

FUNDAMENTALS OF BUILDING CONSTRUCTION

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An ironworker connects a steel wide-flange beam to a column.
(Courtesy of Bethlehem Steel Company.)

We build to satisfy our practical and spiritual needs. Not all human activity can take place outdoors. We need shelter from sun, wind, rain, and snow. We need dry, level surfaces on which to work, play and live. On these sheltered surfaces, we need air that is warmer or cooler, more or less humid, than outdoors. We need less light by day, and more by night, than is offered by the natural world. We need services that provide energy, communications, water, and disposal of wastes. And we need structures that house and express our cultural and spiritual aspirations. So, we gather materials and assemble them into the constructions we call buildings in an attempt to satisfy these needs.

LEARNING TO BUILD

This book is about the materials and methods of building construction. Throughout it, alternative ways of building are described: different structural systems, different methods of building enclosure, and different interior finishes, each with characteristics that distinguish it from the alternatives. Sometimes a choice between alternatives is based on visual characteristics, such as when a particular finish material is preferred for its surface character and beauty, or when a material such as concrete is selected over steel for its massiveness and plasticity. Sometimes choices are purely technical, such as the selection of a membrane that is impervious to water for a low-slope roof, or when a particular method of masonry wall reinforcing is selected to provide resistance to earthquake forces. Choices of materials and building systems may be made with the goal of minimizing environmental impacts, or they may be dictated by regulations intended to protect public safety and welfare. Construction costs, energy efficiency, durability, and many other factors come into consideration.

This textbook will start you down the path of becoming skilled at making such choices. But it is incumbent upon the you, the reader, to go beyond what is provided here—to other books, product literature, trade publications, professional periodicals, websites, and

especially the design office, workshop, and building site. One must learn how materials feel in the hand; how they look in a building; how they are manufactured, worked, and put in place; how they perform in service; how they age with time. One must become familiar with the people and organizations that produce buildings—the architects, engineers, product manufacturers, materials suppliers, contractors, subcontractors, workers, inspectors, managers, and building owners—and learn to understand their respective methods, problems, and points of view. There is no other way to gain the breadth of information and experience necessary than to get involved in the art and practice of building.

In the meantime, this long and hopefully enjoyable process of education in the materials and methods of building construction can begin here, with this text.

Go into the field where you can see the machines and methods at work that make the modern buildings, or stay in construction direct and simple until you can work naturally into building-design from the nature of construction.

—Frank Lloyd Wright, “To the Young Man in Architecture,” 1931

BUILDINGS AND THE ENVIRONMENT

In constructing and occupying buildings, we consume large quantities of the earth’s resources and generate a significant portion of its environmental pollution. The construction and operation of buildings account for more than a third of the world’s consumption of energy and emissions of the global warming gas carbon dioxide. In the United States, building design, construction, and operation are responsible for the consumption of more than 35 percent of the country’s energy, 12 percent of its potable water, and a third of its raw materials, while generating a third of its solid wastes and almost 40 percent of its carbon dioxide emissions. In short, building construction and operation are major contributors to many forms of environmental degradation and place a significant burden on the earth’s resources.

In 1987, the United Nations report “Our Common Future” provided a concise definition of *sustainable development*: building to meet the needs of the present generation without compromising the ability of future generations to meet their needs. But, by consuming irreplaceable fossil fuels and other nonrenewable resources, building in sprawling patterns on prime agricultural land, using destructive land development and forestry practices that degrade natural ecosystems, generating substances that pollute water, soil, and air, and generating copious amounts of waste materials that are eventually incinerated or buried in the earth, we have been building in a manner that will make it increasingly difficult for our children and their children to meet their needs for communities, buildings, and healthy lives. Sustainable building construction demands a more symbiotic relationship between people, buildings, communities, and the natural world. Sustainable

FIGURE 1.1

The Bullitt Center, Seattle, designed by architect Miller Hull Partnership, was the first commercial building to achieve Living Building certification in 2015. This building generates as much as 60 percent more electricity than it uses and consumes less than one-quarter of the energy of a typical U.S. office building.

(Photo by Joseph Iano.)

buildings—in both their construction and operation—must consume fewer resources, cause less pollution, reduce waste, discourage wasteful land development practices, and contribute to the protection of natural environments and ecosystems.

In the decades since the release of “Our Common Future,” the understanding of the interplay between buildings and the environment has deepened and the standards for assessing the sustainability of building materials and construction practices have matured in approach. The definition of sustainability has expanded to include human health impacts of buildings and consideration of issues of social and economic justice. Expectations for the performance of sustainable buildings have also advanced beyond simply reducing environmental harms to doing no harm, or even undoing previous such harms (Figure 1.1).

In 2015, the United Nations adopted its “2030 Agenda for Sustainable Development,” which provides a comprehensive framework of 17 *Sustainable Development Goals* for global peace and prosperity. Concerns of the broadest possible social relevance—such as poverty and hunger, human health and well-being, education, inequality, and justice—are addressed. Topics directly relating to the construction and habitation of our buildings are also considered, for example: clean water and sanitation, clean energy, resilient infrastructure, sustainable communities, sustainable consumption and production of materials, protection of the natural environment, and



climate action. Throughout this book, the ways in which the materials and methods of building construction intersect with these concerns are addressed.

Sustainable Buildings and Standards

Sustainable building (also called *green building*) requires a holistic, interdisciplinary approach to design and construction. For example, one project goal may be to provide natural daylighting, as a means to improving productivity and the well-being of building occupants. Good daylighting design reduces reliance on electric lighting. This, in turn, reduces electricity consumption and excess heat generated by the electric lights. This, then, reduces cooling loads and allows the building’s cooling system to be reduced in capacity. Daylighting design can also influence building siting and shape, the arrangement and sizes of spaces within the building,

and the building structure and enclosure. As a result of the decision to provide natural daylighting, many building systems are impacted, and many opportunities for cost savings, reductions in energy consumption, improvements in occupant health and comfort, and lessening of environmental impacts are created.

This kind of design thinking, sometimes called *integrated design process (IDP)*, is a whole-systems way of working that breaks down traditional boundaries between disciplines and parts of the work. The key members of the design, construction, and owner groups are brought together. A shared vision and goals are established. The process spans from the earliest conceptual phase through design, construction, and *post-occupancy* (the operational phase that begins once construction is completed). A collaborative, interdisciplinary approach is used that maximizes opportunities for synergies and innovation.



LEED v4.1 BD+C
Project Checklist

Y	?	N			
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Integrative Process	1
0	0	0	Location and Transportation		16
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	LEED for Neighborhood Development Location	16
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Sensitive Land Protection	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	High Priority Site and Equitable Development	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Surrounding Density and Diverse Uses	5
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Access to Quality Transit	5
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Bicycle Facilities	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Reduced Parking Footprint	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Electric Vehicles	1
0	0	0	Sustainable Sites		10
Y			Prereq	Construction Activity Pollution Prevention	Required
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Site Assessment	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Protect or Restore Habitat	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Open Space	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Rainwater Management	3
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Heat Island Reduction	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Light Pollution Reduction	1
0	0	0	Water Efficiency		11
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Outdoor Water Use Reduction	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Indoor Water Use Reduction	6
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Optimize Process Water Use	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Water Metering	1
0	0	0	Energy and Atmosphere		33
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Enhanced Commissioning	6
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Optimize Energy Performance	18
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Advanced Energy Metering	1
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Grid Harmonization	2
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Renewable Energy	5
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Credit	Enhanced Refrigerant Management	1

0	0	0	Materials and Resources		13
Y			Prereq	Storage and Collection of Recyclables	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Environmental Product Declarations	2
			Credit	Sourcing of Raw Materials	2
			Credit	Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	0	0	Indoor Environmental Quality		16
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	0	0	Innovation		6
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0	Regional Priority		4
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0	TOTALS		Possible Points: 110
Certified: 40 to 49 points, Silver: 50 to 59 points, Gold: 60 to 79 points, Platinum: 80 to 110					

FIGURE 1.2

The LEED v4.1 Project Checklist for New Construction and Major Renovation. (A significantly restructured LEED v5 is expected in 2025.) (Courtesy of U.S. Green Building Council.)

In the United States, the most widely applied program for assessing building sustainability is the U.S. Green Building Council's *Leadership in Energy and Environmental Design*, or *LEED*[®], rating system. LEED for New Construction and Major Renovation groups sustainability goals into eight broad categories addressing areas such as site

selection and development, energy efficiency, conservation of materials and resources, and others (Figure 1.2). Within each category are mandatory *prerequisites* and optional *credits* that contribute points toward a building's overall rating. During the design and construction process, the achievement of prerequisites and credits is documented

and submitted to the Green Building Council, which then verifies the project's compliance. Depending on the point total achieved, four levels of recognition are possible, including, in order of increasing performance, Certified, Silver, Gold, and Platinum. The LEED rating system is itself voluntary. It is used when adopted by a private building

developer or mandated by a public building agency.

The Green Building Council also provides rating systems for building core and shell construction, interior design and construction, building operations and maintenance, and cities and community development. Through affiliated organizations, LEED is implemented in Canada and other countries.

The International Living Future Institute's *Living Building Challenge*TM standard for sustainable development is formulated with the goal of not simply reducing harms to the environment and human well-being, but rather, to eliminating or even reversing such harms. For example, a building constructed and operated to this standard will (when considered on an annualized basis) produce all its own energy from on-site renewable resources, consume no fresh water, and make no contribution to increased greenhouse gas emissions.

The Living Building Challenge contains seven categories called Petals, including: Place, Water, Energy, Health & Happiness, Materials, Equity, and Beauty. Within these are 20 *Imperatives*, such as net positive carbon, responsible materials sourcing, healthy interior environment, and others. There are various certification levels: Living Certification meets all imperatives; Petal and

Core Certifications signify compliance with some but not all imperatives; Zero Energy and Zero Carbon Certifications pertain to performance in those specific areas. All certifications are *performance based*. That is, they do not prescribe practices or methodologies for achieving these goals. Rather, certification is based on end results, verified after a building has been operational for at least one year and demonstrates compliance through its real-world performance. The Living Building Challenge can also be applied to other types of construction and development, such as neighborhoods, landscape and infrastructure projects, and building renovations.

Sustainable Building Materials

Describing Sustainable Materials

Designing sustainable buildings requires access to information about the environmental and health impacts of the materials used in their construction. For example, when selecting a material, the designer might ask: Does its manufacture depend on the extraction of nonrenewable resources, or is it made from recycled or rapidly renewable materials? Is additional energy required to ship this material from a distant location, or can it be obtained from local sources? Does the material contain toxic ingredients or

generate unhealthful emissions, or is it free of such health concerns?

Information about building materials and products can come from different sources and take various forms:

- It may be self-reported by the product manufacturer, or it may come from an independent, trusted third party.
- It may take the form of a neutrally expressed, transparent disclosures of material attributes, or it may gauge the merits (or demerits) of such attributes and provide a rating of the material's sustainability.
- It may address a limited scope of concerns, or it may describe the full range of impacts of a material throughout its life from raw materials extraction to end-of-life disposal or repurposing.

The industry-standard *Product Data Sheet (PDS)* is a simple example of manufacturer self-reported information. The PDS provides a description of a product, its material makeup and physical properties, and guidelines for use. It may also include information relevant to sustainability concerns, although this is not its primary purpose. The scope of information provided in a PDS is left entirely to the manufacturer, and the information is not independently verified.

OTHER SUSTAINABLE BUILDING PROGRAMS AND STANDARDS

There are myriad programs and standards offering pathways to sustainable building construction. For example, the National Association of Home Builders' National Green Building Standard addresses both single-family and multi-unit residential building types. CALGreen is the sustainable construction code for the state of California. Green Globes certifies sustainably designed buildings in the United States and Canada. The Building Research Establishment Environmental Assessment Method, (BREEAM) and the German Sustainable Building Council's DGNB do the same for buildings constructed principally in the United Kingdom and

other European countries. The North American *Passive Building* and European Passive House standards, implemented in many places around the globe, emphasizes dramatic reductions in the energy consumption of residential and commercial buildings. The WELL standard certifies building construction with regard to human health and safety, well-being, and equity criteria. Many professional organizations and government agencies offer programs to support sustainable building, such as the Architecture 2030 Challenge and ASHRAE's Standard for the Design of High-Performance Green Buildings, to name just two.

Environmental labels, also called *ecolabels*, are third-party environmental ratings. An example is the Green Seal Standard GS-11 for Paints and Coatings. Green Seal is an independent organization that develops sustainability standards and certifications. For a paint product to be certified to its standard, the product must meet minimum performance criteria, be free of toxic ingredients, and not exceed content limits on *volatile organic compounds (VOCs)*. (VOCs are air polluting and unhealthy chemical compounds that are released in particularly heavy concentrations from wet-applied products as they dry.) By relying on this certification, the designer can confidently make environmentally responsible choices, without having to perform in-depth investigations of individual products.

Product disclosures are another form of reporting that provide transparent information about material ingredients and manufacturer practices. For example, the International Living Future Institute's Declare label describes a product's origins, its material ingredients, and end-of-life disposal or recycling options. By providing this information in a standardized format, designers can more easily compare the attributes of alternative materials or products and make better-informed choices. Like a Product Data Sheet, the Declare label is self-reported by manufacturers, albeit with an option for independent auditing to verify accuracy. Unlike ecolabels, product disclosures do not grade or rate the sustainability of the product—it remains up to the user to interpret the information provided for this purpose.

Environmental Product Declarations (EPDs) describe the fuller, life-cycle impacts of building materials and products. An example is the Western Red Cedar Lumber Association's Typical Red Cedar Decking Product Declaration. This 10-page document describes this product's material characteristics and quantifies—in detail—environmental impacts throughout

its life. For example, for every 1 square meter (11 square feet) of decking harvested, milled, trucked to the construction site, installed, maintained through its useful life, and then disposed of at the end of its life, this declaration reports the following:

- 73MJ (70,000 BTU) of nonrenewable energy consumed
- 6.8kg (15 pounds) of CO₂ equivalent *global warming potential*
- 86L (23 gallons) of fresh water consumed

Additional information in the report quantifies materials consumption, smog production, ozone depletion, and more. Information about the standards to which this information is prepared and independent verification of the results are also included. While this document does not provide an environmental rating, it can be used, for example, in comparing Western red cedar to some other material, such as recycled plastic decking, to assess the relative environmental consequences of choosing one of these materials over the other.

As life-cycle data has become broadly reported for building materials, this type of analyses can be expanded and applied to whole buildings as well. Such *environmental building declarations (EBDs)*, allow the big picture impacts of alternative building designs to be more meaningfully and easily compared. Whole building life-cycle data is typically reported on an annualized basis. For example, the Athena Institute's EBD for the Brock Commons Tallwood House (see pages 146–147) reports a global warming impact of 20 kg (44 pounds) of CO₂ equivalent global warming potential per square meter of building area per year.

Much of the environmental reporting provided by construction product manufacturers is developed according to the international series of standards designated ISO 14020, which establish guidelines for the development and use of environmental labels,

declarations, and other forms of product data. By relying on information produced to common, accepted standards, designers and builders can have the greatest confidence in the consistency and relevance of the information provided.

The Material Life Cycle and Environmental Impacts

Preparation of environmental product and building declarations depends on the full accounting of the environmental impacts of materials and products throughout their useful life. This begins with raw materials extraction, continues with manufacture, transportation to the building site, construction, and building use, and finishes at end of life when a material is disposed of or put to a new use. Such a *life-cycle analysis (LCA)*, is a comprehensive method for quantifying the environmental impacts associated with construction materials and buildings. Through each life-cycle stage, impacts are tallied: How much fossil fuel, electricity, water, and other resources are consumed? How much solid waste, global warming gasses, and other air and water pollutants are generated? The total of all these impacts describes the *environmental footprint* of the material (Figure 1.3).

A life-cycle analysis that includes the full life of a product or system, from resource extraction to end of life, is called a *cradle-to-grave analysis*. Other life-cycle assessments may be calculated for only a part of a material's life. A *cradle-to-gate* analysis begins with materials extraction but extends only as far as when the material leaves the factory, excluding the effects of transportation to the building site, installation, use, maintenance, and disposal or reuse. Though less comprehensive, such analyses can still provide a useful basis for comparison between products. This is because, for many materials, the difference in impacts between a cradle-to-grave and cradle-to-gate analysis is small, as most of the energy expenditure, greenhouse gas

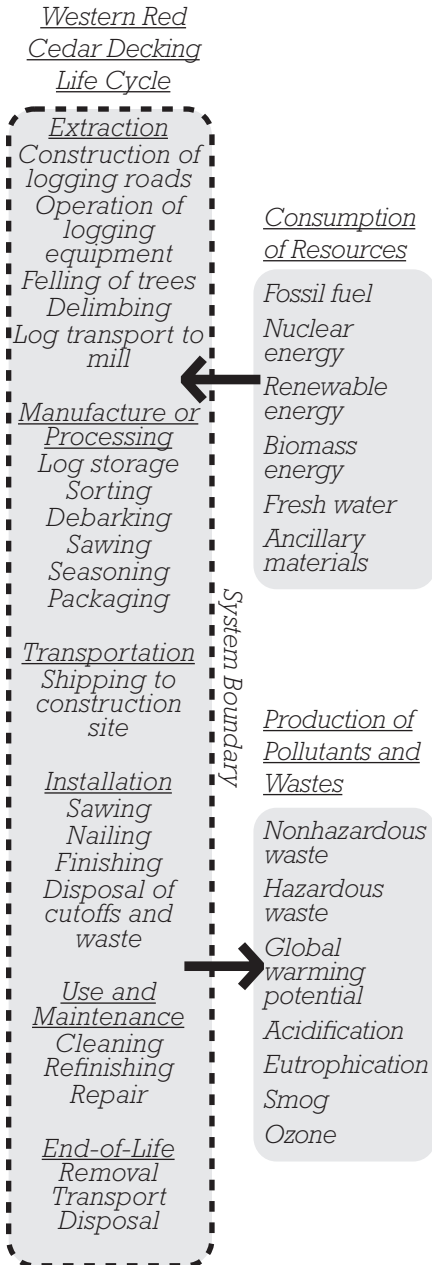


FIGURE 1.3

Life-cycle analysis of Western red cedar decking. The *system boundary* defines the materials and processes within the scope of the analysis. Within this boundary, the underlined life-cycle stages (Extraction, Manufacture or Processing, etc.) are generally applicable to any construction material LCA, while the activities listed under each stage will vary depending on the particular materials and processes under consideration. On the right, impacts, such as resources consumed (for example, energy and water) and pollutants generated (the creation of global warming gasses and wastes, etc.) are listed. Though not shown here, LCAs quantify these impacts so that materials, assemblies, or whole buildings can be meaningfully compared with one another.

if 2 pounds of the prior material are required to accomplish the same purpose as 1 pound of the latter. The types of energy consumed for each material, such as fossil, nuclear, or renewable, must also be considered, as impacts differ from one energy source to another.

Closely tied to LCA are the concepts of embodied and operational environmental impacts. In simple terms, a building's embodied impacts are the environmental costs of its construction, and its operational impacts are the environmental costs of its use. For example, *embodied energy* refers to the energy expended in the extraction, manufacture, transportation, and construction on site of a building material. *Operational energy* refers to energy consumed over the life of a building resulting from the activities that take place within it.

Embodied energy tells us the energy cost to put a material into a building. These costs are incurred in a relatively brief period of perhaps several years, at the start of the building life cycle. Operational energy tells us the energy costs of using the building over its full, useful life. In contrast to embodied energy, operational energy costs accrue more gradually, typically over a span of 50 years or more. A full life-cycle accounting of the energy impacts of a building includes consideration of both embodied and operational energy. However, one may also consider that because embodied impacts are concentrated at the start of the building life cycle, their impact on the environment comes

sooner and is potentially more consequential.

The concept of embodied effects can also be applied to other inputs or outputs from a life-cycle analysis. For example, *embodied carbon* refers to the carbon equivalent emissions associated with the manufacture and construction of a material into a building. As the energy efficiency of buildings has improved and *operational carbon* impacts have decreased, building with low embodied carbon materials has become an increasingly important consideration in building sustainably.

While life-cycle analysis represents the most generally comprehensive materials assessment method currently available, it does not necessarily address all impacts arising from the use of a material or product. LCA of wood products, for example, does not capture the potential loss of biodiversity, decreased water quality, or soil erosion caused by poor forestry practices. In this case, these concerns are better addressed by sustainable forestry certification programs. Or, although global warming potential is quantified in environmental product declarations, the ultimate consequences of climate change for ecosystems, wildlife populations, and human well-being are not necessarily addressed.

Health Impacts of Building Materials

Similar to environmental product declarations, *health product declarations (HPDs)* provide information about material ingredients and their associated human and environmental

emissions, and other impacts occur during the material's extraction and manufacture, prior to its installation, use, and eventual disposal.

When comparing life cycle impacts between different materials, it is important to be sure that the comparison is functionally equivalent. For example, a material with an embodied energy of 10,000 BTU per pound is not necessarily environmentally preferable to another with an embodied energy of 15,000 BTU per pound,

health risks. For example, many building products, such as coatings, adhesives, sealants, wood composites, floor, wall and ceiling finishes, and furniture, are potential sources of chemical air pollutants or toxins that can be harmful to the workers that manufacture these products, construction personnel, or building occupants.

The standard for creating HPDs is defined by the HPD Collaborative, an independent organization with representation from many construction industry stakeholders. HPDs list the material contents of the product being reported and indicate associated hazards, such as the presence of persistent bio-accumulative toxic compounds, carcinogens, respiratory irritants, neurotoxins, and more. Like EPDs, HPDs do not grade the healthfulness of a product. They do, however, provide reliable information in a standardized format that can be used to make meaningful comparisons between products.

Other types of environmental labels and product disclosures also frequently provide health-related data. The Living Building Challenge *Red List* is one such notable source, cataloging compounds that pose especially grave risks to human health or the natural environment.

Both LEED and the Living Building Challenge rating systems discourage the presence of Red List materials in buildings.

Other Considerations in Sustainable Materials and Design

Products with a high *recycled materials content* help to divert waste that would otherwise be disposed of in landfills or by incineration. *Preconsumer recycled materials* originate as byproducts of manufacturing processes. For example, when a glass manufacturer reclaims broken glass during its manufacture and reprocesses this waste into new glass, this is preconsumer recycled waste. *Postconsumer recycled materials* are generated by end users of a material. A gypsum board manufacturer recycling used newsprint into paper facing for its board products is an example of postconsumer recycled waste. When assessing recycled content in the LEED system, preconsumer waste is counted at only half of its weight or cost, while postconsumer waste is counted at its full value.

Materials reuse or *salvaging*, the taking of materials from decommissioned buildings for use in new ones, *design for disassembly*, the design of new structures for future disassembly and materials repurposing, and *extended*

producer responsibility programs, in which manufacturers assume responsibility for diverting end of life products into recycling or reuse programs, are ways to reduce the demand for new raw materials and lessen the volume of waste going to landfills or incineration.

Bio-based materials are produced by agricultural or animal biological processes, for example, cornstarch derived from grain and used as an ingredient in the manufacture of gypsum wallboard, or resins made from wood lignin or plant proteins used as substitutes for traditional petroleum-derived resins in the manufacture of composite wood products. Bio-based materials are biodegradable and generally carbon-neutral (meaning they contribute less to global warming).

As extreme weather and natural disasters occur with more frequency, *building resilience* has become an important consideration in sustainable design. Resilient buildings must be able to absorb and recover from exceptionally high winds, flooding, drought, wildfires, high temperatures, and other life- and property-threatening events while protecting occupants and minimizing the time during which these buildings may be rendered unsafe or inoperable (Figure 1.4).

FIGURE 1.4

An example of resilient building design:

This modest sea-side bathhouse is constructed of materials suitable to the harsh, day-to-day effects of coastal, wind-driven, water- and salt-laden air. It is also designed to survive exceptional storm surge events of the type that have become increasingly common in recent years. *Flood resistant design* such as this includes, for example, ensuring that the building structure and its foundation are strong enough to resist the pressures of flowing water and wave action, and that parts of the building below the expected level of flooding are made of materials that can withstand temporary submersion without suffering permanent damage.

(Photo by Joseph Iano.)



Increasing attention is also being given to consideration of *social equity* and *responsible industry practices*. That is, how do raw materials extraction practices, land use policies, manufacturing processes, and labor practices impact not only the natural environment, but also the communities and societies within which these activities occur? For example, the Natural Stone Council's 373 Sustainability Assessment for Natural Dimension Stone includes consideration of land reclamation efforts and human health and safety. The Forest Stewardship Council certification of sustainable forestry includes, along with attention to responsible forestry practices, consideration of community relations, worker's rights, and the rights of indigenous or other vulnerable communities.

Achieving High-Performance, Sustainable Buildings

Sustainable building practices produce measurable improvements in building performance. Post-occupancy evaluations of U.S. buildings constructed to LEED standards report reductions in energy consumption and greenhouse gas emissions in the range of 20 to 40 percent on average in comparison to buildings constructed to conventional standards.

Even higher levels of performance are achievable. For example, the Living Building certified Bullitt Center (page 5) consumes 83 percent less energy than an average office building in the same city. *Zero energy buildings* (also called *net-0 energy buildings*) can achieve efficiency improvements of as high as 90 percent, which when combined with onsite renewable energy production, effectively reduce to zero these buildings' annual consumption of energy from external sources.

Building Commissioning

Achieving high-performance results requires a committed, sustained effort by the design and construction

team. As noted earlier in this chapter, integrated design process is one example of such an effort. *Building commissioning* (abbreviated *Cx*) is another. Commissioning begins with the definition of performance objectives at the start of design. As design progresses, these objectives are used to guide decision-making and assess progress at interim milestones. As construction is drawing to completion, real-world performance is verified through on-site testing. Finally, operational guidance is provided to the building owner or operator to ensure that the finished, occupied building will continue to perform as designed.

Building commissioning has in the past been applied most frequently to the testing and verification of heating, ventilating, and air conditioning systems in new buildings. With sustainable design and construction, commissioning has been elevated to address many overarching aspects of building performance such as energy use, water consumption, life safety systems, accessibility, acoustical performance, occupant health and well-being, operational procedures and costs, and more. A rigorous, fully documented commissioning process is a prerequisite for LEED certification.

THE WORK OF THE DESIGN PROFESSIONAL

A building begins as an idea in someone's mind, a desire for new and ample accommodations for a family, many families, an organization, or an enterprise. For any but the smallest buildings, the next step for the owner of the prospective building is to engage the services of building design professionals. An architect helps to organize the owner's ideas about the new building while various engineering specialists work out concepts and details of foundations, structural support, and mechanical, electrical, and communications services.

The architect should have construction at least as much at his fingers' ends as a thinker his grammar.

—Le Corbusier, *Towards a New Architecture*, 1927

This team of designers, working with the owner, then develops the scheme for the building in progressively finer degrees of detail. *Construction drawings*, primarily graphic in content, and *specifications*, mostly written, are produced by the architect/engineer team to describe how the building is to be made and of what. These drawings and specifications, collectively known as the *construction documents*, are submitted to the local government building authorities, where they are checked for conformance with various codes and regulations before a permit is issued to build. A general contractor is selected, who then plans the construction work in detail. Once construction begins, the general contractor oversees the construction process and hires the subcontractors who carry out many portions of the work, while the building inspector, architect, and engineering consultants observe the work at intervals, to be sure that it is completed according to plan. Finally, construction is finished, the building is made ready for occupancy, and that original idea—often initiated years earlier—is realized.

Environmental and Land Use Regulations

For many buildings, the first step in the legal approval process may be an *environmental impact assessment*. Concerns related to both the natural and built environments may be addressed, including, for example, potential impacts on water resources, natural habitats, protected species, air and water pollution, municipal water and sewer systems, transportation systems,

urban open space, community facilities, neighborhood character, and more. Impact assessments identify potentially undesirable outcomes, create opportunities for stakeholder input, and provide a legal framework for proposing mitigating measures. The scope of issues addressed and level of effort required to complete such assessments can vary significantly depending on the size of the project and complexity of the issues involved.

In many locations, buildings must also comply with land use regulations called *zoning ordinances*. These govern the types of activities that may take place on a given piece of land, how much of the land may be covered by buildings, how much parking must be provided, how large a total floor area may be constructed, and how tall the buildings may be. In larger cities, zoning ordinances may include fire zones with special fire-protection requirements, neighborhood enterprise districts with economic incentives for new construction or revitalization of existing buildings, or other special conditions.

Building Codes

Local governments also regulate building activity by means of *building codes*. Building codes protect public health and safety by setting minimum standards for construction quality, structural integrity, durability, livability, and especially fire safety.

Most building codes in North America are based on one of several *model codes*: standardized compilations of building regulations that local jurisdictions may adopt for their own use as a simpler alternative to writing their own. In Canada, the *National Building Code of Canada* is published by the Canadian Commission on Building and Fire Codes. It is the basis for most of that country's provincial and municipal building codes. In the United States, the *International Building Code*[®] (*IBC*) is the predominant model code. This code is published by the International Code Council,

a private, nonprofit organization whose membership consists of local code officials from throughout the country. It is the basis for most U.S. building codes enacted at the state, county, and municipal levels.

Building Occupancies

Building code-related information in this book is based on the IBC. The IBC begins by defining *occupancies* for buildings as follows:

- A Assembly: public theaters, auditoriums, lecture halls, nightclubs, restaurants, houses of worship, libraries, museums, sports arenas, and so on
- B Business: banks, administrative offices, college and university buildings, post offices, banks, professional offices, and the like
- E Educational: schools for grades K through 12 and some types of child day-care facilities
- F Factory and Industrial: industrial processes using materials that are noncombustible or only moderately flammable
- H High Hazard: occupancies in which toxic, corrosive, highly flammable, or explosive materials are present
- I Institutional: occupancies in which occupants under the care of others may require assistance during a building emergency, such as 24-hour residential care facilities, hospitals, nursing homes, prisons, and some day-care facilities
- M Mercantile: stores, markets, service stations, salesrooms, and other retail and wholesale establishments
- R Residential: apartment buildings, dormitories, fraternity and sorority houses, hotels, one- and two-family dwellings, and assisted-living facilities
- S Storage: facilities for the storage of moderate- and low-hazard materials, respectively
- U Utility and Miscellaneous: agricultural buildings, carports, greenhouses, sheds, stables, fences, tanks, towers, and other secondary buildings

The IBC's purpose in describing occupancies is to identify different levels of life-safety risk within buildings. For example, a hospital, in which patients may be unable to escape without assistance from others must provide added forms of protection from the spread of fire and smoke within a floor, protections that a hotel occupied by able-bodied residents does not need. A large retail mall building, containing large quantities of combustible materials and occupied by many users varying in age and physical capacity, requires a greater level of fire protection than a warehouse storing noncombustible materials and occupied by relatively few people who are all familiar with their surroundings. A theater, with patrons densely packed in dark spaces, requires more attention to emergency exiting than does an ordinary office building.

Building Construction Types

The IBC also classifies materials of construction according to their capacity to resist fire, using two criteria: combustibility and resistance to the heat of fire. For example, masonry, concrete, and steel are considered *noncombustible*, as they do not, on their own, catch fire and burn. Wood, in contrast, is a *combustible* material. Resistance to the heat of fire is also considered, as even noncombustible materials lose their strength at high temperatures, and wood construction, in some forms, can be surprisingly resistant to the effects of fire for extended periods.

Five *construction types* are defined: Types I and II construction must consist of principally noncombustible materials; Types III and IV permit certain combinations of combustible and noncombustible materials; Type V construction may be constructed of any materials, both combustible or noncombustible. These types are then further subdivided to reflect varying degrees of resistance to fire and high temperatures (Figure 1.5).

TABLE 601—FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)												
BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame ^f (see Section 202)	3 ^{a,b}	2 ^{a,b,c}	1 ^{b,c}	0 ^c	1 ^{b,c}	0	3 ^a	2 ^a	2 ^a	HT	1 ^{b,c}	0
Bearing walls	See Table 705.5											
Exterior ^{e,f}	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3 ^a	2 ^a	1	0	1	0	3	2	2	1/HT ^g	1	0
Nonbearing walls and partitions Exterior	See Table 705.5											
Nonbearing walls and partitions Interior ^d	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	1½ ^b	1 ^{b,c}	1 ^{b,c}	0 ^c	1 ^{b,c}	0	1½	1	1	HT	1 ^{b,c}	0

TABLE 705.5—FIRE-RESISTANCE RATING REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE ^{a,d,g}				
FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP H ^e	OCCUPANCY GROUP F-1, M, S-1 ^f	OCCUPANCY GROUP A, B, E, F-2, I, R ⁱ , S-2, U ^h
X < 5 ^b	All	3	2	1
5 ≤ X < 10	IA, IVA	3	2	1
	Others	2	1	1
10 ≤ X < 30	IA, IB, IVA, IVB	2	1	1 ^c
	IIB, VIB	1	0	0
	Others	1	1	1 ^c
X ≥ 30	All	0	0	0

For SI: 1 foot = 304.8 mm.

FIGURE 1.5

Fire resistance rating requirements of building elements, excerpted from the IBC. The lower table applies to all exterior walls, both bearing and nonbearing, as well as structural columns within the exterior wall. When determining rating requirements for such elements, read from both tables and use the larger number given by either one. Data provided for instructional purposes only. (2024 International Building Code / with permission of International Code Council.)

The upper table in Figure 1.5 specifies minimum *fire resistance ratings*, measured in hours, for the different parts of a building, for each construction type. Consider, for example, Type I-A construction. The first table row indicates that the structural frame, including such elements as columns, beams, and trusses, must

be rated to withstand high temperatures for at least 3 hours. The second row mandates a 3-hour resistance for *bearing walls*, which serve to carry floors or roofs above. The third row indicates that exterior walls must also comply with the requirements of IBC Table 705.5, reproduced in the lower portion of the figure,

which sets requirements based on proximity to adjacent buildings or properties. Additional requirements are defined in the remaining table rows. Type I-A construction, being noncombustible and having the highest fire resistance ratings, is the construction type most resistant to fire. As we will see later in this

section, it is the only type of construction permitted for the very tallest of buildings.

Next in the list are Types I-B, II-A, and II-B construction, also required to be of noncombustible materials, but each with progressively lesser fire resistance ratings. Types III and IV may include various combinations of combustible and noncombustible materials, including, for example, mass timber construction. Types V-A

and V-B, permitted to be entirely made from combustible materials and with low or no fire resistance rating, are the types least resistant to fire. In North America, most single-family homes are constructed as Type V-B construction.

Building Height and Area Limits

With occupancies and construction types defined, the IBC proceeds to relate the two, stating which

occupancies may be housed in which types of construction, and under what limitations of building height and area (Figure 1.6).

Consider, for example, an office building. Under the IBC, this building is classified as Occupancy B, Business. Reading across the table from left to right, we find immediately that this building may be built to any desired height and area, without limit, using Type I-A construction.

Occupancy		Types of Construction— <u>Unsprinklered</u>									
		Noncombustible				Mixed Noncombustible/ Combustible				Combustible	
		Type I		Type II		Type III		Type IV	Type V		
		A	B	A	B	A	B	See Chapter 4	A	B	
Height ^a		U ^d	160	65	55	65	55			50	40
A-2, A-3, A-4	Stories ^b	U	11	3	2	3	2			2	1
	Area ^c	U	U	15,500	9500	14,000	9500			11,500	6000
B	Stories	U	11	5	3	5	3			3	2
	Area	U	U	37,500	23,000	28,500	19,000			18,000	9000
E	Stories	U	5	3	2	3	2			1	1
	Area	U	U	26,500	14,500	23,500	14,500			18,500	9500
F-1	Stories	U	11	4	2	3	2			2	1
	Area	U	U	25,000	15,500	19,000	12,000			14,000	8500
F-2	Stories	U	11	5	3	4	3		3	2	
	Area	U	U	37,500	25,000	28,500	18,000		21,000	13,000	
M	Stories	U	11	4	2	4	2		3	1	
	Area	U	U	21,500	12,500	18,500	12,500		14,000	9000	
R-1, R-2, R-4	Stories	U	11	4	4	4	4		3	2	
	Area	U	U	24,000	16,000	24,000	16,000		12,000	7000	
R-3	Stories	U	11	4	4	4	4		3	3	
	Area	U	U	U	U	U	U		U	U	

^a Height: Roof height above grade in feet (1 ft = 0.3048 m).
^b Stories: Number of stories above grade.
^c Area: Area per floor in square feet (1 sq ft = 0.0920 m²). For buildings taller than three floors, maximum area for all floors combined is three times the area listed in the table.
^d U: Unlimited.

FIGURE 1.6

Simplified IBC height and area limitations for selected occupancies and construction types in buildings that are not fully sprinklered. As explained in the text, these values are further modified according to additional provisions to arrive at the final allowable height and area for a building. Floor areas shown in the table are for single floors. In multistory buildings, total area of all floors is normally limited to 3 times the area permitted for a single floor. Data provided for instructional purposes only. (2024 International Building Code / with permission of International Code Council.)

Reading across the table, we find other construction types, some with lesser fire resistance ratings and some with fewer restrictions on the use of combustible materials. At the far right of the table, we find Type V-B construction, with no restriction on combustible materials and no special fire resistance required. These differences are reflected in the table, in which the most resistant construction type, Type I-A, is permitted the greatest height and area, and other less resistant types are limited to progressively lower heights and lesser areas.

Fire-Resistance Rated Construction

Once fire resistance rating requirements for the major parts of a building have been determined, the design of these parts can proceed, using building assemblies meeting these requirements. Tabulated fire resistance ratings for building materials and assemblies come from many sources, such as the IBC itself, as well as from catalogs and handbooks issued by building material manufacturers, construction trade associations, and organizations concerned with fire protection of buildings. In each case, the ratings are derived from large-scale laboratory tests carried out in accordance with an accepted standard protocol to ensure uniformity of results. (The most important of such tests, ASTM E119, is described more fully in Chapter 22 of this book.) Figure 1.7 shows examples of how such ratings are commonly presented.

Applying Construction Types to Building Design

In general, when determining the construction type for a building, the greater its resistance to fire, the higher

the cost. Most frequently, therefore, buildings are designed to the least resistive type permitted by the building code. Our hypothetical office building could be built using Type I-A

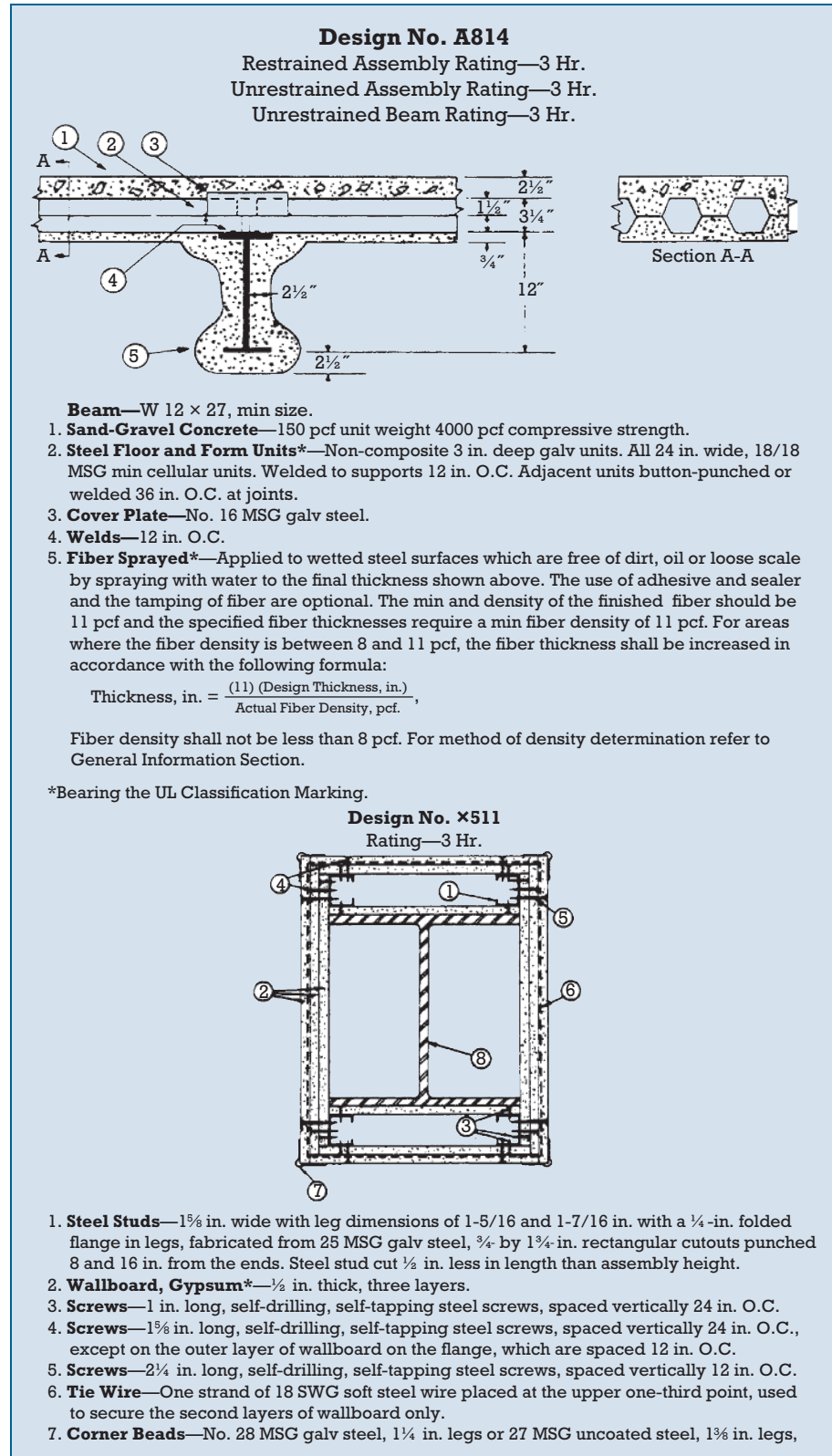


FIGURE 1.7

Fire resistance ratings for a steel floor structure (*top*) and column (*bottom*), taken from the Underwriters Laboratories' *Fire Resistance Directory*.

In the floor assembly, the terms “restrained” and “unrestrained” refer to whether or not the floor is connected to its supporting structure in such a way that it is, or is not, prevented from expanding longitudinally when subjected to the heat of a fire. (Reproduced with permission of Underwriters Laboratories Inc.)

construction, but does it really have to be constructed to this high standard?

Let us suppose that the owner desires a three-story building with 30,000 square feet per floor. Referring again to Figure 1.6, we can see that in addition to Type I-A construction, the building can be of Type I-B construction, which permits a building of 11 stories and unlimited floor area; or of Type II-A construction, which permits a building of 5 stories and 37,500 square feet per floor. But it cannot be of Type II-B construction, which allows a building of three stories but only 23,000 square feet per floor, nor of Types III or V construction.

If a building is protected throughout by an automatic sprinkler system for suppression of fire, the tabulated area per floor may, in many cases, be tripled for a multistory building or quadrupled for a single-story building. The rationale for this increase is the added protection to life and property provided by such a system. A one-story increase in allowable height is frequently also granted in such circumstance. For example, if the three-story, 30,000-square-foot office building that we have been considering is provided with an automatic sprinkler system, a bit of arithmetic will show that it can be built of any construction type included in Figure 1.6, with the exception of Type V-B.

Additional factors come into play in these determinations. For example, buildings surrounded by generous expanses of open space accessible to firefighting equipment

may be increased in area. Or, buildings may be divided by special types of construction, called *fire walls*, that permit each divided portion to be considered a separate building for purposes of computing its allowable area (Figure 1.8). In fact, the code includes many adjustments to its basic building height and area limits, which when taken together, can make the determination of allowable building size an often complex task in actual practice. For the purposes of this book, many of these possible modifications are simplified or ignored.

Other Code Requirements

The IBC establishes standards for natural light; ventilation; *means of egress* (exiting during building emergencies); accessibility for disabled persons; structural design; interior finishes; chimney construction; fire-protection systems; and many other aspects of building design. In addition to the IBC, the International Code Council also publishes the *International Residential Code for One- and Two-Family Dwellings (IRC)*, a simpler model code addressing the construction of detached one- and two-family homes and townhouses of limited size. Within any particular building agency, these codes may be adopted directly in their model form. Or as is more common, they may be adopted with amendments, adjusting the code to suit the needs of that jurisdiction while still retaining its overall structure and intent.

The building code is not the only code with which a new building must

comply. Energy codes establish standards of energy efficiency for buildings, affecting a designer's choices of windows, heating and cooling systems, and many aspects of the construction of a building's enclosing walls and roofs. Because of the significant environmental impacts associated with energy consumption, the development of energy codes that require buildings to consume less energy is one of the important contributors to improving building sustainability.

Health codes regulate aspects of design and operation related to sanitation in public facilities such as swimming pools, food-service operations, schools, or healthcare facilities. Fire codes regulate the operation and maintenance of buildings to ensure that egress pathways, fire-protection systems, emergency power, and other life-safety systems are properly maintained. Electrical and mechanical codes regulate the design and installation of building electrical, plumbing, and heating and cooling systems. Like the building codes discussed earlier, most of these are also based on national models. In fact, an important task in the early design of any major building is determining what agencies have jurisdiction over the project and what codes and regulations apply.

Other Constraints

Other types of legal restrictions must also be observed in the design and construction of buildings. Along

FIGURE 1.8

Fire resistance requirements for fire walls, according to the IBC. For more information about fire walls, see Chapter 23. (2012 International Building Code / with permission of International Code Council.)

GROUP	FIRE-RESISTANCE RATING (hours)
A, B, E, H-4, I, R-1, R-2, U	3 ^a
F-1, H-3 ^b , H-5, M, S-1	3
H-1, H-2	4 ^b
F-2, S-2, R-3, R-4	2

a. In Type II or V construction, walls shall be permitted to have a 2-hour fire-resistance rating.
b. For Group H-1, H-2 or H-3 buildings, also see Sections 415.6 and 415.7.

with the accessibility provisions of the IBC, the *Americans with Disabilities Act (ADA)* makes accessibility to public buildings a civil right of all Americans, and the Fair Housing Act does the same for much multifamily housing. Together, these *equal access standards* regulate the design of entrances, stairs, doorways, elevators, toilet facilities, public areas, living spaces, and other parts of many buildings to ensure that they are usable by members of the population with special access needs. The U.S. *Occupational Safety and Health Administration (OSHA)* controls the design of workplaces to minimize hazards to the health and safety of workers. OSHA sets safety standards under which a building must be constructed and also has an important role in the design of industrial and commercial buildings.

Fire insurance companies exert a major influence on construction standards. Through their testing and certification organizations (Underwriters Laboratories and Factory Mutual, for example) and the rates they charge for building-insurance coverage, these companies offer financial incentives to building owners to build hazard-resistant construction. Federal labor agencies, building contractor associations, and construction labor unions have standards, both formal and informal, that affect the labor force practices and the ways in which buildings are built. Contractors have particular types of equipment, certain kinds of skills, and customary ways of going about things. All of these affect a building design in myriad ways and must be appropriately considered by building designers.

Construction Standards and Information Resources

The tasks of the architect and the engineer would be much more difficult to carry out without the support of dozens of standards-setting agencies, trade associations, professional organizations, and other groups

that produce and disseminate information on materials and methods of construction, some of the most important of which are discussed in the following sections.

Standards-Setting Agencies

ASTM International is a private organization that establishes specifications for materials and methods of construction accepted as standards throughout the United States. Numerical references to ASTM standards—for example, ASTM C150 for portland cement, used in making concrete—are found throughout building codes and construction specifications, where they are used as a precise shorthand for describing the quality of materials or the requirements of their installation. Throughout this book, references to ASTM standards are provided for the major building materials presented. In Canada, corresponding standards are set by the *Canadian Standards Association (CSA)*. The *International Organization for Standardization (ISO)*, an organization with more than 160 member countries, performs a similar role internationally.

The American National Standards Institute (ANSI) is another private organization that certifies North American standards for a broad range of products, such as exterior windows and mechanical components of buildings. Government agencies, most notably the U.S. Department of Commerce's National Institute of Science and Technology (NIST) and the National Research Council Canada's Institute for Research in Construction (NRC-IRC), also sponsor research and establish standards for building products and systems.

Construction Trade and Professional Associations

Design professionals, building materials manufacturers, and construction trade groups have formed a large number of organizations that work to develop technical standards and disseminate information

related to their respective fields of interest. The Construction Specifications Institute, whose MasterFormat™ standard is described in the following section, is one example. This organization is composed both of independent building professionals, such as architects and engineers, and of industry members. The Western Wood Products Association, to choose one example from among hundreds of *trade associations*, is made up of producers of lumber and wood products. It carries out research programs 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. In some cases, the standards published by these organizations are even incorporated by reference into the building codes, making them, in effect, legal requirements. Selected publications from professional and trade associations are identified in the references listed at the end of each chapter in this book. The reader is encouraged to obtain and explore these publications and others available from these various organizations.

MasterFormat and Other Systems of Organizing Building Information

The *Construction Specifications Institute (CSI)* of the United States, and its Canadian counterpart, *Construction Specifications Canada (CSC)*, have evolved over a period of many years a comprehensive outline called *MasterFormat* for organizing information about construction materials and systems. This format is used for the written construction specifications for the vast majority of large building

construction projects in these two countries. It is frequently used to organize construction cost data, and it forms the basis on which most trade associations' and manufacturers' technical literature is cataloged. In some cases, MasterFormat is used to cross-reference materials information on construction drawings and within digital building models as well.

MasterFormat is organized into 50 primary *specification divisions* intended to cover a broad range of construction materials and buildings systems. The portions of MasterFormat relevant to the types of construction discussed in this book are as follows:

- Division 00—Procurement and Contracting Requirements
- Division 01—General Requirements
- 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
- 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

- Division 31—Earthwork
- Division 32—Exterior Improvements
- Division 33—Utilities

These divisions are further subdivided into *sections*, each describing a discrete scope of work often provided by a single construction trade or subcontractor. Individual sections are identified by six-digit codes, in which the first two digits correspond to the division number and the remaining four digits identify subcategories and individual units within the division. Within Division 05—Metals, for example, some commonly referenced sections are:

- Section 05 12 00—Structural Steel Framing
- Section 05 21 00—Steel Joist Framing
- Section 05 31 00—Steel Decking
- Section 05 40 00—Cold-Formed Metal Framing
- Section 05 50 00—Metal Fabrications

At the end of each chapter in this book, MasterFormat designations relevant to the chapter content are listed, to help familiarize the reader with this system, and to provide guidance on where to look in construction specifications and other technical resources for further information (Figure 1.15).

MasterFormat organizes building systems information primarily according to work product, that is, the work of discrete building trades. This makes it especially well suited for use during the construction phase of building. For example, Section 06 10 00—Rough Carpentry specifies the materials and work of rough carpenters who erect a wood light frame building structure. However, finish carpentry, such as the installation of interior doors and trim, occurring later during construction, requires different materials, and is performed by different workers with different

skills and tools. So it is specified separately in Section 06 20 00—Finish Carpentry. Defining each of these aspects of the work separately allows the architect to describe the work accurately and the contractor to efficiently manage the work's execution.

The *UniFormat*TM standard organizes building systems information into functional groupings. For example, UniFormat defines eight Level 1 categories:

- A Substructure
- B Shell
- C Interiors
- D Services
- E Equipment and Furnishings
- F Special Construction and Demolition
- G Building Sitework
- Z General

Where greater definition is required, these categories are subdivided into so-called Level 2 classes, Level 3 and 4 subclasses, and even Level 5 or higher-numbered sub-subclasses, each describing more finely divided aspects of a system or assembly. For example, wood floor joist framing can fall under any of the following UniFormat descriptions:

- Level 1: B Shell
- Level 2: B10 Superstructure
- Level 3: B1010 Floor Construction
- Level 4: B1010.10 Floor Structural Frame
- Level 5: B1010.10.WF Wood Floor Framing
- Etc.

UniFormat provides a view of construction elements organized by function or system (rather than by work product as in MasterFormat). This system is well suited, for example, to the description of systems and assemblies during early project definition and design, or to the performance specification of building systems, such as discussed later in

this chapter for design/build project delivery.

The *OmniClass™ Construction Classification System* is designed to organize construction information throughout the full facility life cycle and incorporates multiple other building information organizational systems, such as MasterFormat, UniFormat, and others. OmniClass consists of 15 Tables, some of which include:

- Table 13: Spaces by Function
- Table 21: Elements
- Table 22: Work Results
- Table 23: Products
- Table 31: Phases
- Table 32: Services
- Table 35: Tools
- Table 41: Materials
- Table 49: Properties

For example, Table 13—Spaces by Function merges a number of existing systems for the management of information about rooms and spaces within buildings, useful to building owners and facilities managers. Table 21—Elements is based on UniFormat, and Table 22—Work Results is based on MasterFormat.

UniFormat and OmniClass are also well suited to organizing and maintaining construction and facilities data in building information models and other technology platforms, and to efficiently share this data between disciplines throughout the full building life cycle: from initial conception, through construction and occupancy, and eventually, decommissioning or demolition.

The Building Information Model

Today, the vast majority of building designs are developed in *building information modeling (BIM)* systems. That is, these designs are produced as digital,

object-based models that include both a three-dimensional description of the facility and its parts, along with integrated data relating to the properties, functions, and relationships of the modeled components.

The introduction of BIM to the design and construction industry has come with the promise of many benefits. For the design team: BIM can aid in the visual communication of concepts or the exploration of complex building geometries; it can facilitate coordination between disciplines; it can reduce errors, for example, finding spatial conflicts between ductwork, piping, structural members, and other components designed by separate teams; it can support the analysis of building energy use, daylighting design, and other performance objectives. For the builder, the BIM model can assist with project planning, improve coordination of trades, drive the automated fabrication of building components, track changes to the design, and integrate cost and schedule data with construction activities. For the building owner, information accumulated in the building model during design and construction can be carried forward for use with facility operations and maintenance.

BIM implementation also brings challenges. Open data formats must be developed to permit interoperability, that is, the easy and reliable sharing of data even as parties rely on different software systems and technology platforms. Or, as data from separate parties is combined in a shared model, new concepts for the protection of intellectual property and the allocation of liability among partners must be incorporated into the contractual framework of projects.

Effective BIM implementation also depends on the clear definition of procedures for those contributing

to the model. The *BIM execution plan* defines the role of the building model and its level of development at various project stages, identifies the sources of data that will contribute to the model, assigns responsibilities for authoring and managing the model, establishes protocols for information exchange among parties, and defines the technical and project infrastructure required to support these activities (Figure 1.9).

The as-yet unrealized, full promise of BIM technology is to integrate all information about a facility into one resource that can be readily accessed throughout the design, construction, and operational life stages of a facility, while saving time and money for all parties.

THE WORK OF THE CONSTRUCTION PROFESSIONAL

Providing Construction Services

An owner wishing to construct a building hopes to achieve a finished project that meets their functional and aspirational needs, is of good quality, costs as little as possible, and is completed on a predictable schedule. A contractor offering its construction services hopes to produce a quality building, earn a profit, and complete the project safely and in a timely fashion. Yet, the process of building itself is fraught with uncertainty: It is subject to the vagaries of the labor market, commodity prices, and the weather. Despite the best planning efforts, unanticipated conditions arise, delays occur, and mistakes are made. Not infrequently, requirements change over the course of the project and the pressures of schedule and cost inevitably reduce the margin for miscalculation. In this

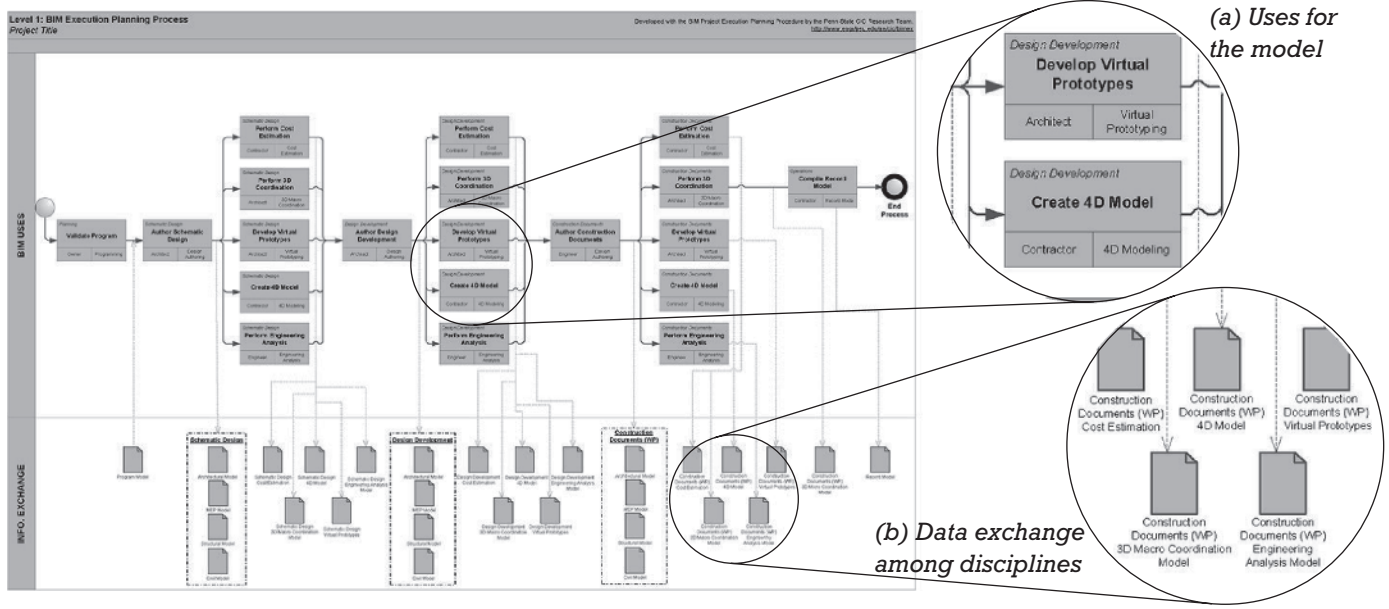


FIGURE 1.9

A sample high-level diagram of the BIM execution process through design and construction phases. Note how the model is used for numerous purposes at each phase by a variety of disciplines (a), while data must be exchanged regularly between disciplines in order to support the continued development of the model (b). (*Building Information Modeling Execution Planning Guide (Version 2.1)*, 2011. State College, PA: Computer Integrated Construction Research Program, Pennsylvania State University / CC BY 4.0. / The Pennsylvania State University.)

high-stakes environment, the relationship between the owner and contractor must be structured to share reasonably between them the potential rewards and risks.

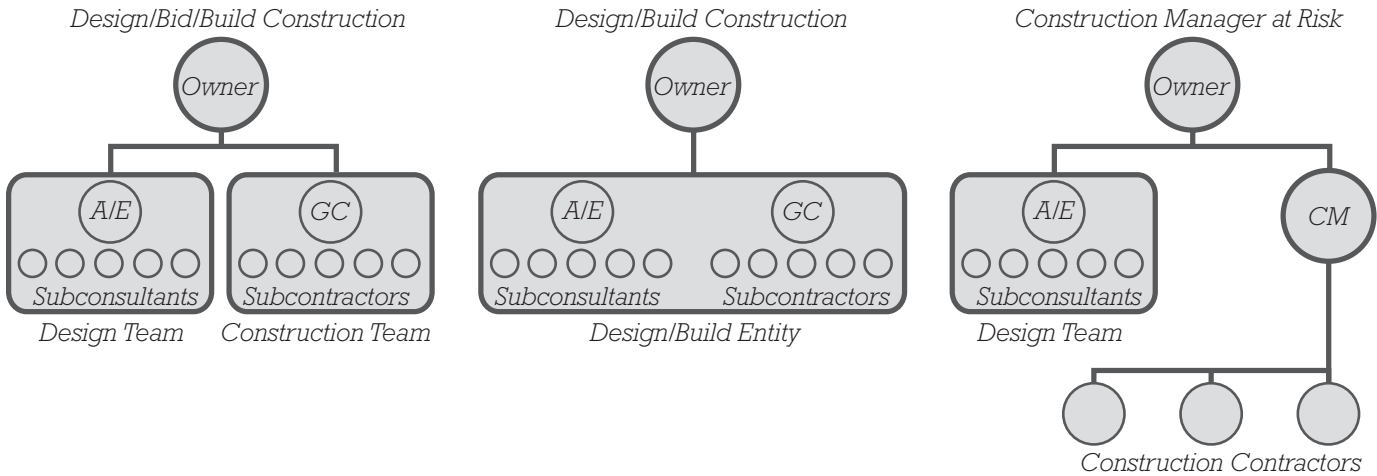
Construction Project Delivery Methods

In traditional *design/bid/build* project delivery (Figure 1.10, left), the owner first hires a team of architects and engineers to perform design services, leading to the creation of construction documents that comprehensively describe the facility to be built. Next, construction firms are invited to bid on the project. Each bidding firm reviews the construction documents and proposes a cost to construct the facility. The owner

evaluates the submitted proposals and awards the construction contract to the bidder deemed most suitable. This selection may be based on bid price alone, or other factors related to bidders' qualifications may also be considered. The construction documents then become part of the construction contract, and the selected firm proceeds with the work. On all but small projects, this firm acts as the *general contractor*, coordinating and overseeing the construction process but frequently relying on smaller, more specialized *subcontractors* to perform significant portions or even all parts of the work. During construction, the design team continues to provide services to the owner, helping to ensure that the facility is built

according to the requirements of the documents as well as answering questions related to the design, changes to the work, verification of payments to the contractor, and similar matters.

Among the advantages of design/bid/build project delivery are its easy-to-understand organizational scheme, well-established legal precedents, and relative simplicity of management. The direct relationship between the owner and the design team ensures that the owner retains control over the design and provides a healthy set of checks and balances during the construction process. With design work complete before the project is bid, the owner starts construction with a well-defined scope of work and a high degree of

**FIGURE 1.10**

In design/bid/build project delivery (*left*), the owner contracts first the architect/engineer (A/E) design team for design services and then later, the construction general contractor (GC) for construction services. In a design/build project (*center*), the owner contracts with a single organizational entity that provides both design and construction services. In Construction Manager at Risk (*right*), the owner contracts with an A/E design team and construction manager (CM). The CM provides construction services through all phases of the planning, design, and construction.

confidence regarding the construction schedule and costs.

In design/bid/build project delivery, the owner contracts with two entities, and design and construction responsibilities remain divided between these two throughout the project. In *design/build* project delivery, one entity assumes responsibility for both design and construction (Figure 1.10, *center*). A design/build project begins with the owner developing a conceptual design or program that describes the functional or performance requirements of the proposed facility but does not detail its form or how it is to be constructed. Next, using this preliminary information, a design/build organization is selected to complete the design and construction of the project. Selection of the designer/builder may be based on a competitive bid process similar to that for design/bid/build projects, on negotiation and evaluation of an organization's qualifications for the proposed work, or on some combination of these. Design/build organizations themselves can take a variety of forms: a single firm encompassing

both design and construction expertise; a construction management firm that subcontracts with a separate design firm to provide those services; or a joint venture between two firms, one specializing in construction and the other in design. Regardless of the internal structure of the design/build organization, the owner contracts with this single entity throughout the remainder of the project, and this entity assumes responsibility for all design and construction services.

Design/build project delivery gives the owner a single source of accountability for all aspects of the project. It can place the designers and constructors in a closer working relationship, introducing construction expertise into the design phases of a project and allowing the earliest possible consideration of constructability, costs, scheduling, and similar matters. This delivery method also readily accommodates phased construction, a scheduling technique for reducing construction time that is described later in this chapter.

Project design and construction can also be structured around the

services of a *construction manager* (CM), an entity that provides oversight through all phases of a project. As in design/build, prior to construction, the CM provides expertise related to planning, construction budgeting, scheduling, and other such matters. During construction, the CM's role can take a variety of forms. For example, it may continue to act in a strictly management capacity while the owner contracts directly for construction services (*construction management for fee*). Or the CM may assume responsibility for the work itself, acting much as a general contractor (*construction manager at risk*, Figure 1.10, *right*). Throughout the project, the architect/engineering design team acts independently. CM project delivery is frequently associated with especially large or complex projects requiring sophisticated management expertise.

In *integrated project delivery* (IPD), the major parties—the design team, construction team, and owner—share mutually the responsibilities, decision-making, and financial risks and rewards of the project. In this

method's purest form, the parties share one agreement, as a single-purpose entity, binding them all to the same objectives, responsibilities, and outcomes. In other cases, a shared joining agreement may be used to mutually bind parties contracted under separate agreements. The goal of IPD is to increase efficiency and reduce conflict and litigation.

In *turnkey construction*, an owner contracts with a single entity that provides not only design and construction services, but financing for the project as well. In a *public-private partnership (PPP or P3)*, a government entity and private company agree to jointly design and build a facility, typically one with a public purpose. The private company provides capital and shares in the risk of development, in return for which it later also shares in the income resulting from the project. Aspects of any of these project delivery methods can also be intermixed, allowing organizational schemes for the delivery of design and construction services that are suitable to all variety of owner requirements and project circumstances.

Paying for Construction Services

With *fixed-fee*, or *lump-sum*, compensation, the general contractor or other construction entity is paid a fixed dollar amount to complete the construction of a project regardless of that entity's actual costs to perform the work. With this compensation method, the owner begins construction with a known, fixed cost and assumes minimal risk for unanticipated cost increases. In contrast, the construction contractor assumes most of the risk of unforeseen costs, but also stands to gain from potential savings. Fixed-fee compensation is most suitable to projects where the scope of the construction work is well defined when the construction fee is set, as is the case, for example, with design/bid/build construction.

With *cost plus a fee* compensation, the owner agrees to pay the construction entity for the actual costs of construction—whatever they may turn out to be—plus an additional amount to account for overhead and profit. In this case, the construction contractor is shielded from most cost uncertainty, and it is the owner who assumes most of the risk of added costs and stands to gain the most from potential savings. Cost plus a fee compensation is most often used with projects for which the scope of construction work is not fully defined at the time compensation is established, a circumstance most frequently associated with construction management or design/build contracts.

Cost plus a fee compensation may also include a *guaranteed maximum price (GMAX or GMP)*. In this case, there is a maximum fee that the owner may be required to pay. While the contractor's compensation remains under the guaranteed amount, compensation is made in the same manner as with a standard cost plus a fee contract. However, once the compensation reaches the guaranteed maximum, the owner is no longer required to make additional payments and the contractor assumes responsibility for all additional costs. This compensation method retains some of the scope and price flexibility of cost plus a fee compensation while also establishing a limit on the owner's cost risk.

Incentive provisions in owner/contractor agreements can be used to more closely align owner and contractor interests. For example, in simple cost plus a fee construction, there may be temptation for a contractor to add costs to a project, as these added costs will generate added fees. To eliminate such a counterproductive incentive, a bonus fee or profit-sharing provision can provide for some portion of construction cost savings to be returned to the contractor.

In this way, the contractor and owner jointly share in the benefits of reduced construction cost. Bonuses and penalties for savings or overruns in costs and schedules can be part of any type of construction contract.

Surety bonds are another form of legal instrument used to manage financial risks of construction, most frequently with publicly financed or very large projects. The purpose of a surety bond is to protect an owner from the risks of default, such as bankruptcy, by the construction contractor. For a fixed fee, a third party (surety) promises to complete the contractual obligations of the contractor if that contractor should for any reason fail to do so. Most commonly, two separate bonds are issued, one for each of the general contractor's principal obligations: a *performance bond* to assure completion of the construction and a *payment bond* to assure full payment to suppliers and subcontractors.

With competitive bidding and fixed-fee compensation, the owner is assured of competitive pricing for construction services and the contractor assumes most of the risk for unanticipated costs. With a negotiated contract and simple cost plus a fee compensation, the risks of non-competitive pricing and unanticipated costs are shifted more toward to the owner. By adjusting project delivery and compensation methods, these and other construction-related risks can be allocated in varying degrees between the two parties to best suit the requirements of any particular project.

Sequential Versus Fast Track Construction

In *sequential construction* (Figure 1.11), each major phase in the design and construction of a building is completed before the next phase begins, and construction does not start until all design work has been completed.

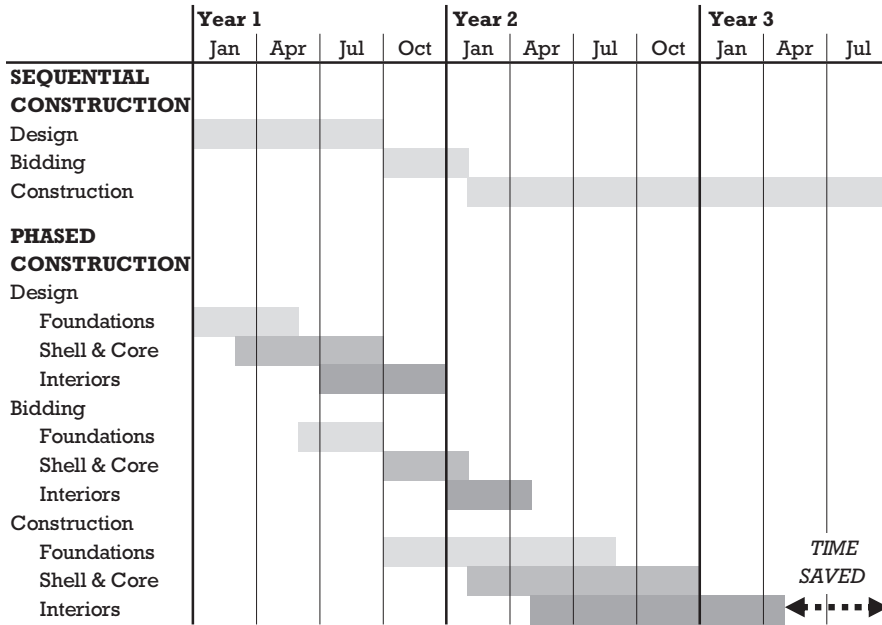


FIGURE 1.11
 In sequential construction, construction does not begin until design is complete. In phased construction, design and construction activities overlap, with the goal of reducing the overall time required to complete a project.

Sequential construction can take place under any of the project delivery methods described previously. It is frequently associated with design/bid/build construction, where the separation of design and construction phases fits naturally with the contractual separation between design and construction service providers.

Phased construction, also called *fast track construction*, aims to reduce the time required to complete a project by overlapping the design and construction of various project parts (10). By allowing construction to start sooner and by overlapping the work of design and construction, phased construction can reduce the total time required to complete a project. However, phased construction also introduces its own risks. Because construction on some parts of the project begins before all design is complete, an overall cost for the project cannot be established until a significant portion of construction is underway. Phased construction also introduces

more complexity into the design process and increases the potential for design errors (for example, if foundation design does not adequately anticipate the requirements of the not yet fully engineered structure above). Phased construction can be applied to any construction delivery method discussed earlier. It is frequently associated with design/build and construction management project delivery methods, where the early participation of the construction entity provides resources that are helpful in managing the coordination of overlapping design and construction activities.

FIGURE 1.12
 In this photo, the construction sequence of a tall building is readily apparent: A pair of concrete core structures leads the construction, followed by concrete columns and floor plates and, finally, the enclosing curtain wall. (Photo by Joseph Iano.)

Construction Scheduling

Constructing a building of any significant size is a complex endeavor, requiring the combined efforts of countless participants and the coordination of myriad tasks. Managing this process requires an in-depth understanding of the work required, of the ways in which different aspects of the work depend upon each other, and of the constraints on the sequence in which the work must be performed.

Figure 1.12 captures one moment in the construction of a tall building. The process is led by the construction of the building’s central, stabilizing core structures (in the photograph, the pair of concrete tower-like structures extending above the highest floor levels). This work is followed by construction of the surrounding floor plates, which rely, in part, on the previously completed cores for support.



Attachment of the exterior skin can follow only after the floors are securely in place. As the building skin is installed and floor areas become protected from the weather, further operations, such as the roughing in of mechanical and electrical systems, and eventually, the installation of finishes and other elements, can proceed in turn. This simple example illustrates considerations that apply to virtually every aspect of building construction and at every scale from a building's largest systems to its smallest details: Successful construction requires a detailed understanding of the tasks required and their interdependencies in time and space.

The construction project schedule is used to analyze and represent

construction tasks, their relationships, and the sequence in which they must be performed. Development of the schedule is a fundamental part of construction project planning, and regular updating of the schedule throughout the life of the project is essential to its successful management. In a *Gantt* (or *bar*) *chart*, a series of horizontal bars represents the duration of various tasks or groups of tasks that make up the project. Gantt charts provide an easy-to-understand representation of construction tasks and their relationships in time. They can be used to provide an overall picture of a project schedule, with only a project's major phases represented (Figure 1.11), or they can be expanded to represent a larger

number of more narrowly defined tasks at greater levels of project detail (Figure 1.13).

The *critical path* of a project is the sequence of activities that determines the least amount of time in which a project can be completed. For example, the construction of a building's primary structural system is commonly on the critical path of a project schedule. If any of the activities on which the completion of this system depends—such as design, shop drawing production and review, component fabrication, materials delivery, or erection on site—are delayed, then the final completion date of the project will be extended. In contrast, other systems not on the critical path have more flexibility in their

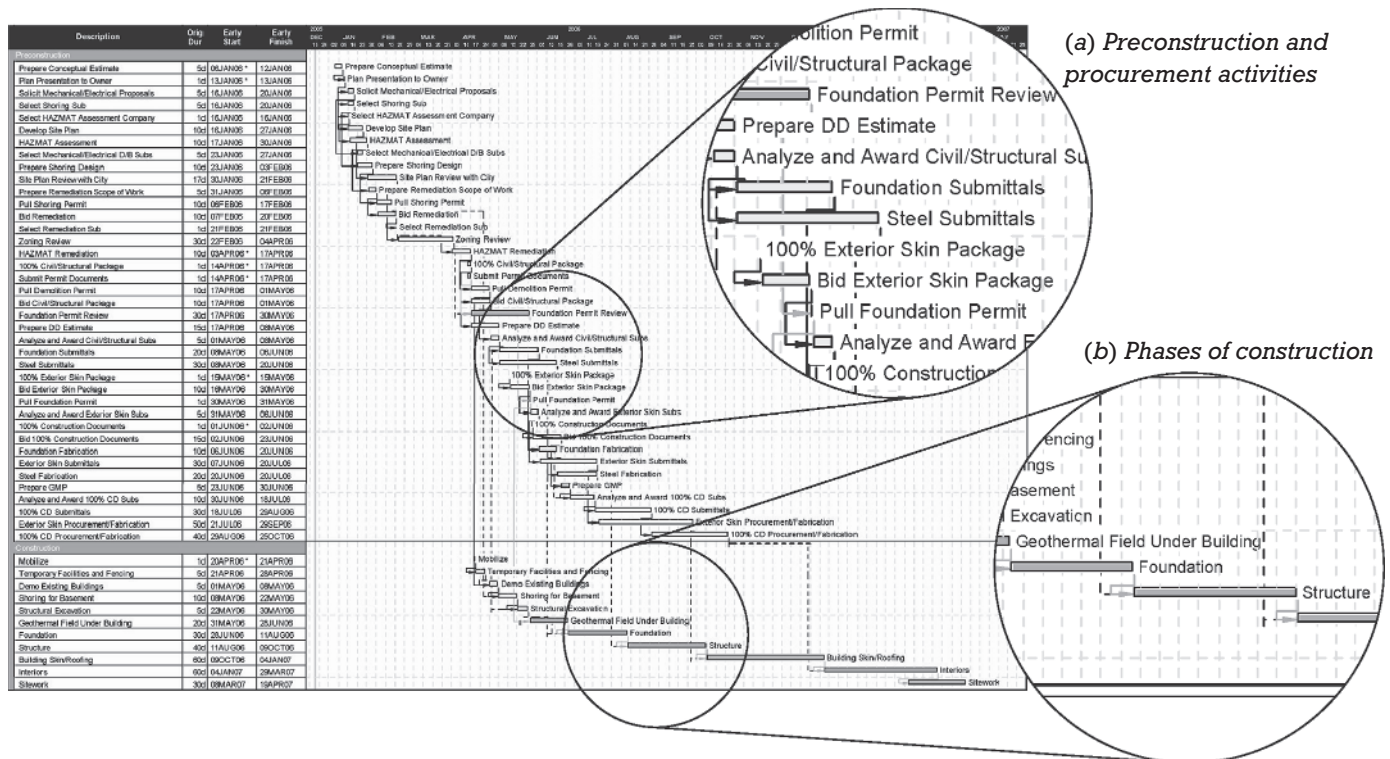


FIGURE 1.13

In a Gantt chart, varying levels of detail can be represented. In this example, roughly the top three-quarters of the chart is devoted to a breakdown of preconstruction and procurement activities, such as bidding portions of the work to subtrades, preparing cost estimates, and making submittals to the architect (a). Construction activities, represented more broadly, appear in the bottom portion (b).

scheduling, called *float*, and delays (within limits) in their execution will not necessarily affect the overall project schedule.

The *critical path method (CPM)* is a technique for analyzing collections of activities and optimizing the project schedule to minimize the duration and cost of a project. This requires a detailed breakdown of the work involved in a project and the identification of dependencies among the parts (Figure 1.14). This information is combined with considerations of cost and resources available to perform the work, and then analyzed, usually with the assistance of computer software, to identify optimal scenarios for scheduling and worker and resource allocation. Once the critical path of a project has been established, the elements on this path are likely to receive a high degree of scrutiny during the life of the project, as delays in any of these steps will have a direct impact on the overall project schedule.

Projects of different sizes and degrees of complexity, and even different phases of planning and work within a single project, require schedules that differ in their degree of definition and level of detail. AACE International, an organization dedicated to promoting effective cost management practices, provides a useful system for defining different types of construction schedules. The degree of project definition in a schedule is described by five schedule classes, for example: a Class 5 schedule provides the least project definition and is appropriate to early conceptual work; a Class 3 schedule relies on a medium degree of definition and is suitable, for example, to project budgeting during design phases; a Class 1 schedule provides the highest degree of project definition, such as that needed for project bidding and costing.

Similarly, schedule levels define the amount of detail provided within the construction schedule. For example, a Level 1 schedule may be

represented as a simple Gantt chart, outlining major project components and their duration. This type of schedule is appropriate for high-level description of a project, but is not sufficient for monitoring and controlling project processes. A Level 3 schedule, such as a comprehensive CPM schedule, provides much more detail and can perform as an effective project management tool. Level 4 schedules provide an even finer degree of detail and are used to describe segments of an overall schedule. *Rolling (or look-ahead) schedules*, in which day-to-day processes extending a limited number of weeks or months into the future are described, are examples of Level 4 schedules.

Managing Construction

Once a construction project is underway, the general contractor assumes responsibility for day-to-day oversight of the construction site, management of trades and suppliers, and communications between the construction team and other major parties, such as the owner and the architect. On projects of any significant size, this may include responsibility for filing construction permits, securing the project site, providing temporary power and water, setting up office trailers and other support facilities, providing insurance coverage for the work in progress, managing personnel on site, maintaining a safe work environment, stockpiling materials, performing testing and quality control, providing site surveying and engineering, arranging for cranes and other construction machinery, providing temporary structures and weather protection, disposing or recycling of construction waste, soliciting the work of subcontractors and coordinating their efforts, submitting product samples and technical information to the design team for review, maintaining accurate records of the construction as it proceeds, monitoring costs and schedules, managing

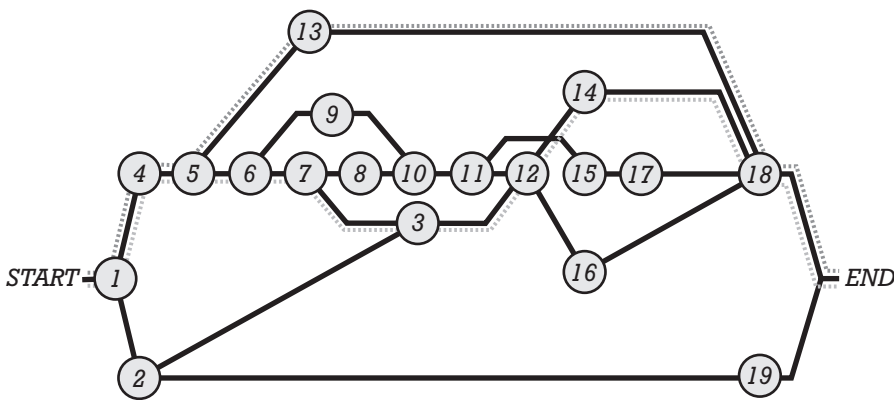


FIGURE 1.14

The critical path method depends on a detailed analysis of work tasks and their relationships to generate an optimal construction schedule. Shown here is a schematic network diagram representing task dependencies. For example, task 6 cannot begin until tasks 1, 4, and 5 are completed, and tasks 7 and 9 cannot begin until task 6 is finished. The dashed lines on the diagram trace two of many possible paths from the start to the end of the diagram. To determine the critical path for this collection of tasks, all such paths must be identified and the time required to complete each one calculated. The path requiring the most time to complete is the critical path, that is, the sequence of activities that determines the least time in which the collection of tasks as a whole can be completed.

changes to the work, protecting finished work, and more.

TRENDS IN THE DELIVERY OF DESIGN AND CONSTRUCTION SERVICES

Productivity and Automation in Construction

Building construction is a complex activity, requiring large investments of resources and time. An ordinary single-family home may be made from more than 100,000 parts, assembled by perhaps 1000 workers over a span of a year or more. Economic measures suggest that the construction industry as a whole has, for decades, remained

stubbornly fragmented and inefficient in comparison to other industries. While U.S. nonfarm industrial productivity has more than doubled since 1964, productivity in the construction sector has remained unchanged or even declined during this same period. Today, some studies peg inefficiency (i.e., wasted work) in the construction sector at greater than 50 percent.

Some examples of efforts to improve efficiency in the design and construction of buildings have already been discussed in this chapter, such as exploiting BIM to improve the flow and accuracy of project information or implementing project delivery systems, such as IPD, that encourage collaboration between parties.

Moving construction activities from the building site to the factory floor is another way to pursue

efficiencies in construction. Prefabrication of building components, modular construction, and factory-made housing are all discussed later in this text. As one example, relying on factory prefabrication of mass timber components, erection of the 17-story tall Brock Commons Tallwood Tower (pages 145–146) was able to progress on site at the remarkable rate of two floors per week. Recent developments in factory-fabricated mass timber façade systems are another example (pages 622–625).

Other efforts focus on the restructuring of construction business operations. For example, lean construction applies lessons from other large-scale manufacturing industries to construction so as to reduce complexity, eliminate wasteful activities, and streamline methods of production.

FIGURE 1.15

At the end of each chapter, a list of MasterFormat sections relevant to the topics discussed in that chapter is included. Here, Division 0 includes sections related to the solicitation of construction services and awarding of the contract for construction. Division 1 addresses project requirements that apply broadly to all aspects of the work.

MasterFormat Sections for Procurement of Construction and General Requirements

00 10 00	SOLICITATION
00 11 00	Advertisements and Invitations
00 20 00	INSTRUCTIONS FOR PROCUREMENT
00 21 13	Instructions to Bidders
00 40 00	PROCUREMENT FORMS AND SUPPLEMENTS
00 41 00	Bid Forms
00 50 00	CONTRACTING FORMS
00 52 00	Agreement Forms
00 60 00	PROJECT FORMS
00 61 13	Performance and Payment Bond Form
00 70 00	CONDITIONS OF THE CONTRACT
01 10 00	SUMMARY
01 11 00	Summary of the Work
01 30 00	ADMINISTRATIVE REQUIREMENTS
01 31 13	Project Management and Coordination
01 32 13	Scheduling of Work
01 40 00	QUALITY REQUIREMENTS
01 41 00	Regulatory Requirements
01 45 00	Quality Control
01 50 00	TEMPORARY FACILITIES AND CONTROLS
01 70 00	EXECUTION AND CLOSEOUT REQUIREMENTS
01 80 00	PERFORMANCE REQUIREMENTS
01 81 13	Sustainable Design Requirements

Vertically integrated construction companies opt to manufacture key materials and components in their own facilities, instead of depending on outside, third-party suppliers, with the goal of leveraging economies of scale otherwise not possible.

New information technologies and automation are impacting the construction sector. Sophisticated business

analytics are being applied to the economics of manufacturing building components and building construction. Advanced computational methods and data visualization techniques are opening up new possibilities for exploring the design of building systems related to structural performance, energy use, environmental impacts, and more. The networking of

embedded sensors and devices within the building fabric is creating new possibilities for smart buildings that can be monitored in more detail and operated more efficiently. Robotics and 3D printing technologies are creating new possibilities for the automated assembly and construction of building components and whole buildings (page 544).

KEY TERMS

sustainable development
United Nations 17 Sustainable

Development Goals
green building
integrated design process (IDP)
post-occupancy
Leadership in Energy and Environmental

Design, LEED

LEED prerequisite
LEED credit
Living Building Challenge
Living Building Challenge Imperative
Performance based certification
Passive Building Standard
Product Data Sheet (PDS)
environmental label, ecolabel
volatile organic compound (VOC)

product disclosure
Environmental Product
Declaration (EPD)

global warming potential
Environmental Building
Declaration (EBD)

life-cycle analysis (LCA)
environmental footprint
system boundary
cradle-to-grave analysis
cradle-to-gate analysis

embodied energy
operational energy
embodied carbon
operational carbon

health product declaration (HPD)
red list materials
recycled materials content
postconsumer recycled material
postconsumer recycled material
materials reuse
materials salvaging

design for disassembly
extended producer responsibility

bio-based materials
building resilience, resilient

building design
floor resistant design

social equity
responsible industry practices

zero energy building, net-0
energy building

building commissioning (Cx)
construction drawings

construction specifications
construction documents

environmental impact assessment
zoning ordinance

building code
model code

National Building Code of Canada
International Building Code (IBC)

building code occupancy
noncombustible materials

combustible materials
construction type

fire resistance rating
bearing wall

fire wall
means of egress

International Residential Code (IRC)
Americans with Disabilities Act (ADA)

equal access standard
Occupational Safety and Health

Administration (OSHA)
ASTM International

Canadian Standards Association
(CSA)

International Organization for
Standardization (ISO)

trade association

Construction Specifications
Institute (CSI)

Construction Specifications
Canada (CSC)

MasterFormat
specification division

specification section
UniFormat

OmniClass Construction
Classification System

building information modeling (BIM)
BIM execution plan

design/bid/build project delivery
general contractor

subcontractor
design/build project delivery

construction manager (CM)
construction manager for fee

construction manager at risk
integrated project delivery (IPD)

turnkey construction
public-private partnership (PPP or P3)

fixed-fee compensation, lump-sum
compensation

cost plus a fee compensation
guaranteed maximum price

(GMAX, GMP)
incentive provision

surety bond
performance bond

payment bond
sequential construction

phased construction, fast track
construction

Gantt chart, bar chart
critical path

float
critical path method (CPM)

rolling schedule, look-ahead schedule

REVIEW QUESTIONS

1. What is sustainable development? In the United States, what is the most widely adopted sustainable building program?
2. What is the difference between a product disclosure and an ecolabel? Give an example of each.
3. What is a life-cycle analysis? What are the major life-cycle stages in such an analysis?
4. What is the embodied energy of a material?
5. Who are the three principal team members involved in the creation of a new building? What are their respective roles?
6. What are construction documents? What two items are they comprised of?
7. What types of subjects are covered by zoning ordinances? By building codes?
8. What is a building code occupancy? What is a construction type? How are they related in a building code?
9. In what units is fire resistance measured? How is the fire resistance of a building assembly determined?
10. What is MasterFormat? What is it used for?
11. Compare and contrast design/bid/build and design/build construction.
12. What is the difference between lump-sum and cost plus a fee compensation?
13. What are the two common types of surety bonds? What are they used for?
14. What is fast track construction, and what types of contracts and fee compensation is it most commonly associated with?
15. What is the critical path? Why is it important to construction scheduling?
16. You are designing a three-story office building (Occupancy B) with 19,000 square feet per floor. Referring to Figure 1.6, what types of construction will you be permitted to use under the IBC if you do not install sprinklers? How does the situation change if you install sprinklers (assume both an area and height increase are permitted)? In the second, sprinklered case, what is the least fire-resistant construction type permitted? With this construction type, what level of fire resistance is required for the structural frame of the building?

EXERCISES

1. Choose a building material or product. Visit the manufacturer's website and determine what types of information are available that document the material or product's sustainable attributes.
2. Choose two similar products from two different manufacturers (for example, exterior finish paints), both of which have published EPDs. Choose two life-cycle impacts, such as global warming, acidification, etc., and compare the results for the two products. Describe how the differences between the two materials might positively or negatively affect the environment or human health.
3. Apply the International Building Code to your current studio design project. What occupancies are included in your project? How large a building is permitted? What construction types may be employed? What are the minimum fire resistance ratings for the structural and nonstructural parts of the building?
4. Arrange permission to shadow an architect or CM during visits to a construction site or during project meetings related to a construction project. Take notes. Interview the architect or CM about their role and the challenges they have encountered. Report back to the class what you have learned.

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International Living Future Institute. *Living Building Challenge 4.0*. Seattle, WA, updated regularly.

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U.S. Green Building Council. *LEED V4.1 Building Design and Construction*. Washington, DC, updated regularly.

Provides essential information for the design and construction of buildings meeting the requirements of the U.S. Green Building Council's LEED for New Construction and Major Renovations and related rating systems.

WEBSITES

Learning to Build

Whole Building Design Guide: www.wbdg.org

Buildings and the Environment

Architecture 2030: www.architecture2030.org

Athena Sustainable Materials Institute: www.athenasmi.org

Athena Sustainable Materials Institute, Environmental Product and Building Declarations: www.athenasmi.org/resources/publications/#lci_and_epd_reports

BEES (Building for Environmental and Economic Sustainability): www.nist.gov/services-resources/software/bees

Building Green: www.buildinggreen.com

Declare: living-future.org/declare

HPD Collaborative: www.hpd-collaborative.org

The International EPD System: www.environdec.com/resources/indicators

International Living Building Institute: www.living-future.org

International WELL Building Institute: www.wellcertified.com

Passive House Institute (European standard): passiv.de/en/

PHIUS Passive Building (North American standard): www.phius.org

U.S. Green Building Council (LEED standard): www.usgbc.org

The Work of the Design Professional

American Institute of Architects: www.aia.org

American National Standards Institute (ANSI): www.ansi.org

ASTM International: www.astm.org

Construction Specifications Institute (CSI): www.csiresources.org

International Code Council: www.iccsafe.org

International Codes, Public Access: codes.iccsafe.org

National Institute of Building Sciences (NIBS): www.nibs.org
NRC Institute for Research in Construction: nrc.canada.ca/en
OmniClass: www.omniclass.org
UniFormat: www.csiresources.org/practice/standards/uniformat
U.S. National BIM Standard: www.nationalbimstandard.org

The Work of the Construction Professional

AACE International: web.aacei.org
Associated General Contractors of America (AGC): www.agc.org
Building Owners and Managers Association (BOMA): www.boma.org
ConsensusDocs: www.consensusdocs.org
Construction Management Association of America (CMAA): <http://cmaanet.org>
Design-Build Institute of America (DBIA): www.dbia.org
Engineers Joint Contract Documents Committee: www.ejcdc.org
Integrated Project Delivery: A Guide: www.aiacontracts.org/resources/64146-integrated-project-delivery-a-guide

Trends in the Delivery of Design and Construction Services

Construction Robotics: www.construction-robotics.com
Core Studio, Thornton Tomasetti: core.thorntontomasetti.com/core-studio
ICON: www.iconbuild.com
Lean Construction Institute: leanconstruction.org