connect the utilities, and complete the painting.
Source: Courtesy of Fischer SIPS, Louisville, Kentucky

Houses are built for a number of different reasons, depending principally on who pays for their construction (Table 1.1):

- Many are built for personal use and are financed from start to finish by the future owner. Houses in this category are virtually always single-family detached dwellings, although a few are condominium units within larger buildings.
- Houses may also be built for profit, either to be sold or to be rented by entrepreneurial housing developers. This activity is called *speculative building* and accounts for more than half of all housing units built each year. Speculative houses built for sale are most likely to be detached dwellings, whereas speculative rental housing is usually consolidated into large buildings.

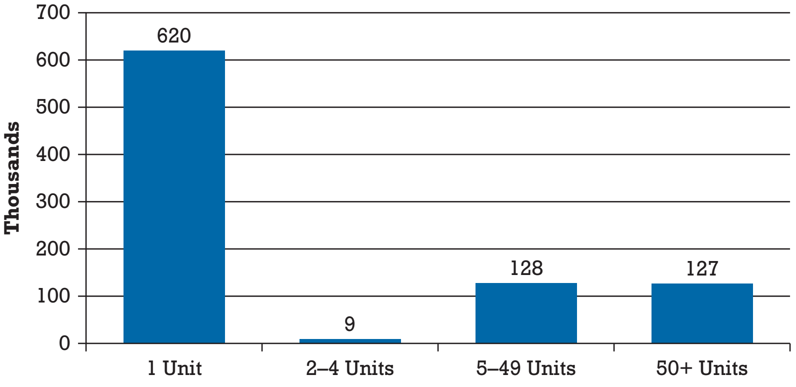

FIGURE 1.13
2014 U.S. housing production measured in thousands of units, broken down by the number of separate dwelling units per building.
Source: U.S. Census Bureau, Characteristics of Housing. www.census.gov/construction/chars/pdf/c25ann2014.pdf

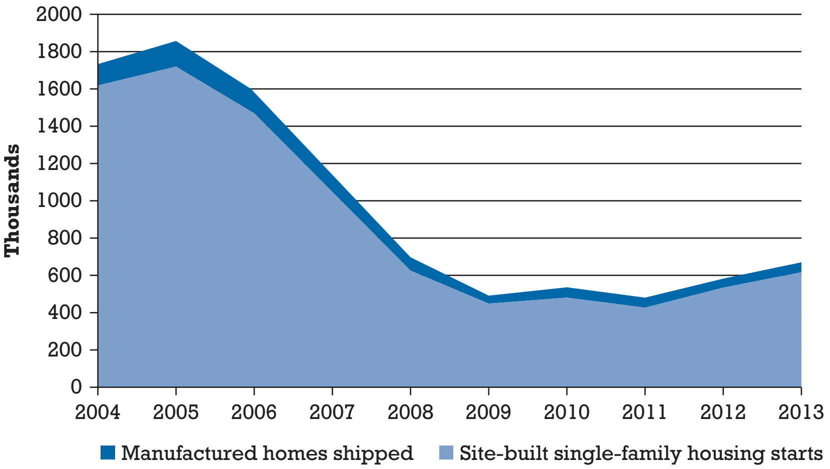

FIGURE 1.14
New site-built single-family housing starts vs. manufactured-home shipments.
Source: Manufactured Housing Institute. www.manufacturedhousing.org/lib/forcedownload.asp?filepath=/admin/template/subbrochures/396temp.pdf

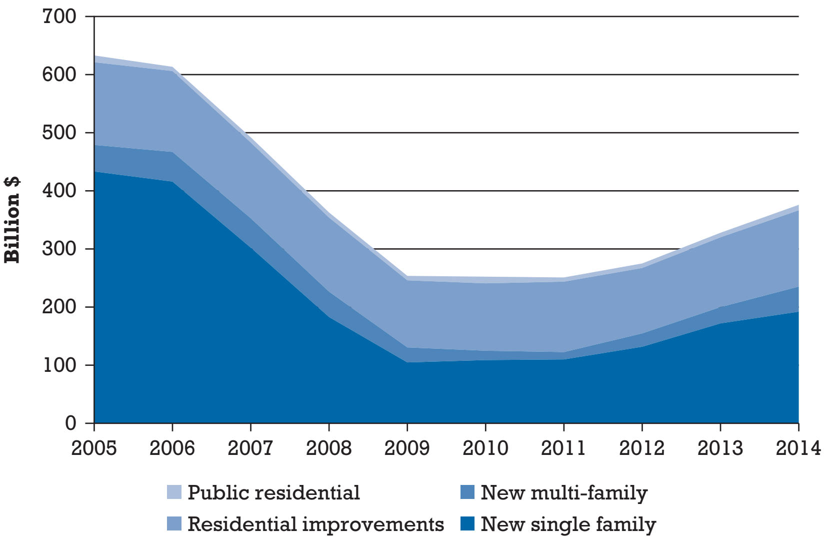

FIGURE 1.15
Annual value of construction put in place: new housing units vs. improvements. Residential construction accounted for 38 percent of all construction in the United States in 2014.
Source: U.S. Census Bureau, Annual Value of Construction Put in Place in the U.S. www.census.gov/construction/c30/historical_data.html

TABLE 1.1
Statistics for privately owned housing units completed in two separate years: 2003 and 2014

	2003		2014	
	Number of Units (1000s)	Percentage of Total	Number of Units (1000s)	Percentage of Total
All units	1848	100%	884	100%
One unit total	1499	81%	620	70%
For sale	1120	61%	450	51%
Contractor built for owner	205	11%	99	11%
Owner built	127	7%	43	5%
For rent	47	3%	28	3%
Two units or more total	349	19%	264	30%
For sale	51	4%	13	1%
For rent	262	14%	252	29%

Source: U.S. Census Bureau: Characteristics of New Housing. www.census.gov/construction/c30/historical_data.html

- Finally, low-cost houses intended for low-income families are built for the public good by government or nonprofit agencies. Like houses built for profit, *affordable housing* can be detached or part of a large structure, for sale or for rent.

The most popular form of residence in North America has always been the *single-family detached house.* In 2014, 620,000 detached units were built, representing 70 percent of all site-built residential construction activity (Figure 1.13). Symbolic of independence, family life, and a connection with nature, the single-family detached house has evolved through numerous styles, including Colonial, Federal, Victorian, Bungalow, and Ranch (Figure 1.16). More recent styles are: Mid-Century Modern, and Contemporary. In a survey of prospective buyers conducted by *Professional Builder* magazine, all respondents indicated a strong preference for a detached house when offered a choice between this and an attached house such as a townhouse or condominium (Table 1.2). This preference for detached housing has been largely responsible for the proliferation of suburbs since the end of World War II.

The largest number of single-family houses is built in *tracts* of many units, where builder/developers repeat house plans in order to reduce construction costs by means of production line repetition (Figure 1.17). In tracts, a considerable amount of time and money must be invested to obtain governmental approvals and install infrastructure such as roads, storm drains, sewers, water lines, electricity, and telecommunications before any houses can be built. This large initial investment limits the development of large- and medium-sized tracts to experienced builder/developers to whom financial institutions will loan the large sums of money required for such endeavors.

The design of housing tracts must conform to zoning ordinances that stipulate minimum street widths, off-street parking requirements, minimum lot sizes, minimum distances of buildings from lot lines, maximum building heights, and many other constraints. These regulations are designed to avoid infringement of any homeowner's rights and property values by the activities of other homeowners. A tract that is developed to comply completely with these regulations is called a *subdivision*, whether the houses are all the same or are unique (Figure 1.18). Most municipalities also have laws that allow a residential tract to be developed as a *planned unit development (PUD).* In a PUD, the houses are designed simultaneously with a coordinated site plan to assure privacy, individuality, visual harmony, and a pleasant neighborhood environment. A PUD generally achieves the qualities that are sought by zoning ordinances but often does so without literally complying with them. For example, in an area where zoning ordinances call for half-acre lots, a PUD might achieve this overall density by clustering houses in tight groupings, each with a small private yard or garden, and providing generous communal open spaces between the clusters. The concept of the PUD is that, in recognition of the quality of design that can be achieved when the entire project is designed by a coordinated team of design professionals, the literal enforcement of zoning ordinances may be relaxed (Figure 1.19).

Many new single-family detached houses are built on individual lots, independently of the construction of other units. These houses may be speculative projects offered for sale or may be built for or by the owner of the lot. Speculative houses on individual lots tend to be

FIGURE 1.16

The single-family detached house has always been the most popular type of residence in North America. It has been constructed in a variety of styles throughout its evolution.

Source: Reproduced with permission from John Milnes Baker, A.I.A., American House Styles: A Concise Guide*, New York, Norton, 1994*

TABLE 1.2

In a consumer survey, several types of potential buyers were asked, "Which one type of home described is the type you would attempt to purchase if you were buying a home at the present time?" Results of surveys such as this influence the construction and design of all types of housing.

	Buyer Type			
Type of Home	**First Time**	**Move-Up**	**Empty Nester**	**Retiree**
Detached production house	50.0	46.1	48.7	42.4
One-of-a-kind custom house	22.5	42.1	22.0	24.6
Specialty home	6.6	4.8	1.1	8.8
Modular, panelized, package home	5.3	2.6	16.2	8.6
Townhouse	10.1	0.6	3.7	5.2
Mobile home	1.6	1.8	1.2	2.8
Condominium in low-rise building	1.4	—	5.9	3.0
Duplex	2.1	0.7	1.2	4.0
Condominium in high-rise building	0.5	1.3	—	0.7

Source: Professional Builder Consumer Survey on Housing, 1998, Cahners Business Information

FIGURE 1.17
Tracts of identical or similar houses built at the edges of existing developments are largely responsible for the sprawl of the suburbs. Production line repetition and a dearth of landscape features contribute most significantly to the lack of character in these instant neighborhoods.
Source: Photo © Bill Owens

FIGURE 1.18
This subdivision has streets and building lots designed to accommodate houses that vary considerably in design from one lot to the next. For the sake of efficiency, builders usually repeat several house designs again and again in each subdivision, but each design can be built in both its original configuration and its mirror image, and small cosmetic features can be introduced for variety.
Source: Photo by Rob Thallon

constructed by small-scale developers or by developers who prefer the variety of experience this type of project affords. The construction of a new residence on individual lots by owners for their own occupancy is also a very common occurrence, accounting for as much as 20 percent of all new housing construction (Figure 1.20). In this case, owners either hire a general contractor to manage the construction or act as the general contractor themselves. When acting as a general contractor, owners may do some or most of the work themselves, with the remaining work performed under their direction by subcontractors.

Large *multiunit structures* up to four stories in height (even up to six in some jurisdictions) are usually built with the same materials and methods as single-family residences but invariably require a larger, more highly capitalized contractor to do the work (Figure 1.21). Multiunit structures are almost always built either for profit or for the public good and tend to be sited as densely as possible. In 2009, new residential structures with 5 or more units contained an average of 23 units. Because cities, counties, and other jurisdictions have regulations about how many automobile parking spaces must be provided for each unit, the number of units that can be located on a given site often depends entirely on the number of parking spaces that the site and the neighborhood can accommodate. Without building a parking garage, the greatest density can be achieved by covering as much of the street level of a site as possible with parking and placing the living units on the second floor and above (Figure 1.22). When units are located at ground level, private outdoor yards can be obtained at the expense of density.

Multiunit, multistory structures are designed and built essentially the same as single-family detached houses but have special problems:

1. The site-planning process is more involved, requiring more neighborhood meetings, necessitating more permits and approvals, and taking more time than a single residence. Parking and the movement of vehicles onto and through the site strongly influence the building design.

INTERACTIVE EXERCISE

FIGURE 1.19

The street in this PUD is narrower than normal and the garages are located close to the street in order to create an intimate feeling for the residents. Adjustments like this to zoning regulations are possible in PUDs because the entire tract is designed at the same time by a professional design team.

Source: Photo by Alexander Schreyer

FIGURE 1.20

Custom-designed houses, built by or for owners on their own lots, account for about 20% of all residential construction. Custom-designed houses may also be built on speculation. In either case, the builder/developers of these unique houses tend to be small-volume entrepreneurs who value the challenge of variety more than that of efficient production.

Source: Photo by Rob Thallon

FIGURE 1.21
A four-story apartment building under construction in an urban area. The ground floor will be commercial space, and there is a parking garage below grade. The parking and commercial levels are constructed of concrete, and the upper residential floors are constructed of manufactured wood panels lifted into place with a crane. This is a common construction type for urban multiunit housing.
Source: Photo courtesy of Rowell/Brokaw Architects

FIGURE 1.22
For rental housing, the design goal is most often to maximize density within the guidelines allowed by governmental regulations. The more units there are on the site, the more income for the owner.
Source: Photo by Rob Thallon

2. These projects are commonly designed according to the more general and less-prescriptive *International Building Code*, rather than the *International Residential Code*, which is used for one- and two-family dwellings.

3. Code requirements are more stringent with regard to accessibility by emergency vehicles and emergency egress by occupants.

4. Building codes require that individual units be separated by walls or floor/ceiling assemblies that are resistant to the passage of fire. Most residences in multiunit buildings are acoustically insulated as well.

5. A passenger elevator is required in most cases where buildings are three or more stories tall.

6. Where cars are parked below living units, a garage made of concrete or concrete masonry with a concrete slab ceiling is required as a way of protecting the dwellings from vehicle fires.

1.5 Zoning Ordinances, Building Codes, and Other Legal Constraints

1.5.1 Zoning Ordinances

The legal restrictions on buildings begin with local zoning ordinances. The most basic purpose of zoning ordinances is to designate areas of land in a town or county for particular kinds of uses. In a town or city, some areas are designated for commercial use, some for civic use, some for schools, others for residential use, and so forth. In rural areas, zones are set aside for agriculture, for commerce, for residential development, and for other uses. Residential zones within urban boundaries are usually divided into low-, medium-, and high-density areas. The device of zoning prevents such things as automobile repair shops or slaughterhouses from being located in residential neighborhoods and creates a mix of residential densities. In residential zones, ordinances usually define minimum lot sizes, off-street parking requirements, maximum building heights, and *setback requirements*, which dictate how far buildings must be from each of the property lines. Zoning ordinances often contain other provisions such as tree-cutting restrictions, erosion control measures, fencing restrictions, solar setback requirements, and sidewalk specifications. Copies of the zoning ordinance for a municipality are available for reference or purchase at the office or web site of the building inspector or the planning department, or they may be consulted at public libraries.

Where a planned building project conflicts with zoning regulations, a developer may choose to pursue a *variance*, which is a project-related waiver of specific zoning requirements. This typically involves an application process through the local building authority and includes public hearings and review by applicable municipal boards.

1.5.2 Building Codes

Building codes were originally developed to protect the occupants of a building from careless or unscrupulous builders. In ancient Babylon, building codes held a builder accountable for his work to the extent that he was slain if a house he had built collapsed and killed the householder. Engineers of ancient Roman arches were required to stand beneath each arch as the formwork was removed. Modern building codes still make builders and designers responsible for structural safety, but place more emphasis on checking plans and verifying workmanship during construction and less on penalizing the builder or designer for failures.

Codes that regulate the design and construction of residences came into existence in the United States in response to disastrous fires and unhealthy and unsafe living conditions. One of the first codes was written in the 1630s when the governor of the colony of Massachusetts issued a proclamation forbidding the construction of wooden chimneys or the use of thatch for roofing. In 1867, the New York Tenement House Act called for fire escapes, windows for ventilation, running water within each building, and handrails on all stairways. In the 1920s, fire insurance companies were successful in setting fire safety standards for all major construction throughout the United States, and it wasn't long before other interests followed suit. The first national code intended for adoption by local and state governments, the Uniform Building Code (UBC), was first published in 1927.

Since that time, there has been a proliferation of codes that prescribe minimum standards for building design and construction as well as specialized codes for plumbing, electrical wiring, fire safety, mechanical equipment, and energy efficiency. These codes were called *model building codes* because they were prepared by national organizations of local building code officials. Their purpose was to provide models for adoption by local jurisdictions such as states, counties, and cities. In recent decades, there have been several competing model building codes. In the western United States and parts of the Midwest, most codes were modeled after the UBC. In the East and other areas of the Midwest, the Building Officials and Code Administrators (BOCA) National Building Code was the model. The Standard Building Code (SBC) was adopted by many southern and southeastern states. The specialized codes such as plumbing and electrical codes have followed a similar pattern.

In recent years, the major building code organizations have published residential versions of their model codes. These specialized editions of the model codes were intended only for single-family dwellings and duplexes (two families in one building), while larger residential structures were subject to the standards in the complete codes. The residential codes were replaced in the 1990s with a single national model code created by the *Council of American Building Officials (CABO)*, an organization with representation from all major regional code associations. The CABO One- and Two-Family Dwelling Code, published in 1992 and 1995, combined into one document relevant standards from the model building codes as well as standards from the national model electrical and plumbing codes.

Beginning in the year 2000, local code jurisdictions throughout the United States began adopting the new *International Residential Code (IRC)*, which applies not only to one- and two-family dwellings but also to *townhouses,* which are multiple single-family dwellings with separate means of *egress* (emergency escape). The IRC is drawn largely from its predecessor, the CABO code, and includes standards for electrical wiring, plumbing, and energy conservation. The IRC is updated every three years, at which time it is made available for state and local jurisdictions to adopt in its entirety or after revising or excluding particular provisions. The most recent IRC revision in 2015 provided better design guidelines for decks, and it increased energy efficiency requirements so that new houses will theoretically perform 50 percent better than houses built to the specifications that were in place 10 years ago.

Large multifamily residential buildings with common means of emergency egress are governed by the *International Building Code (IBC).* The IBC is revised on the same three-year schedule as the IRC, and it is a much larger and more complex code because it regulates the construction of all buildings except those covered by the IRC—from the corner store to the tallest skyscraper. Canada publishes its own model code, the *National Building Code of Canada*, the most recent version of which was issued in 2010.

While these model codes for residential structures differ in detail, they are similar in approach and intent. Emergency exit requirements generally include minimum size and maximum sill height dimensions for bedroom windows to allow occupants to escape and firefighters to enter. An automatic fire alarm system, including smoke detectors, is almost universally required in residential buildings to awaken the occupants and get them moving toward the exits before the building becomes fully engulfed in flames. Automatic fire sprinkler systems are also often required in residential construction, and these requirements are likely to become more widespread as simpler, less expensive sprinkler systems are developed. A typical code also establishes standards for natural light; ventilation; structural design; floor, wall, ceiling, and roof construction; chimney construction; plumbing; electrical wiring; and energy efficiency. Because of the many available systems in construction, it is often more efficient for a general code like the IBC to require a certain performance (e.g. a 1 hr. fire rating), rather than prescribing how and with which materials that is to be achieved. This *performance-based approach* leaves it up to the practitioner (or systems manufacturer) to prove compliance. This differs from the *prescriptive approach*, which is largely used in the IRC and provides clear specifications and guidance as to which materials and sizes are to be employed (e.g. by means of span tables for sizing structural members).

Codes will be discussed further in each chapter as they apply.

1.5.3 Other Legal Constraints

The U.S. *Occupational Safety & Health Administration (OSHA)* sets safety standards for construction operations. Fire insurance organizations (*Underwriters Laboratories, UL*, for example) exert a major influence on construction standards through their testing and certification programs and through their rate structures for building insurance coverage, which offer strong financial incentives for more fire-resistant construction.

In addition, an increasing number of states have placed legal limitations on the quantities of volatile organic compounds in paints and construction adhesives that building products can release into the atmosphere. Most states and localities also have conservation laws that protect wetlands and other environmentally sensitive areas from encroachment by buildings.

Multiple-unit residential buildings must adhere to legal restrictions that go beyond the building codes that apply to single-family dwellings. Access standards regulate the design of entrances, stairs, doorways, elevators, and toilet facilities for a small percentage of dwellings in multifamily residential buildings to ensure that they are accessible by physically disabled members of the population. The *Americans with Disabilities Act (ADA)* makes accessibility to buildings by disabled persons a civil right of all Americans.

1.6 Building Costs and Financing

1.6.1 Building Costs

Every building project has a budget, which plays a crucial role in its design and construction. Costs for a typical single-family residence include the initial cost of the land, the costs of site improvements (such as a driveway, utilities, and landscaping), materials and labor to construct the building, building plans or design fees, building permit(s), and the cost of financing (Table 1.3). There are rules of thumb that can be used to make estimates for these various costs and to create a *pro forma,* which is a comprehensive analysis of estimated costs and returns to establish the feasibility of a proposed project.

Once a project begins, there is a series of conversations among the owner, the designer, and the contractor in order to establish precise costs and allocate resources appropriately. In some cases, the owner buys generic plans and deals directly with contractors to establish prices and maintain quality. A construction cost can be established either by negotiating with a single contractor or by means of a competitive bidding process among several contractors. In other cases, the owner employs an architect or designer who makes early estimates of construction costs based on rules of thumb and later consults with contractors during the negotiating or bidding process to establish more accurate cost projections (Table 1.4). In all cases, it is ultimately the owner who makes the decisions that affect the cost and the design of a project.

There are a number of variables that must be considered when determining the

TABLE 1.3

The construction industry is constantly tracking construction costs. This table shows the cost of doing business as a residential developer/builder as a percentage of total unit cost. The cost of design is in the "overhead" category.

	Share of Price					Average Cost
	2004	**2007**	**2009**	**2011**	**2013**	**2013**
Finished lot cost	26.0%	24.5%	20.3%	21.7%	18.6%	$ 74,313
Total construction cost	51.7%	48.1%	58.9%	59.3%	61.7%	$246,511
Financing cost	1.8%	2.4%	1.7%	2.1%	1.4%	$ 5,593
Overhead and general expenses	5.8%	7.0%	5.4%	5.2%	4.3%	$ 17,180
Marketing cost	1.9%	2.5%	1.4%	1.5%	1.1%	$ 4,395
Sales commission	3.0%	4.3%	3.4%	3.3%	3.6%	$ 14,383
Profit	9.8%	11.2%	8.9%	6.8%	9.3%	$ 37,156
Total sales price	$373,349	$454,906	$377,624	$310,619	$399,532	

Source: NAHB Construction Cost Survey. http://nahbclassic.org/generic.aspx?genericContentID=221388 cost of a residential building project. The most important of these are the overall size, the complexity of the design, and the quality of materials. Larger houses are generally more expensive to construct than smaller houses, but the cost per square foot tends to be lower for larger houses because of the economy of scale. Design complexity can have a significant effect on construction cost. Keeping the overall building form simple and respecting the modular sizes of standard materials are key principles in projects where affordability is a primary objective. Material selection can also have a huge impact on budget because material costs vary so considerably. The cost of a simple residence made with the most affordable materials can easily be doubled if the same residence is built with more luxurious materials.

Owners must often grapple with the difference between *first cost* and *long-term value.* The first cost is the initial cost of construction, and the tendency of owners is to keep this cost as low as possible. Unfortunately, a low first cost frequently leads to more expenditure in the long run. More insulation in the walls of a house, for example, can lead to lower heating and cooling bills that can recoup the initial extra investment in a short time (Table 1.5). Higher-quality materials can require less maintenance and add to the overall value of a house when it is sold. Numerous examples such as these have led to the practice of *life-cycle cost analysis,* which is a long-term analysis of construction, operation, and maintenance costs, and is often employed in large-scale projects.

Large residential subdivision projects and multifamily structures follow the same cost analysis procedures as a single-family house except that the cost of site development is a much larger percentage of the cost of the overall project, so more evaluation is required in this area. The amount of building construction is also more extensive in large projects, so the stakes are higher and much more attention is given to repetition of house or apartment designs in order to gain the advantages of the assembly line.

TABLE 1.4

A cost estimate done by an architect for a client (in the year 2007). This type of estimate is based on cost per square foot and is done early in the design process. A contractor will later determine the actual cost of the house based on bids from subcontractors. Construction costs vary considerably from region to region, and permit fees can vary significantly according to the jurisdiction.

Item	Area	Unit Cost	Cost
Main floor	1,853	$155	$287,200
Second floor	1,294	$145	$187,630
Basement	631	$ 40	$ 25,240
Porches (first floor)	270	$ 60	$ 16,200
Porch (second floor)	112	$ 75	$ 8,400
Garage	528	$ 75	$ 39,600
Connector	300	$ 60	$ 18,000
Building Total			$582,270
Architectural fees			$ 54,000
Engineering			$ 2,600
Permits			$ 4,000
Systems development fees			$ 4,000
Site septic			$ 4,000
Road			$ 6,500
Landscape			$ 26,000
Project total			$683,370

TABLE 1.5

A first-cost vs. life-cycle analysis comparing two 2124-square-foot houses in New York State, one with an attached sunspace and additional insulation. The first cost of the sunspace and insulation was $4400, which translated to an additional $25 monthly mortgage payment. With fuel savings, however, the total monthly expenditures for the passive home were $25 less than those of the base home, and the initial additional outlay was recovered in less than 3 years (and has additional amenities).

	Monthly Expenses		
	Mortgage	**Fuel**	**Total**
Base case home	$1057	$ 124	$1181
Passive home	$1082	$ 74	$1156
Difference	$ +25	$–50	$ –25

Source: The Passive Solar Design and Construction Handbook*, Steven Winter Associates, Michael J. Crosbie, Editor, John Wiley & Sons, Hoboken, New Jersey, 2009*

1.6.2 Financing

Building a house is such an expensive endeavor that almost no one can afford to pay for it out of pocket. Banks and savings and loan institutions are in the business of lending money for this significant investment in return for interest, which is a rental cost for the money, expressed as a percentage of the amount loaned. In order to make a loan on the construction of a house, a bank needs to be convinced that the owner has the financial capacity to repay the loan over time and that the house can be resold to pay off the loan if the owner should fail to make the loan payments. The bank assesses the owner's ability to make loan payments on the basis of investigation of the owner's credit record and the evaluation of recent tax returns. Owners often will prequalify for a loan up to a certain amount in order to establish a project budget before the house is designed. The projected *resale value* of a house has a tremendous impact on how much financing a bank will provide or if financing will be provided at all. In order to establish resale value, an official of the bank appraises the building based on plans and material specifications and adds the value of the lot to arrive at a total *appraised value* of the developed property as proposed. To minimize their risk, banks usually require that the owner invest at least 10–20 percent of the appraised value of a project.

The traditional mechanism used to finance the construction of a house is the combination of a *construction loan* while the house is being built and a *permanent mortgage* for the period thereafter. The construction loan is generally limited to a period of 9 months or less and has an interest rate that is higher than the permanent mortgage. As construction proceeds, progress is verified by an agent of the bank, and funds from the construction loan are disbursed to the contractor. The permanent mortgage goes into effect after construction has been completed and runs for a period that may range from 15 to 30 years, with payments due to the bank every month (Figure 1.24). These two loans can be consolidated into a single *all-in-one loan* that is negotiated before construction begins at a single prevailing interest rate and avoids the duplication of closing costs and other costs associated with dual-loan agreements.

FIGURE 1.23
Family cabins and second homes form a significant part of the housing market. Their design often references historical or rustic precedents to create an atmosphere that is different from that of everyday life in the city or the suburbs.
Source: Photo by Rob Thallon

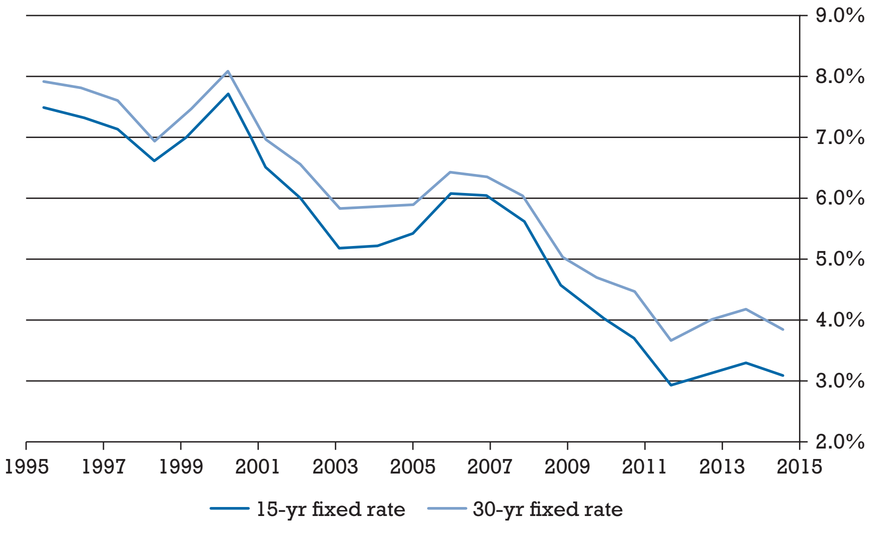

FIGURE 1.24
Average interest rates for 15-year and 30-year fixed-rate mortgages from 1995 to 2015.
Source: Freddie Mac. www.freddiemac.com/pmms/pmms30.htm

1.7 Building a House: The Typical Process

Construction is a time-consuming process that, depending on several different factors, can take many months to complete (Figure 1.25). It is interesting to note that construction of a speculative single-family house takes on average exactly half the time of an owner-built house. And multiunit developments that range from 2 to over 20 units vary only slightly in *construction duration,* averaging 11.7 months, only a single month longer than an owner-built house.

The construction of a house involves a series of steps that vary somewhat from project to project but that typically follow a similar path (Figure 1.26). This path is outlined in the paragraphs that follow and is described in detail for a typical wood light frame house in Chapters 8 to 22. For large subdivision or multifamily projects, the first steps are typically considerably more complicated, but once framing begins, the only significant difference between a large project and a single-family project is one of scale.

1.7.1 Building Permits and Inspections

After the construction documents have been completed, the first step in the construction process is the application for a building permit. Plans for the building, along with engineering calculations and energy compliance forms, are submitted to the city or county building department, where they are reviewed by various *plans examiners* for compliance with local zoning ordinances and building codes. Plans examiners are trained to be comprehensive in their review, which includes many issues of health, safety, energy conservation, and environmental protection. When the review

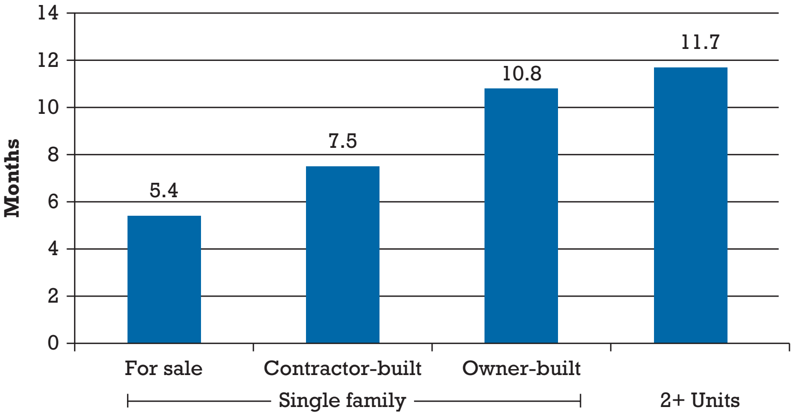

FIGURE 1.25

Average duration of construction in months (2014 data).

Source: U.S. Census Bureau, Average Length of Time from Start to Completion of New Privately Owned Residential Buildings

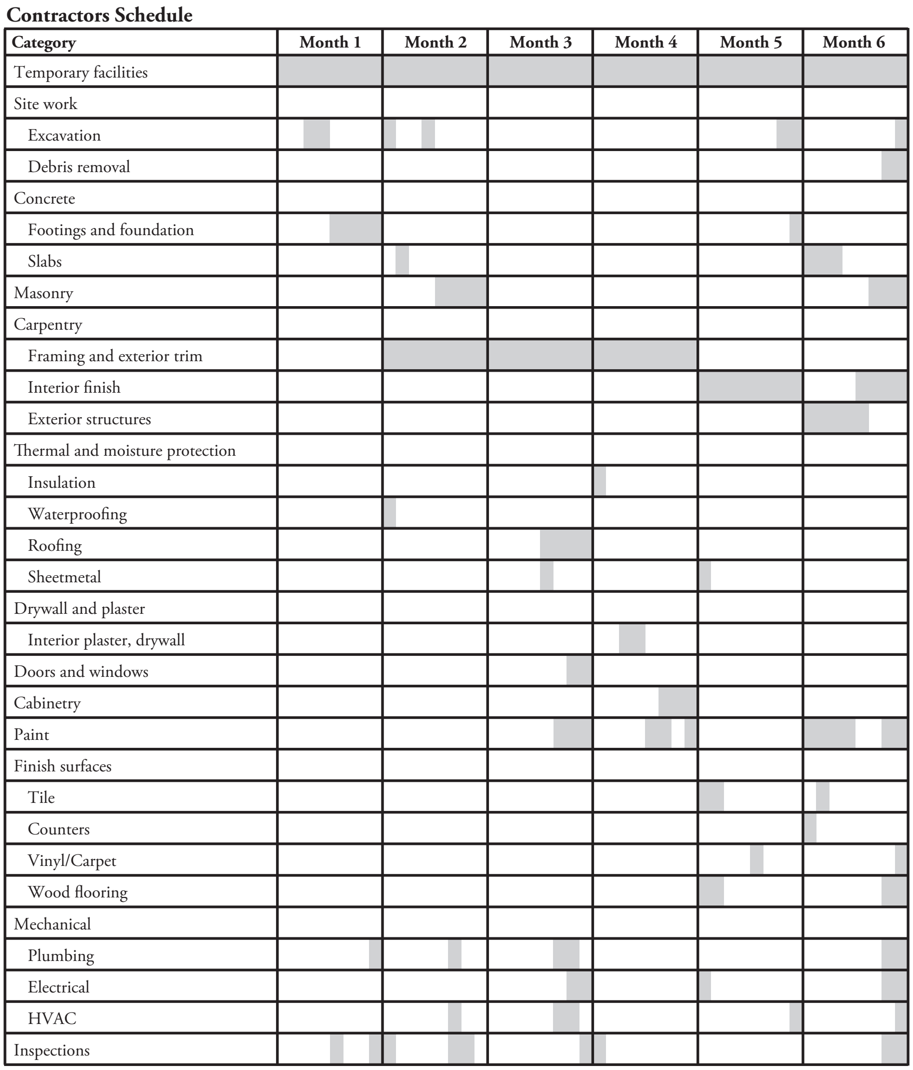

FIGURE 1.26

A typical schedule of the work for an average-sized house. Notice how many different trades are at the site during the last week of construction.

Source: Courtesy of Treeborn Carpentry, Eugene, Oregon has been completed, any necessary corrections have been made, and all fees have been paid, a permit for construction is issued.

As construction proceeds, inspections are requested by the contractor at designated stages of construction, in response to which the building department sends an inspector to verify the quality of the work and its correspondence with the approved plans. Building inspectors are not the same people as plans examiners, although they work for the same agency and their inspections are based on approved plans that are required to be on the site. But inspectors see the completed work in place, so they approve the work or not depending on whether all the details of a particular phase have been completed to their satisfaction. There are usually between 15 and 20 inspections required to build a new house, and the approval of each phase is usually necessary in order to begin the next phase. The bulk of the inspections are conducted by the *building inspector,* who works for the city or county agency that issues the permit, but there are also specialized inspectors, such as a plumbing inspector or an electrical inspector, who may work for state agencies. Once all the inspections have been passed, the building department will issue a *certificate of occupancy*, which will allow the new construction to be occupied.

1.7.2 Building Site Preparation

Preparation of the building site for construction is the first physical step in the building process. The area of the site to be occupied by the house is cleared, the building is located and its corners staked, and a hole is excavated for the foundation. In addition, utilities such as electrical power, water, gas, and phone lines are extended to the building site. Sewage and storm drain lines are installed.

1.7.3 The Foundation

Construction of a foundation to transmit the weight of the building into the earth is the next step in the construction process. Foundations can range from a concrete slab poured on top of the ground to a basement excavated deeply into the site. Foundations for large multifamily buildings often incorporate parking garages and thus involve much more complicated construction.

1.7.4 Structural Framing

When the foundation is in place, the framing can proceed. With a slab foundation that acts as a floor, framing begins with the walls. When there is no slab, a wooden floor structure is constructed on the foundation. A framing crew builds the walls, floors, and roof with lumber and structural wooden panels (Figures 1.27 and 1.28).

FIGURE 1.27
A typical perimeter foundation around a crawlspace. Underfloor plumbing, heating/cooling ducts, and first-floor framing have been completed, and soil has been backfilled around the foundation. Next, the floor deck will be laid, and wall framing will begin.
Source: Photo by Rob Thallon

FIGURE 1.28
The newly begun house in the foreground stands silhouetted against a fully framed house. The roof of the framed house has been covered with building paper, and the windows have been installed to protect the inside so that interior work can proceed protected from the weather.
Source: Photo by Rob Thallon

1.7.5 Roofing and Siding

Exterior finish materials are applied to the completed framing to make the building weathertight and durable. Roofing is applied to the roof, and provisions are made to gather rainwater from the roof and channel it away from the building. Windows and doors are installed, and the walls are covered with siding. Any required exterior painting is done. With roofing and siding in place, the building is "tight to the weather," and the overall project is about 50 percent complete (Figure 1.30).

1.7.6 Utilities and Insulation

While the exterior of the house is being finished, the interior utility systems are installed. First the plumbing, then the heating and cooling ductwork, and finally the electrical wiring are installed within the cavities between the studs, joists, and other framing members (Figure 1.33). When these systems are all in place and fastened to the framing, thermal insulation is placed into the cavities between the studs of exterior walls and ceiling joists to form a continuous thermal envelope around the perimeter of the house.

1.7.7 Interior and Exterior Finish

Upon completion of the thermal insulation, the studs and other framing are covered with interior finish materials, which are immediately painted. Next, the flooring and cabinets are installed, and trim is fastened around floors, doors, and windows to cover the gaps between the various materials (Figure 1.32). To complete the interior of the house, the finish hardware, plumbing fixtures, and electrical trim are installed, and all remaining unfinished surfaces receive a protective coat of paint, stain, or varnish.

FIGURE 1.29
Large-scale residential projects often employ the same wood light frame technology as single-family residences. Separation between the units to inhibit the rapid spread of fire is achieved with gypsum board panels.
Source: Photo by Rob Thallon

FIGURE 1.30
The roofing, windows, doors, siding, gutters, and downspouts complete the weather envelope at the exterior of the structural frame. These workers are applying the last of the siding.
Source: Photo by Rob Thallon

FIGURE 1.32
Finishing the interior of a house involves workers from more than half of the building trades, some of whom are returning to the job for the second or third time. Drywall hangers and tapers, floor installers, tilesetters, cabinetmakers, finish carpenters, painters, plumbers, electricians, and others are required to complete the work.
Source: Photo by Rob Thallon

FIGURE 1.31
The plumbing, heating/cooling system, and electrical wiring are installed inside the house before the walls and ceiling are insulated and covered with a finish surface.
Source: Photo by Greg Thomson

(*a*)

(*b*)

FIGURE 1.33

(a) This contemporary house by Sigrid Miller Pollin FAIA illustrates both the essential simplicity of wood light framing and the complexity of which it is capable.
(b) The house under construction.
Source: Sigrid Miller Pollin FAIA, Miller Pollin Architecture, Amherst MA

Simultaneously with the finishing of the interior of the house, the sitework is completed with the installation of paving, decks and terraces, irrigation system, fencing, and planting.

After the house is occupied, adjustments are often needed, such as balancing the heating/cooling system according to the occupants' preference, adjusting the operation of doors and windows, touching up the paint, and explaining the operating and care instructions for equipment. In most regions, the contractor must warranty the quality of the construction for one year after initial occupation of the house.

1.8 MasterFormat

The *Construction Specifications Institute (CSI)* of the United States and *Construction Specifications Canada (CSC)* have evolved over a period of many years a standard outline called *MasterFormat* for organizing information about construction materials and components. MasterFormat is used as the outline for construction specifications for nearly all large construction projects in the two countries, including most multiunit residential projects. It also forms the basis on which trade associations' and manufacturers' technical literature is cataloged and filed.

MasterFormat was introduced in 1963 and since that time has undergone periodic revisions. Until 2004, there were 16 categories or "divisions" under which products and installation methods were cataloged. The 2004 version was expanded to include 50 categories, including several that are reserved for future expansion. For several years of transition, both the 16-division and the 50-division versions were supported by the construction specification industry, but as of January 1, 2010, only the 2004 edition will be maintained.

There are 50 primary divisions that are categorized into groups and subgroups according to the type of product or work being described. The primary subgroups and divisions are as follows.

The missing numbers are reserved for future expansion of the format. Of the 35 divisions that are currently active, all but a handful would be employed for a multifamily housing project, and about two-thirds would be applicable to the construction of a single-family house.

Within each division, several levels of subdivision are established to allow the user to reach any desired degree of detail. A six-digit code in which the first two numbers correspond to the division numbers gives the exact reference to any category of information. For example, within Division 07, Thermal and Moisture Protection, some standard reference codes are as follows.

C.S.I./C.S.C.
MasterFormat Division Numbers

Division 00	**Procurement and Contracting Requirements General Requirements Subgroup**
Division 01	**General Requirements Facility Construction Subgroup**
Division 02	**Existing Conditions**
Division 03	**Concrete**
Division 04	**Masonry**
Division 05	**Metals**
Division 06	**Wood, Plastics, and Composites**
Division 07	**Thermal and Moisture Protection**
Division 08	**Openings**
Division 09	**Finishes**
Division 10	**Specialties**
Division 11	**Equipment**
Division 12	**Furnishings**
Division 13	**Special Construction**
Division 14	**Conveying Equipment Facility Services Subgroup**
Division 21	**Fire Suppression**
Division 22	**Plumbing**
Division 23	**Heating, Ventilating, and Air Conditioning (HVAC)**
Division 25	**Integrated Automation**
Division 26	**Electrical**
Division 27	**Communications**
Division 28	**Electronic Safety and Security Site and Infrastructure Subgroup**
Division 31	**Earthwork**
Division 32	**Exterior Improvements**
Division 33	**Utilities**
Division 34	**Transportation**
Division 35	**Waterway and Marine Construction Process Equipment Subgroup**
Division 40	**Process Integration**
Division 41	**Material Processing and Handling Equipment**
Division 42	**Process Heating, Cooling, and Drying Equipment**
Division 43	**Process Gas and Liquid Handling, Purification, and Storage Equipment**
Division 44	**Pollution and Waste Control Equipment**
Division 45	**Industry-Specific Manufacturing Equipment**
Division 46	**Water and Wastewater Equipment**
Division 48	**Electrical Power Generation**

Most chapters of this book give the major MasterFormat designations for the information presented, to help the reader know where to look in construction specifications and in the technical literature for further information. The full MasterFormat system is contained in the volume referenced at the end of this chapter.

C.S.I./C.S.C.
MasterFormat Section Numbers for Thermal and Moisture Protection

07 20 00	**Thermal Protection**
07 30 00	**Steep Slope Roofing**
07 31 00	**Shingles and Shakes**
07 60 00	**Flashing and Sheet Metal**
07 61 00	**Sheet Metal Roofing**
07 65 00	**Flexible Flashing**

Review Questions

1. Who are the professionals involved with the production of a typical speculative house from conception to occupation by the owner? How do the participants change if the house is built for the owners on their own property?

2. What are the differences between site-built and manufactured housing?

3. Compare a PUD with a tract development.

4. What are the advantages and disadvantages of multiunit development from the point of view of the developer?

5. Explain the differences between zoning ordinances and building codes. Give examples of specific provisions of each.

6. Describe the typical construction process.

Exercises

1. Have class members interview a residential builder to determine the type of work he or she typically undertakes. Discuss the range of responses in class.

2. Repeat the preceding exercise for residential architects and building designers.

3. Obtain copies of your local zoning ordinances and building code (visit your city's planning board website as a start). Look up the applicable provisions of these documents for a house on a specific site. What setbacks are required? How tall can the house be? How many cars must be able to be parked on the site? What are the requirements for emergency egress from the house?

4. Have class members observe a nearby construction site over the course of the semester, and let them report on which construction processes they observed.

Key Terms and Concepts

wood light frame
contractor
subcontractor
builder
developer
designer
manufacturer
realtor
listing agreement
zoning ordinance
building code
American Institute of Architects (AIA)
National Association of Home Builders (NAHB)
Royal Architectural Institute of Canada (RAIC)
Canadian Home Builders' Association (CHBA)
manufactured housing
mobile home
sectional home
modular home
speculative building
affordable housing
single-family detached house
tract
subdivision
planned unit development (PUD)
multiunit structure
setback requirements
model building code
Council of American Building Officials (CABO)
International Residential Code (IRC)
townhouse
egress
International Building Code (IBC)
National Building Code of Canada
Occupational Safety and Health Act (OSHA)
Americans with Disabilities Act (ADA)
first cost
long-term value
life-cycle cost analysis
resale value
appraised value
construction loan
permanent mortgage
all-in-one loan
construction duration
plans examiner
building inspector
certificate of occupancy
Construction Specifications Institute (CSI)
Construction Specifications Canada (CSC)
MasterFormat

Web Links

Historic American Buildings Survey (HABS). A thorough collection of images and drawings of historic houses, buildings, and structures by the Library of Congress: **www.loc.gov/pictures/collection/hh/**

National Association of Home Builders (NAHB): **www.nahb.org**

Manufactured Housing Institute (MHI): **www.manufacturedhousing.org**

Canada Mortgage and Housing Corporation (CMHC-SCHL): **www.cmhc-schl.gc.ca/**

U.S. Census Construction Data. A thorough and regularly updated collection of national and regional data related to construction: **www.census.gov/econ/construction.html**

U.S. Census Interactive House Statistics. Interactive Web site for much of the U.S. Census' data on housing: **www.census.gov/construction/chars/interactive/**

ICC Codes Public Access. This is a free, online resource for all ICC codes, including the IRC: **codes.iccsafe.org**

Construction Standards Institute MasterFormat: **www.csinet.org/masterformat**

Selected References

1. Fitch, James Marston, and Bobenhausen, William. *American Building: The Environmental Forces That Shape It.* New York: Oxford University Press, 1999.

Connects the environment, the act of building, and human nature. The classic discussion of the evolution of American architecture at all scales.

2. Davis, Howard. *The Culture of Building.* New York: Oxford University Press, 2006.

Elegantly written and beautifully illustrated, this book describes a global building culture that is evaluated for its ability to produce a vital built environment. North American building culture is explored in depth and can be more profoundly understood in the context of examples from other parts of the world.

3. Wright, Gwendolyn. *Building the Dream: A Social History of Housing in America.* Cambridge, MA: MIT Press, 1983.

A scholarly classic describing the reasons behind the form of most American housing. More about social history than about building.

4. International Code Council, Inc. *2015 International Residential Code for One- and Two-Family Dwellings.*

This is the model code for all aspects of residential construction, including detached houses, duplexes, and townhouses.

5. Periodicals are an excellent source for learning about current thinking in the residential building culture. *Fine Homebuilding* (www.finehomebuilding.com) and *The Journal of Light Construction* (www.jlconline.com) focus on construction techniques and also have articles about tools, materials, and design. *Builder* (www.builderonline.com) and *Professional Builder* (www.probuilder.com) focus on marketing and business and also have articles about materials and design.

6. Construction Specifications Institute and Construction Specifications Canada. *MasterFormat—Master List of Section Titles and Numbers.* Alexandria, VA, and Toronto: CSI and CSC, 2010.

This book contains the full set of numbers and titles under which construction information is filed and utilized.

SUSTAINABILITY ASPECTS OF CONSTRUCTION

2

2.1 Why Sustainability Matters for Buildings

As ever-growing populations and diminishing resources begin to produce global-scale environmental and social impacts, there are many who increasingly see the need for a more environmentally aware approach to the way we design and build our houses and communities. Worldwide, more and more people are in need of housing (often at an increasing quality level as they move up the social and economic ladder), which creates a significant demand that will need to be fulfilled through development.

The construction of well over 60 million new dwelling units worldwide per year (2017 projection by The Freedonia Group, Inc.) at an annual increase of over 3 percent represents the consumption of tremendous amounts of raw materials, the emission of uncountable tons of toxic chemicals, and huge long-term energy requirements. Even a relatively small shift in the way our houses and other dwellings are designed and built can have a significant impact on resources and on the lives of those directly affected by their construction (Figure 2.2 and Table 2.1).

It has been estimated by the United Nations (UN) Environmental Programme

TABLE 2.1

Typical construction waste for a new 2000-square-foot house. Siding material was assumed to be vinyl on three sides and brick on the street side.

Material	Weight (lb)
Solid sawn wood	1600
Engineered wood	1400
Drywall	2000
Cardboard	600
Metals	150
Vinyl (PVG)	150
Masonry	1000
Containers	50
Other	1050
Total	8000

Source: NAHB, Residential Construction Waste: From Disposal to Management

FIGURE 2.1

Increased urbanization and densification led to developments such as these residential high-rises in a downtown core (Left: Vancouver, Canada) or sprawling single-family residences (Right: Las Vegas, NV).

Source: Photos by Alexander Schreyer

FIGURE 2.2
Even small residential remodeling projects can produce significant amounts of construction debris.
Source: Photo by Alexander Schreyer

that buildings use about 40 percent of global energy. They also require 25 percent of all global water, 40 percent of global resources, and they emit approximately a third of all *greenhouse-gas (GHG) emissions.* Residential and commercial buildings together also consume approximately 60 percent of the world's electricity (Figure 2.3).

Given these significant demands on resources, the continuation of their availability becomes a major factor. This was succinctly expressed in the 1987 UN "Brundtland" report, "Our Common Future," whose definition of sustainable development as one "that meets the needs of the present without compromising the ability of future generations to meet their own needs" has become the oft-cited goal for everyone who follows these principles.

Those concerned with the environmental consequences of construction have organized into various groups that promote the cause of what is commonly called *green building* or *sustainable building.* While this approach is becoming more and more mainstream and is being included in everyday practices (often because it makes good business sense), a wider understanding and knowledge of sustainability principles are needed.

Sustainable building generally assumes a comprehensive approach to creating better buildings and communities by following four strategies:

1. **Improve the energy efficiency** of buildings by designing and building them to use less energy to heat and cool.
2. **Improve the resource efficiency** of buildings by using fewer and better materials in their construction.
3. **Lower the toxicity** of new buildings and their environments to minimize health risks to workers and occupants.
4. **Reduce the impact on the natural environment** by seeking compact development and promoting less invasive site designs.

Many of these strategies can increase the cost of constructing a new house. This additional burden is, however, often offset by lower follow-up energy and maintenance costs. Also, proponents of environmental responsibility see no alternative in the long run and point out that consumers are increasingly aware of the issues. As a result, home buyers expect some response by those who design and build the houses they buy. This is already reflected in increased consumer demand for efficiency

FIGURE 2.3
Wind turbines, like the ones that appear behind this deer sculpture atop Hoosac Range in Massachusetts, provide a promising source for clean energy that is local, carbon-neutral, and avoids burning fossil fuels.
Source: Photo by Alexander Schreyer

items in homes, such as low-e windows or programmable thermostats (see also Chapter 4).

As the volume of sustainable building activity increases, its cost premiums will likely decrease. This effect already occurred with solar panels, whose cost reduced dramatically over only a few years. Furthermore, efficient materials and systems availability as well as vendor competition is improving, as can be seen in the United States with items like triple-pane windows. While this may not reduce costs in all cases, having a broader array of materials and systems to choose from

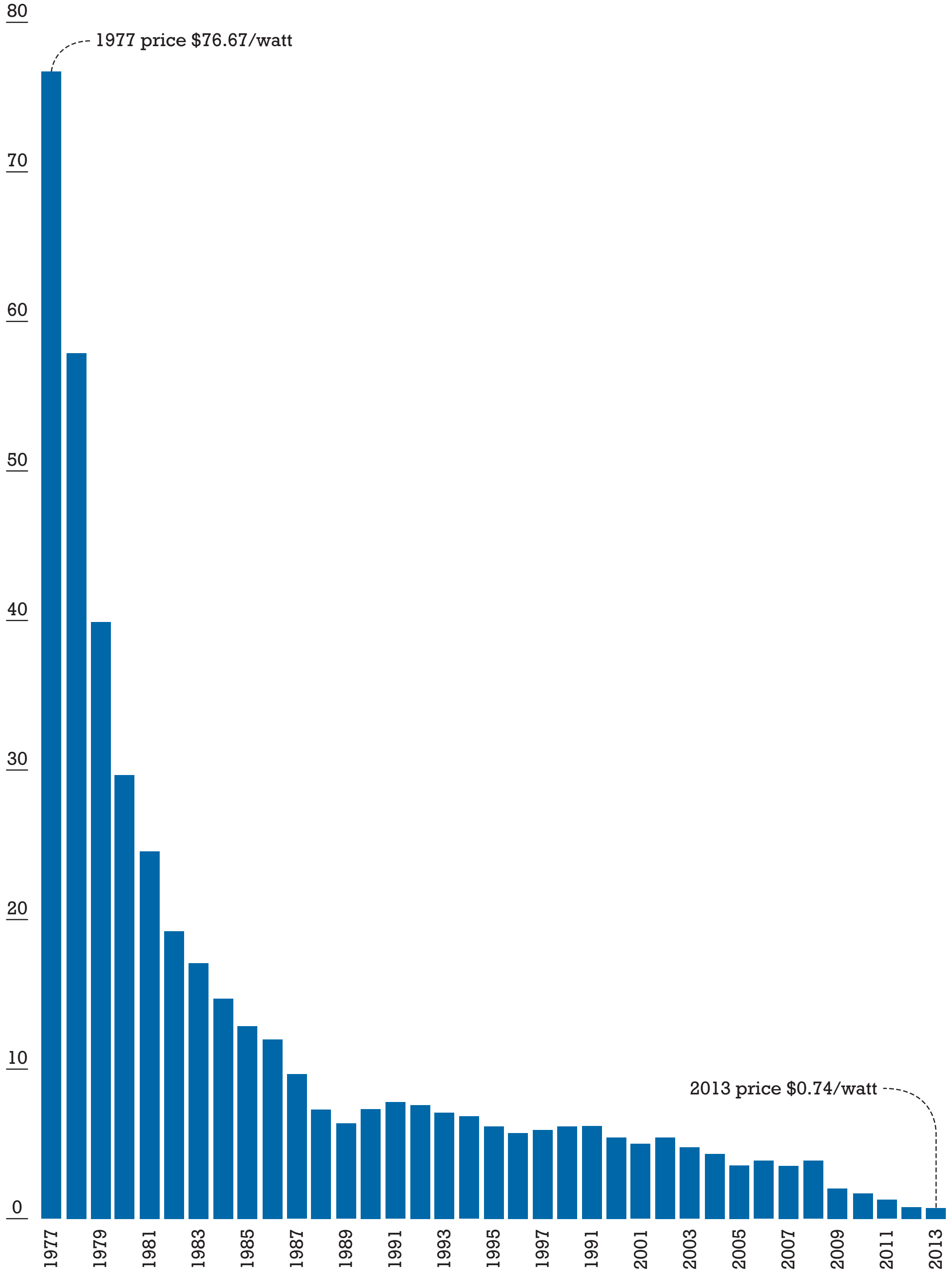

FIGURE 2.4

The cost of solar electricity, as measured by panel cost per watt has dropped by a factor of 100 over a recent period of 36 years and is projected to decrease even more. This is mainly due to economies of scale and global competition.

makes higher standards of sustainable building more feasible to attain.

Sustainable building discussions can be found in special sections at the end of most chapters of this book as well as in this chapter. Overall, the topic of sustainable design and building goes far beyond the scope of this book. The reader is encouraged to look at the Web links and reference sections at the end of this chapter for suggestions for further reading.

2.2 Environmental Responsibility: Building Green

2.2.1 Sustainable Design

All throughout history, region-specific basic ("vernacular") dwelling types, while different in appearance and materials, always followed some main principles: They responded to the local environment through material choice and overall design; they also took advantage of free, natural resources, such as the sun, wind, or water; and they minimized energy losses as much as possible (although the latter was often hard to attain with basic materials and building methods). This was especially the case when the source of energy or materials was scarce. Nowadays, much higher-performing materials and systems are available, but those basic principles still hold true.

Therefore, sustainable design typically starts with an analysis of the local sun

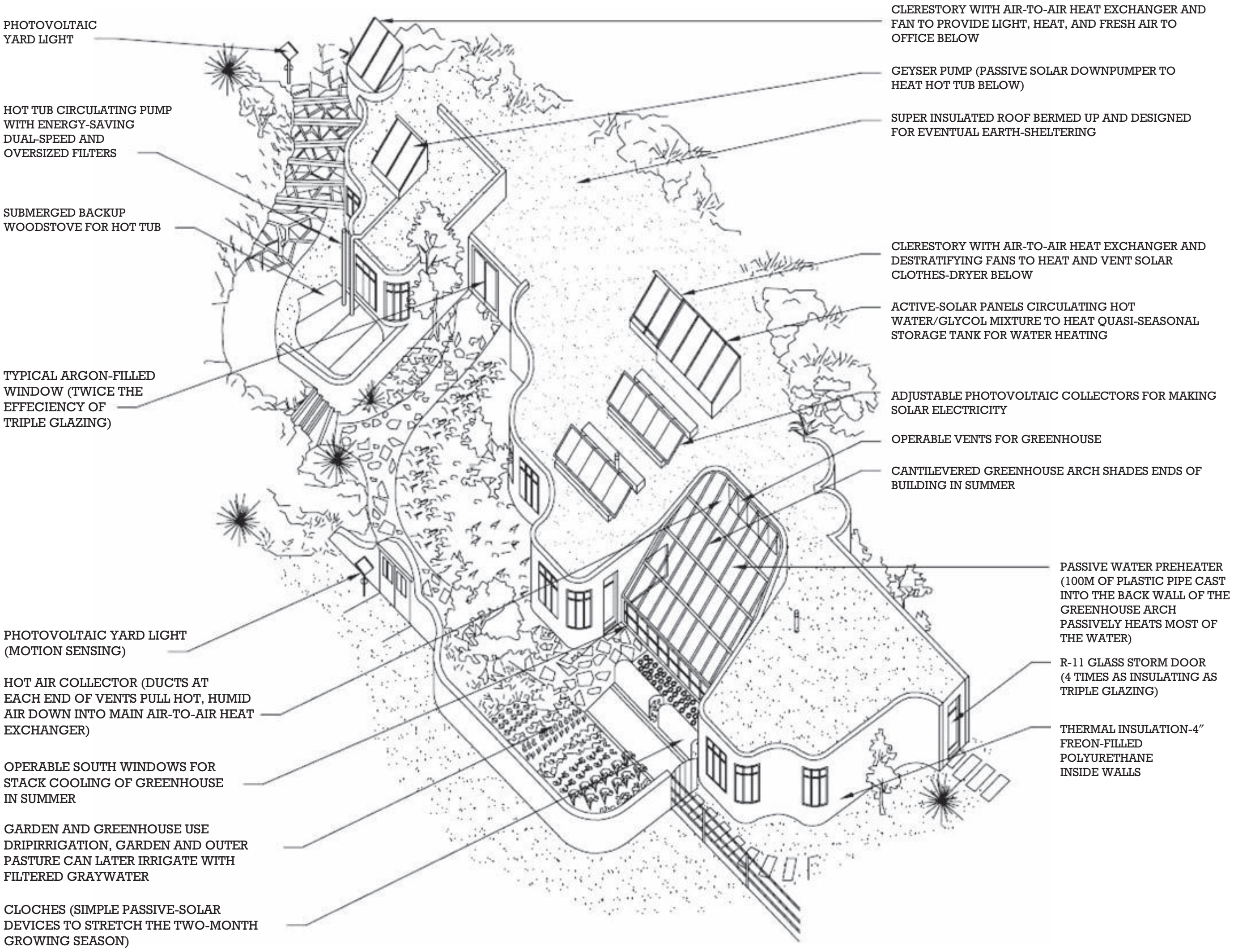

FIGURE 2.5

Diagram of a bermed residence with greenhouse, showing all of its energy-efficiency and sustainability features.
Source: Architectural Graphic Standards, *adapted from Rocky Mountain Institute, Snowmass, Colorado*

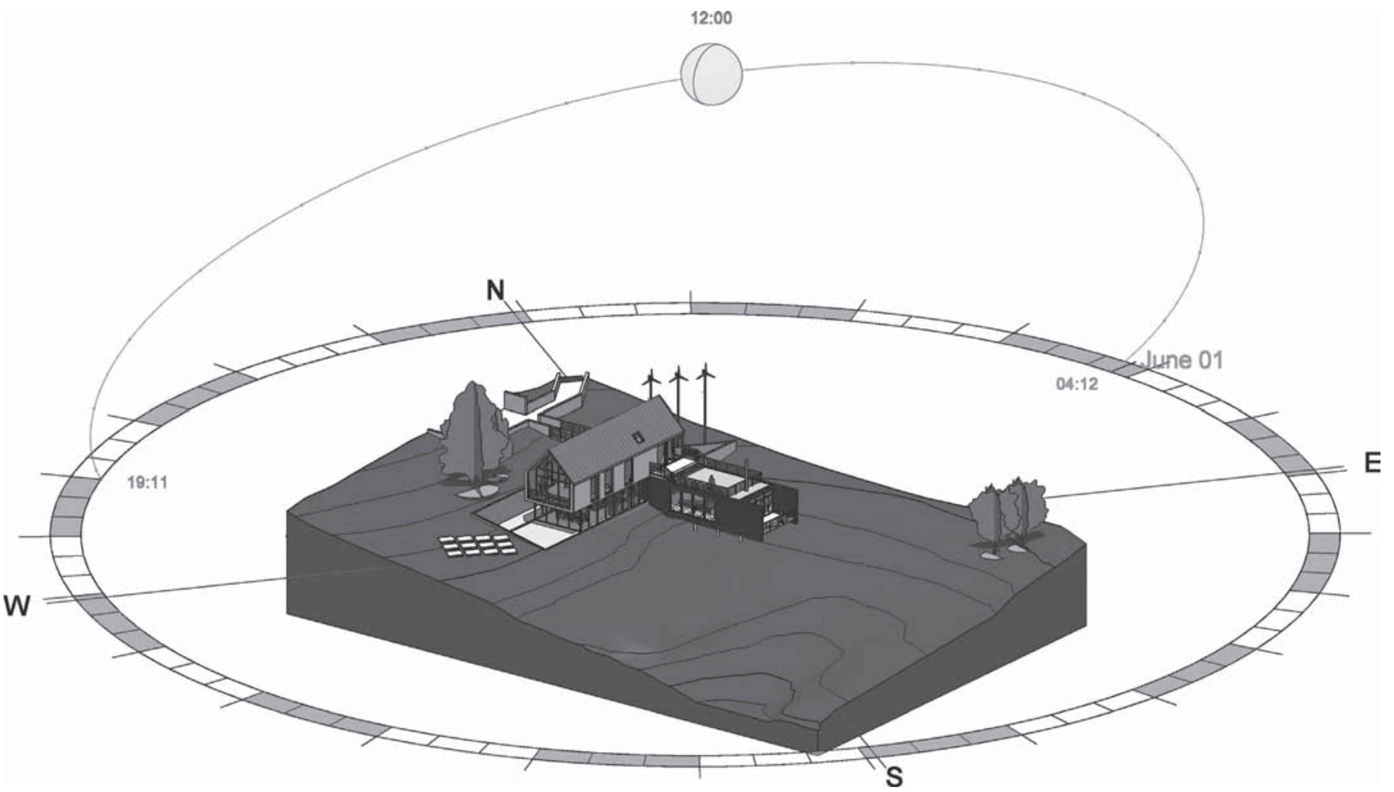

FIGURE 2.6
Visualization of the solar path over a residence in 3D modeling software. Showing shadows in the rendering allows for accurate evaluation of shading devices and window placement.
Source: Photo by Alexander Schreyer

path and climate (Figure 2.6). Does the sun's angle require shading devices to prevent overheating? Can enough windows be provided to have natural daylight in as many spaces as possible? Can building materials be used to insulate where needed and to store or reflect heat where desired? Given favorable prevailing winds, can *natural ventilation* possibly be achieved by way of building orientation, operable windows, or mechanical louvers?

Where rainwater or other water is available, it may be desirable to harvest it and use it as part of a *gray-water system* that then supplies toilets and some appliances. Such a system can reduce the demand for treated, municipal water significantly.

Early builders also noticed that some materials had a tendency to heat up slowly and, once heated, released that heat equally slowly. This is called *thermal storage* and is most pronounced in denser materials like concrete and brick (that have a high

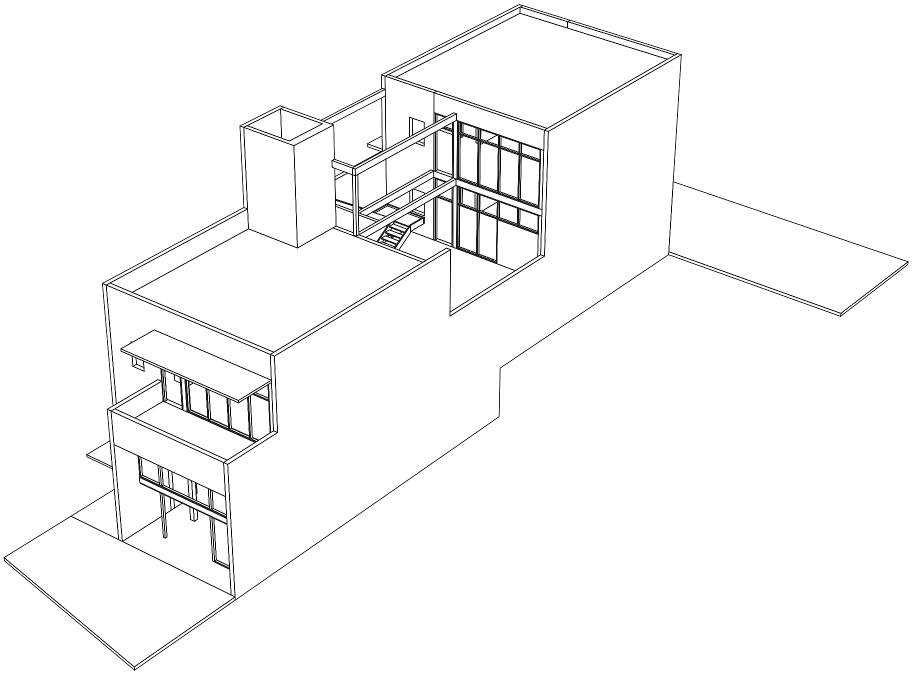

FIGURE 2.7
An infill development preserves valuable land yet provides adequate housing. Shading devices and balcony overhangs protect against overheating in summer, and an interior courtyard provides daylighting to all areas of the house.
Source: Ching/Shapiro Green Building Illustrated, John Wiley & Sons Inc., 2014

thermal mass). Clay, which was often used in brick walls, also showed a capacity to have a similar buffering effect with moisture from the air. Given the right placement of materials, those two effects could then successfully be used to control interior climate and make it less prone to unpleasant spikes and fluctuations (see Chapter 27 for earthen construction methods as well).

The shape of the building and its orientation can be modified to provide possibilities for *passive solar* heating and passive cooling (Figures 2.8 and 2.9). In fact, a thoughtful response by the designer to the climate and microclimate can have more impact on environmental issues than any other design act for a house of a given size.

Common problems relating to energy losses are *thermal bridges* and *air infiltration.* Thermal bridges are paths through exterior walls where heat can escape either by way of overly conductive materials such as metals or through specific building geometry such as tight corners that in turn reduce a building's insulating ability. Air infiltration issues occur when the building envelope is leaky and the air exchange between inside and outside is high. This can lead to inefficient heating and cooling systems as well as condensation and mold problems. Once basic solar and climate design parameters are in place, it is tremendously important for a building designer to develop details that minimize heat-loss and air infiltration effects.

It should be noted that such detailing can often be contrary to the owner's wishes. For example, the most efficient, practical energetic building shape is a simple box because it minimizes surface area for a given building volume. An owner or developer, however, will likely want to add balconies, dormers, cantilevers, and other details that inherently reduce that efficiency. Also, windows and doors, while desired for daylight and access, are not very good insulators (even if triple-paned glazing is used). A designer must then work hard to accurately detail and provide sufficient insulation in those areas (Figure 2.10).

When looking at dwellings in terms of sustainable design, one may come to the conclusion that the popular single-family house may actually not be the most

FIGURE 2.8

This passive solar house, designed by architect Michael Utsey and built in 1976, employs south-facing glass, interior thermal mass, and extra insulation to reduce heating and cooling costs. As a strategy, passive solar heating and cooling have received a new impetus in recent years from designers, whose strategies follow a holistic view of the environment and human health.
Source: Photo © Jane Lidz

FIGURE 2.9

The University of Texas at Austin and Technische Universitaet Muenchen perform a cheer at their demonstration house at the 2015 U.S. Department of Energy Solar Decathlon competition, which showcases solar design and energy efficiency planning. The principles of passive solar design have remained constant in the 40 years since the house in Figure 2.8 was built, but materials and techniques have vastly improved.
Source: Courtesy of Thomas Kelsey/U.S. Department of Energy Solar Decathlon