Fundamentals of Building Construction

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Making Buildings

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 for our activities. 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 student 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 with the information presented within 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 expend large quantities of the earth's resources and generate a significant portion of its environmental pollution. The construction and operation of buildings account for as much as a third of the world's energy consumption and carbon dioxide (a global warming gas) emissions. In the United States, building operation and construction consume between a third and a half of the country's energy, 70 percent of its electricity, 12 percent of its potable water, 30 percent of its raw materials, and a third of its solid waste. And these same activities are responsible for as much as 45 percent of the country's carbon dioxide emissions. Buildings are also significant emitters of particulates and other air pollutants. In short, building construction and operation contribute 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 own needs. But, by consuming irreplaceable fossil fuels and other nonrenewable resources, by building in sprawling patterns on prime agricultural land, by using destructive land development and forestry practices that degrade natural ecosystems, by generating substances that pollute water, soil, and air, and by 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

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 Joe Iano.)*

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

Over the decades since the release of "Our Common Future," the practice of sustainable design and construction, also called *green building*, has grown. The understanding of the interplay between buildings and the environment has deepened, and standards for assessing the sustainability of materials and construction practices have grown in number and matured in approach. The definition of sustainability has expanded to address the human health impacts of buildings and to include issues of social and economic fairness. And the expectations for the performance of sustainable buildings have, in some cases, moved from doing less environmental harm to doing no harm or even undoing previous such harms. That is, a sustainable building can be designed to consume no energy or even generate excess energy, cause no air pollution or even help clean the atmosphere, and so on (Figure 1.1).

Also during this time, interest in and adoption of green building has broadened among public agencies, private owners, and the users of buildings. The design and construction industry has become more skillful at applying green practices, and sustainable building has become more integrated with mainstream practice. As a result, sustainable building performance continues to improve while the premium in cost and effort to design and construct such buildings continues to decline.

Sustainable Buildings

Sustainable 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 and physical size. 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, called *integrated design process* (*IDP*), is a whole-systems way of working that breaks down traditional boundaries between disciplines and parts of the work. All key members of the design, construction, and owner groups are brought together. A clear vision and goals are established. The process spans from the earliest conceptual phase through design, construction, and post-occupancy (the operational phase once the project is completed). And a collaborative, interdisciplinary

LEED for New Construction and Major Renovation

Project Checklist

Project Name

Date

Y	?	N			
			Credit 1	Integrative Process	1
			Location and Transportation	Possible Points:	16
			Credit 1	LEED for Neighborhood Development Location	16
			Credit 2	Sensitive Land Protection	1
			Credit 3	High Priority Site	2
			Credit 4	Surrounding Density and Diverse Uses	5
			Credit 5	Access to Quality Transit	5
			Credit 6	Bicycle Facilities	1
			Credit 7	Reduced Parking Footprint	1
			Credit 8	Green Vehicles	1
			Sustainable Sites	Possible Points:	10
Y			Prereq 1	Construction Activity Pollution Prevention	Required
			Credit 1	Site Assessment	1
			Credit 2	Site Development—Protect or Restore Habitat	2
			Credit 3	Open Space	1
			Credit 4	Rainwater Management	3
			Credit 5	Heat Island Reduction	2
			Credit 6	Light Pollution Reduction	1
			Water Efficiency	Possible Points:	11
Y			Prereq 1	Outdoor Water Use Reduction	Required
Y			Prereq 2	Indoor Water Use Reduction	Required
Y			Prereq 3	Building-Level Water Metering	Required
			Credit 1	Outdoor Water Use Reduction	2
			Credit 2	Indoor Water Use Reduction	6
			Credit 3	Cooling Tower Water Use	2
			Credit 4	Water Metering	1
			Energy and Atmosphere	Possible Points:	33
Y			Prereq 1	Fundamental Commissioning and Verification	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
			Credit 1	Enhanced Commissioning	6
			Credit 2	Optimize Energy Performance	18
			Credit 3	Advanced Energy Metering	1
			Credit 4	Demand Response	2
			Credit 5	Renewable Energy Production	3
			Credit 6	Enhanced Refrigerant Management	1
			Credit 7	Green Power and Carbon Offsets	2

				Materials and Resources	Possible Points: 13
Y			Prereq 1	Storage and Collection of Recyclables	Required
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required
			Credit 1	Building Life-Cycle Impact Reduction	5
			Credit 2	Building Product Disclosure and Optimization — Environmental Product Declarations	2
			Credit 3	Building Product Disclosure and Optimization — Sourcing of Raw Materials	2
			Credit 4	Building Product Disclosure and Optimization — Material Ingredients	2
			Credit 5	Construction and Demolition Waste Management	2

				Indoor Environmental Quality	Possible Points: 16
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
			Credit 1	Enhanced Indoor Air Quality Strategies	2
			Credit 2	Low-Emitting Interiors	3
			Credit 3	Construction Indoor Air Quality Management Plan	1
			Credit 4	Indoor Air Quality Assessment	2
			Credit 5	Thermal Comfort	1
			Credit 6	Interior Lighting	2
			Credit 7	Daylight	3
			Credit 8	Quality Views	1
			Credit 9	Acoustic Performance	1

				Innovation	Possible Points: 6
			Credit 1	Innovation	5
			Credit 2	LEED Accredited Professional	1

				Regional Priority	Possible Points: 4
			Credit 1	Regional Priority: Specific Credit	1
			Credit 2	Regional Priority: Specific Credit	1
			Credit 3	Regional Priority: Specific Credit	1
			Credit 4	Regional Priority: Specific Credit	1

				Total	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 New Construction and Major Renovation Project Checklist. *(Courtesy of U.S. Green Building Council.)*

approach is used that maximizes opportunities for synergies and innovation.

In the United States, the most widely applied program for 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 makes the certification of the project's LEED compliance after construction is completed. Depending on the point total achieved, four levels of sustainable performance are recognized, 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 owner or mandated by a public building agency.

The Green Building Council also provides rating systems for existing buildings, commercial interior buildouts, building core and shell construction, schools, retail buildings, healthcare facilities, homes, neighborhood developments, building operations and maintenance, and other project types. Through affiliated organizations, LEED is also implemented in Canada and other countries.

The International Living Future Institute's *Living Building Challenge*™ sets a higher standard for sustainable building. This program aspires to move past making buildings that do less environmental harm to those that do no harm or even improve the natural environment and our well-being. For example, a building constructed and operated to this standard will (when considered on an annualized basis) generate all its own energy from on-site renewable resources, consume no fresh water, and have no 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 zero energy, appropriate sourcing of materials, embodied carbon footprint, and more. There are three certification levels: Living Building Certification meets all imperatives appropriate to the building type, Petal Certification signifies a lower level of partial compliance, and Zero Energy Certification applies to projects that generate all energy on site without reliance on combustion processes. Certification occurs after a building has been operational for at least one year, when its real-world performance can be assessed. 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 disclosure 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 cycle 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 many programs and standards offering alternative pathways to sustainable building construction, suitable to various building types, objectives, and construction markets. For example, the U.S. National Association of Home Builders' National Green Building Standard addresses both single-family and multi-unit residential building types. The International Green Construction Code is a model code that puts green building standards into a legally enforceable format that is useful for municipalities that wish to mandate sustainable construction. CALGreen is the sustainable construction code for the state of California. Green Globes certifies new and existing sustainably designed buildings in the United States and Canada. The Building Research Establishment Environmental Assessment Method, or BREEAM, does the same for buildings constructed in the United Kingdom and other European countries. The Passive House Standard, implemented in many places around the globe, emphasizes dramatic reductions in the energy consumption of residential and commercial buildings. The International WELL Building Institute's WELL Building Standard certifies building construction with regard to human health and well-being criteria. In addition, 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 unhealthful 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 relative 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 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 full, life-cycle environmental 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 some 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:

- 73 MJ (70,000 BTU) of nonrenewable energy consumed
- 6.8 kg (15 pounds) of CO_2 equivalent *global warming potential*
- 86 L (23 gallons) of fresh water consumed

Additional information in the report quantifies materials consumption, smog production, ozone depletion, acidification and eutrophication potential, waste materials generated, 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.

In relative infancy are *Environmental Building Declarations*, or *EBD*s. As life-cycle data become available for the majority of materials and products used in construction, the same type of life-cycle analysis can be applied to whole buildings, allowing the environmental impacts of alternative building designs to be meaningfully compared.

Much of the environmental reporting provided by 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 and declarations. 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 Embodied Impacts

Preparation of environmental product and building declarations depends on the accounting of the environmental impacts of materials and products throughout their life cycles. This begins with raw materials extraction, continues with manufacture, construction, and 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*), or *cradle-to-grave analysis*, is one of the most comprehensive methods for quantifying the environmental impacts associated with materials and buildings. Through each life-cycle stage, impacts are tallied: How much fossil fuel, electricity, water, and other materials 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).

The concept of embodied energy also derives from life-cycle analysis. *Embodied energy* is the sum total of energy consumed during a material's life cycle. Because energy consumption frequently correlates with the consumption of nonrenewable resources and the generation of greenhouse gasses, it is easy to assume that materials with lower embodied energy are better for the environment than others with greater embodied energy. However, in making such comparisons, 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, 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,

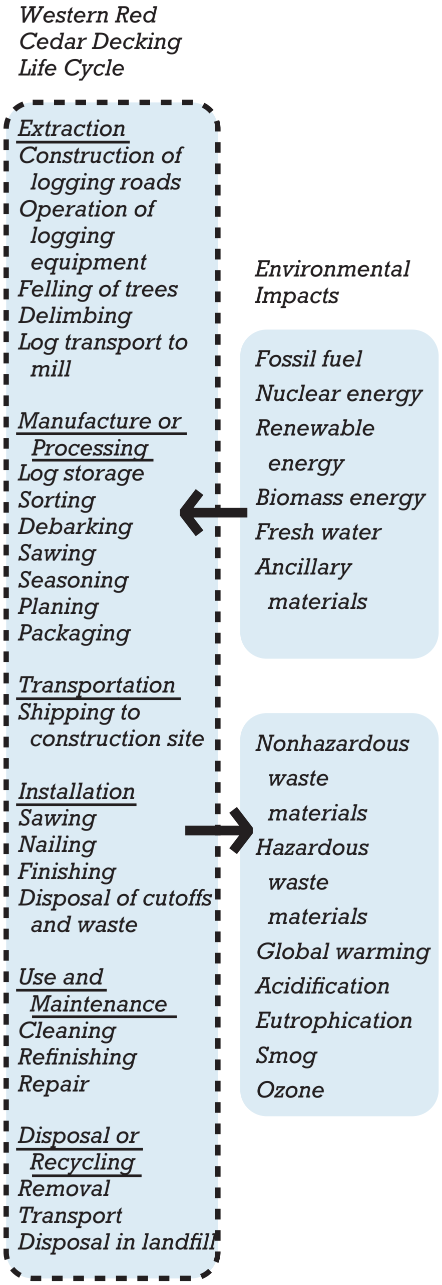


FIGURE 1.3

Life-cycle analysis of Western red cedar decking. The underlined life-cycle stages (Extraction, Manufacture or Processing, etc.) are applicable to any building construction material LCA. The activities listed under each stage here are specific to the example of Western red cedar decking. For other materials, other activities would be listed. The right-hand column lists the types of environmental impacts associated with this material, both resources consumed (such as energy and water) and pollutants and wastes emitted (such as global warming gasses and nonhazardous waste). Though not included here, the LCA also quantifies these impacts so that one material can be readily compared with another.

should also be considered, as impacts differ from one energy source to another.

Embodied energy and other life-cycle effects may sometimes be calculated for only a part of the material life cycle. 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 recycling. Though less comprehensive, such analyses can still provide a useful basis for comparison between products. For example, for many materials, the difference in embodied energy between a cradle-to-grave and cradle-to-gate analysis is small, as most of the energy expenditure occurs prior to the material's installation, use, and eventual disposal.

The concept of embodied effects can also be applied to other measured inputs or outputs from a life-cycle analysis. For example, *embodied water* refers to the fresh water consumed as a consequence of building with a particular material.

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 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 a material environmental product declaration, the ultimate consequences of that effect for ecosystems, wildlife populations, and human well-being are not fully described.

Health Impacts of Building Materials

Much like the sources of information available for the assessment of material environmental impacts, information useful to understanding the human health-related impacts of materials and products can also be provided in various formats.

Similar to environmental product declarations, *health product declarations* (*HPDs*) may be prepared by the product manufacturer or an independent agency. The standard for creating HPDs is defined by the HPD Collaborative, an independent organization with representation from many construction industry stakeholders. HPDs provide reliable and consistent information about material ingredients and associated human and environmental health hazards. They 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 are not a certification or rating tool—that is, they do not, in themselves, assess the healthfulness of a product. They do, however, provide important information in a standard format that can be used to make health-related comparisons.

Other Sustainable Material Attributes

Products with a high *recycled materials content* help to divert waste materials that would otherwise be disposed of in landfills or by incineration. Recycled content can be distinguished as either preconsumer or postconsumer. *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 wasted. 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.

Bio-based materials are produced by agricultural or animal biological processes. Examples include cornstarch derived from grain and used as an ingredient in the manufacture of gypsum wallboard, or resins made from wood lignin, starch, or other plant proteins used as substitutes for traditional petroleum-derived resins in the manufacture of composite wood products. Bio-based materials are biodegradable or compostable, and carbon-neutral (meaning they have little if any impact on global warming). Their production can contribute to employment in rural areas. And when cultivated and harvested in a sustainable manner, they are a renewable resource that can reduce dependence on irreplaceable fossil fuels. However, the production of bio-based materials occupies arable land and requires fresh water, fertilizer or feedstock, and energy. Determining the potential benefit of a bio-based material requires analysis of the environmental impacts throughout the material's life cycle and comparing those to the impacts of alternative materials.

Some bio-based materials are *rapidly renewable*, that is, they are grown and harvested in a relatively short time span. LEED defines rapidly renewable materials as those harvested within a 10-year or shorter cycle.

Regional, or *locally sourced*, *materials* are produced near the construction site. Relying on locally sourced materials reduces energy consumption and emissions associated with materials transportation. And it contributes to the economic well-being of the community in which the building is being constructed. LEED defines regional materials as those extracted, manufactured, and purchased within 100 miles (160 km) of the construction site.

Materials Assessment Within Sustainable Building Programs

Within LEED, the Living Building Challenge, and other sustainable building programs, material attributes can be evaluated in relation to a range of environmental, health, and social impact considerations.

Energy performance. Appropriate materials choices and design can reduce heat losses through the building enclosure, moderate peak heating and cooling loads, and support passive heating and cooling strategies, all of which can contribute to reductions in building energy use.

Building and material life-cycle impacts. Adaptive reuse of existing buildings, salvaging materials from existing buildings for use in new ones, and design of new structures for future disassembly and materials repurposing are ways to reduce the demand for new raw materials and reduce the volume of waste going to landfills or incineration.

Life-cycle analysis reveals the fullest range of environmental impacts and embodied attributes of materials used in building construction. As the energy required to operate buildings continues to decrease, embodied energy and global warming potential of materials themselves are becoming a larger share of a building's energy consumption and global warming profile, and increasingly important targets for continued reductions in these measures.

Material and production attributes. Transparently disclosing material ingredients, recycled content, rapidly renewable or bio-based materials content, and the geographic source of raw materials encourages the selection of products that reduce environmental impacts. The Declare label, previously discussed, is one such example of a materials disclosure. Another is the Cradle to Cradle Products Innovation Institute's Cradle to Cradle Certification, which provides information about material ingredients, reutilization, and environmental impacts.

Unhealthy materials and emissions. Health-related disclosures can identify material ingredients or compounds used in manufacture that are hazardous to humans or the environment. Health Product Declarations provide transparent disclosure, but without rating. The Living Building Challenge *Red List* identifies materials to be excluded from Living Buildings because these materials are severely polluting, bio-accumulating, or harmful to factory workers, construction workers, or building occupants.

Coatings, sealants, adhesives, wood composites, insulation materials, wall and floor coverings, ceiling materials, and furniture are just some of the potential sources of chemical air pollutants that can be harmful to construction workers or building occupants. For wet-applied materials, in which the majority of VOC emissions occur shortly after the product is installed, the chemical VOC content is limited and may be self-reported by the manufacturer or established by third-party certification. For broader, general emissions compliance of materials and products, third-party testing is required by both LEED and the Living Building Challenge.

Responsible industry practices and social impacts. Manufacturers may self-report or provide independently verified information about raw materials extraction, land use, labor practices, community relations, and manufacturing processes. For example, the Forest Stewardship Council certifies sustainable forestry and timber harvesting operations. The Natural Stone Council's 373 Sustainability Assessment for Natural Dimension Stone does the same for sustainable quarrying and production of stone.

The International Living Future Institute's JUST program provides a format for product manufacturers to disclose information about social justice practices, such as supportive employee policies, local community support, and socially responsible activities. LEED also recognizes company efforts to address local or regional social and economic priorities.

The Impact of Sustainable Buildings

Sustainable building practice is producing measurable, positive results in building performance. Post-occupancy evaluations of U.S. buildings constructed to LEED standards show reductions in energy consumption and greenhouse gas emissions in the range of 25 to 35 percent in comparison to national averages. Additional improvements also are seen in such areas as reduced water consumption, lowered operating costs, increased occupant satisfaction, higher property values, and more. Sustainable building also creates new challenges. New or reformulated materials may prove to be less durable than those they replace. Innovative products from unique sources may be difficult to source or more costly. Or inexperience with green building technologies may lead to design or construction errors. Ensuring that sustainable buildings meet their performance expectations is another important challenge. While average performance, as noted above, exceeds that of conventional buildings, it is also true that the performance of individual buildings deviate greatly from these averages. And, while many green buildings do outperform conventional buildings, a significant number also underperform expectations.

Building commissioning (abbreviated *Cx*) is a process used to ensure that performance expectations are realized in finished buildings. 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 review progress at interim milestones. Close to the end of construction, actual performance is verified through on-site testing. Finally, operational guidance is provided to ensure that the finished, occupied building will continue to perform as intended. Building commissioning is traditionally associated with the testing and verification of heating, ventilating, and air conditioning systems in new buildings. With sustainable design, the emphasis is on integrated, whole-building performance, addressing a broader range of building systems and objectives. An effective, fully documented commissioning process is a prerequisite to achieving LEED certification. Under the Living Building Challenge, a full year of operational data, showing successful compliance with design and performance objectives, must be collected before Living Building certification is awarded.

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. *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—which may have been 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 an impact assessment can vary dramatically 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 far buildings must be set back from property lines, how many parking spaces 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 codes 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 code–related information in this book is based on the IBC. The IBC begins by defining *occupancies* for buildings as follows:

- A-1 through A-5 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-1 and F-2 Factory Industrial: industrial processes using moderate-flammability and noncombustible materials, respectively
- H-1 through H-5 High Hazard: occupancies in which toxic, corrosive, highly flammable, or explosive materials are present
- I-1 through I-4 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-1 through R-4 Residential: apartment buildings, dormitories, fraternity and sorority houses, hotels, one- and two-family dwellings, and assisted-living facilities
- S-1 and S-2 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 degrees of life-safety hazard in buildings. For example, a hospital, in which patients are bedridden and cannot escape a fire without assistance from others, must be designed to a higher standard of safety than a hotel or motel occupied by able-bodied residents. A large retail mall building, containing large quantities of combustible materials and occupied by many users varying in age and physical capacity, must be designed to a higher standard than a warehouse storing noncombustible materials and occupied by relatively few people who are all familiar with their surroundings. An elementary school requires more protection for its occupants than a university building. A theater, with patrons densely packed in dark spaces, requires more attention to emergency exits than does an ordinary office building.

These occupancy classifications are followed by a set of definitions for *construction types*. At the head of this list is Type I construction, made with highly fire-resistant, noncombustible materials. At the foot of it is Type V construction, which is built from combustible light wood framing—the least fire-resistant of all construction types. In between are Types II, III, and IV, with levels of resistance to fire falling between these two extremes.

With occupancies and construction types defined, the IBC proceeds to match the two, stating which occupancies may be housed in which types of construction, and under what limitations of building height and area. Figure 1.4 is a simplified summary of starting values in the IBC for maximum building height and area per floor for many combinations of occupancy and construction type. Once the values in this table are adjusted according to other provisions of the code, the

		Type of Construction								
		Type I		Type II		Type III		Type IV[a]	Type V	
		A	B	A	B	A	B	HT	A	B
Occupancy	**Height[b]**	**U[e]**	**160**	**65**	**55**	**65**	**55**	**65**	**50**	**40**
A-1	**Stories[c]**	U	5	3	2	3	2	3	2	1
	Area[d]	U	U	15,500	8,500	14,000	8,500	15,000	11,500	5,500
A-2	**Stories**	U	11	3	2	3	2	3	2	1
	Area	U	U	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-3	**Stories**	U	11	3	2	3	2	3	2	1
	Area	U	U	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-4	**Stories**	U	11	3	2	3	2	3	2	1
	Area	U	U	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-5	**Stories**	U	U	U	U	U	U	U	U	U
	Area	U	U	U	U	U	U	U	U	U
B	**Stories**	U	11	5	3	5	3	5	3	2
	Area	U	U	37,500	23,000	28,500	19,000	36,000	18,000	9,000
E	**Stories**	U	5	3	2	3	2	3	1	1
	Area	U	U	26,500	14,500	23,500	14,500	25,500	18,500	9,500
F-1	**Stories**	U	11	4	2	3	2	4	2	1
	Area	U	U	25,000	15,500	19,000	12,000	33,500	14,000	8,500
F-2	**Stories**	U	11	5	3	4	3	5	3	2
	Area	U	U	37,500	23,000	28,500	18,000	50,500	21,000	13,000
M	**Stories**	U	11	4	2	4	2	4	3	1
	Area	U	U	21,500	12,500	18,500	12,500	20,500	14,000	9,000
R-1	**Stories**	U	11	4	4	4	4	4	3	2
	Area	U	U	24,000	16,000	24,000	16,000	20,500	12,000	7,000
R-2	**Stories**	U	11	4	4	4	4	4	3	2
	Area	U	U	24,000	16,000	24,000	16,000	20,500	12,000	7,000
R-3	**Stories**	U	11	4	4	4	4	4	3	3
	Area	U	U	U	U	U	U	U	U	U
R-4	**Stories**	U	11	4	4	4	4	4	3	2
	Area	U	U	24,000	16,000	24,000	16,000	20,500	12,000	7,000
S-1	**Stories**	U	11	4	2	3	2	4	3	1
	Area	U	48,000	26,000	17,500	26,000	17,500	25,500	14,000	9,000
S-2	**Stories**	U	11	5	3	4	3	4	4	2
	Area	U	79,000	39,000	26,000	39,000	26,000	38,500	21,000	13,500

[a] See this figure's caption for information about new Type IV construction types to appear in the 2021 IBC.

[b] Height: Roof height above grade in feet (1ft = 0.3048 m).

[c] Stories: Number of stories above grade.

[d] Area: Area per floor in square feet (1 sq ft = 0.0920 m^2).

[e] U: Unlimited.

Figure 1.4

Simplified height and area limitations for common occupancies, from the 2018 IBC. In use, these values are further modified according to additional provisions to arrive at the final allowable height and area for any particular building. For the purposes of this book, many of these modifications are simplified or ignored. For information about new Type IV construction types related to tall mass timber buildings that will appear in the 2021 IBC, see Chapter 4.

maximum permitted size for a building of any particular use and type of construction can be determined.

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.

Type I-A construction is defined in the IBC as consisting of only noncombustible structural materials—masonry, concrete, or steel, for example—and meeting certain requirements for resistance to the heat of fire. On the other hand, wood, being combustible, is (barring a few exceptions) not permitted for use in this construction type. Looking at the upper table in Figure 1.5, reproduced from the IBC, we find under Type I-A construction a listing of the required *fire resistance ratings*, measured in hours, for various parts of our proposed office building. For example, the first table row indicates that the structural frame, including such elements as columns, beams, and trusses, must be rated at 3 hours. The second row also 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 Table 602, which gives fire resistance rating requirements based on proximity to adjacent buildings or properties. (Table 602 is included in the lower portion of Figure 1.5.) Minimum requirements for interior *nonbearing walls and*

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[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f,g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	1½[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

TABLE 602
FIRE-RESISTANCE RATING REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE[a, e, h]

FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP H[f]	OCCUPANCY GROUP F-1,M, S-1[g]	OCCUPANCY GROUP A, B, E, F-2, I, R, S-2[g], U[b]
X < 5[c]	All	3	2	1
5 ≤ X < 10	IA Others	3 2	2 1	1 1
10 ≤ X < 30	IA, IB IIB, VB Others	2 1 1	1 0 1	1[d] 0 1[d]
X ≥ 30	All	0	0	0

For SI: 1 foot = 304.8 mm.

FIGURE 1.5

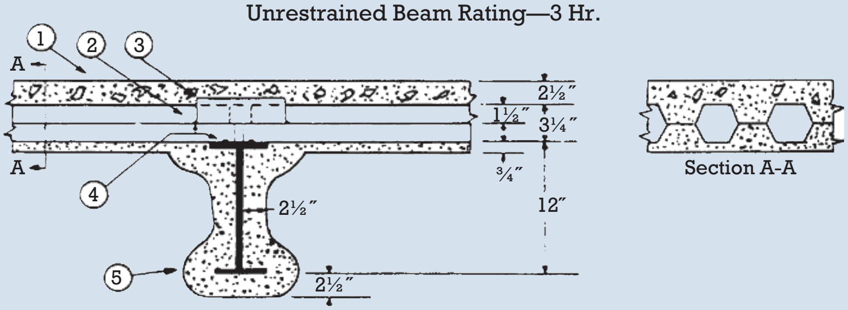
Fire resistance of building elements, excerpted from the IBC. Types I and II construction restrict the building structure to noncombustible materials, that is, steel, concrete, and masonry. Type V construction allows any material, including wood. Types III and IV allow combinations of internal wood structure surrounded by noncombustible exterior walls. Additional provisions have been omitted for simplicity. For information about new Type IV construction types related to tall mass timber buildings that will appear in the 2021 IBC, see Chapter 4.

partitions, which carry no loads from above, and for floor and roof construction are defined in the other rows of the table.

Taking a closer look at Tables 601 and 602 in Figure 1.5, we see that Type I-A construction is the least vulnerable to fire: It is constructed of noncombustible structural materials and with the highest fire resistance ratings. Reading across the table, we see 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, in which any structural material is permitted, both noncombustible and combustible, and no fire protection is required. These differences are reflected in Figure 1.4, in which the least vulnerable construction type, Type I-A, is permitted the greatest height and area, and other increasingly vulnerable types are limited to progressively lesser heights and areas.

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 a variety of sources, including 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

Design No. A814
Restrained Assembly Rating—3 Hr.
Unrestrained Assembly Rating—3 Hr.
Unrestrained Beam Rating—3 Hr.



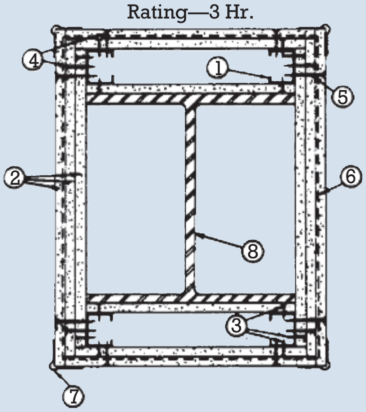
Beam—W 12 × 27, min size.
1. **Sand-Gravel Concrete**—150 pcf unit weight 4000 pcf compressive strength.
2. **Steel Floor and Form Units***—Non-composite 3 in. deep galv units. All 24 in. wide, 18/18 MSG min cellular units. Welded to supports 12 in. O.C. Adjacent units button-punched or welded 36 in. O.C. at joints.
3. **Cover Plate**—No. 16 MSG galv steel.
4. **Welds**—12 in. O.C.
5. **Fiber Sprayed***—Applied to wetted steel surfaces which are free of dirt, oil or loose scale by spraying with water to the final thickness shown above. The use of adhesive and sealer and the tamping of fiber are optional. The min and density of the finished fiber should be 11 pcf and the specified fiber thicknesses require a min fiber density of 11 pcf. For areas where the fiber density is between 8 and 11 pcf, the fiber thickness shall be increased in accordance with the following formula:

$$\text{Thickness, in.} = \frac{(11)\ (\text{Design Thickness, in.})}{\text{Actual Fiber Density, pcf.}},$$

Fiber density shall not be less than 8 pcf. For method of density determination refer to General Information Section.

*Bearing the UL Classification Marking.

Design No. ×511
Rating—3 Hr.



1. **Steel Studs**—1⅝ in. wide with leg dimensions of 1-5/16 and 1-7/16 in. with a ¼ -in. folded flange in legs, fabricated from 25 MSG galv steel, ¾- by 1¾-in. rectangular cutouts punched 8 and 16 in. from the ends. Steel stud cut ½ in. less in length than assembly height.
2. **Wallboard, Gypsum***—½ in. thick, three layers.
3. **Screws**—1 in. long, self-drilling, self-tapping steel screws, spaced vertically 24 in. O.C.
4. **Screws**—1⅝ in. long, self-drilling, self-tapping steel screws, spaced vertically 24 in. O.C., except on the outer layer of wallboard on the flange, which are spaced 12 in. O.C.
5. **Screws**—2¼ in. long, self-drilling, self-tapping steel screws, spaced vertically 12 in. O.C.
6. **Tie Wire**—One strand of 18 SWG soft steel wire placed at the upper one-third point, used to secure the second layers of wallboard only.
7. **Corner Beads**—No. 28 MSG galv steel, 1¼ in. legs or 27 MSG uncoated steel, 1⅜ in. legs,

Figure 1.6

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.

(Reprinted with permission of Underwriters Laboratories Inc.)

Interactive Exercise

of this book.) Figure 1.6 shows examples of how such ratings are commonly presented.

In general, when determining the level of fire resistance required for a building, the greater the degree of fire resistance, the higher the cost. Most frequently, therefore, buildings are designed to the lowest level of resistance permitted by the building code. Our hypothetical office building could be built using Type I-A 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. Reading across the table in Figure 1.4, 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 only three stories and 23,000 square feet per floor. It can also be built of Type IV-HT construction but not of Type III or Type V.

Other factors also come into play in these determinations. If a building is protected throughout by a fully 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 permitted increase is the added safety to life and property provided by such a system. A one-story increase in allowable height is also granted under most circumstances if such a sprinkler system is installed. If the three-story, 30,000-square-foot office building that we have been considering is provided with such a sprinkler system, a bit of arithmetic will show that it can be built of any construction type shown in Figure 1.4 except Type V.

If more than a quarter of the building's perimeter walls face public ways or open spaces accessible to firefighting equipment, an additional increase of up to 75 percent in allowable area is granted in accordance with another formula. Furthermore, if a building is divided by fire walls having the fire resistance ratings specified in another table (Figure 1.7), each divided portion may be considered a separate building for purposes of computing its allowable area, which effectively permits the creation of a building many times larger than Figure 1.4 would, at first glance, indicate. (For the sake of simplicity, additional considerations in determining the allowable building height and area in the IBC have been omitted from these examples.)

The IBC also establishes standards for natural light; ventilation; *means of egress* (exiting during building emergencies); structural design; construction of floors, walls, and ceilings; chimney construction; fire-protection systems; accessibility for disabled persons; and many other important 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 simplified 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 building energy consumption, the development of more stringent 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

TABLE 706.4
FIRE WALL FIRE-RESISTANCE RATINGS

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.

Figure 1.7
Fire resistance requirements for fire walls, according to the IBC. For more information about fire walls, see Chapter 23. *(Table 706.4 excerpted from the 2012 International Building Code, Copyright 2011. Washington, DC: International Code Council. Reproduced with permission. All rights reserved. www.ICCSAFE.org)*

life-safety systems are properly maintained. Electrical and mechanical codes regulate the design and installation of building electrical, plumbing, and heating and cooling systems. Some of these codes may be locally written, but, like the building codes discussed earlier, most are 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 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 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 an 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 as well.

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

Procurement and Contracting Requirements Group
- Division 00—Procurement and Contracting Requirements

Specifications Group
- General Requirements Subgroup
  - Division 01—General Requirements
- Facility Construction Subgroup
  - Division 02—Existing Conditions
  - Division 03—Concrete
  - Division 04—Masonry
  - Division 05—Metals
  - Division 06—Wood, Plastics, and Composites
  - Division 07—Thermal and Moisture Protection
  - Division 08—Openings
  - Division 09—Finishes
  - Division 10—Specialties
  - Division 11—Equipment
  - Division 12—Furnishings
  - Division 13—Special Construction
  - Division 14—Conveying Equipment
- Facilities Services Subgroup
  - Division 21—Fire Suppression
  - Division 22—Plumbing
  - Division 23—Heating, Ventilating, and Air Conditioning (HVAC)
  - Division 25—Integrated Automation
  - Division 26—Electrical
  - Division 27—Communications
  - Division 28—Electronic Safety and Security
- Site and Infrastructure Subgroup
  - Division 31—Earthwork
  - Division 32—Exterior Improvements
  - Division 33—Utilities

These broadly defined 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

Every chapter in this book gives MasterFormat designations for the information it presents 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.

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, occurs 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*™ 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 more systems-based view of construction in comparison to MasterFormat and is most useful where a broader, more flexible description of building information is needed. This includes, for example, description of building systems and assemblies during project definition and early design, or the performance specification of building systems, such as discussed later in this chapter for design/build project delivery. UniFormat is also well suited to organizing construction data in computer-aided design and building information modeling systems, which naturally tend to aggregate information into functional groupings. (Building information modeling is discussed at greater length later in this chapter.)

The *OmniClass™ Construction Classification System* is an overarching scheme that attempts to incorporate multiple existing building information organizational systems, including MasterFormat, UniFormat, and others, into one system. 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. OmniClass is an open standard that is described broadly by its authors as "a strategy for classifying the built environment." It is based on an international standard for organizing construction information, ISO 120006-2, and it continues to undergo active development.

The increasing attention given to organizational systems like UniFormat and OmniClass reflects the building industry's need to manage increasingly complex sets of data and efficiently share that data between disciplines, across diverse information technology platforms, and throughout the full building life cycle, from conception to extended occupancy.

The Work of the Construction Professional

Providing Construction Services

An owner wishing to construct a building hopes to achieve a finished project that functions as intended, meets expectations for quality, costs as little as possible, and is completed on a predictable schedule. A contractor offering its construction services hopes to produce quality building, earn a profit, and complete the project 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 minimize the margin for miscalculation. In this 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 1.8, *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 of the work itself. 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.

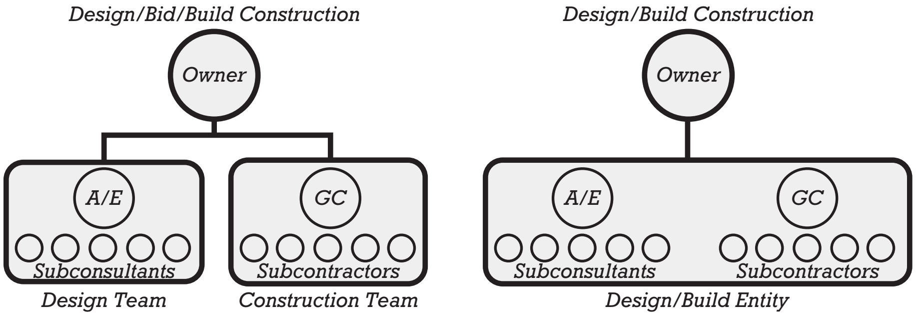


FIGURE 1.8
In design/bid/build project delivery (*left*), the owner contracts separately with the architect/engineer (A/E) design team and the construction general contractor (GC). In a design/build project (*right*), the owner contracts with a single organizational entity that provides both design and construction services.

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 completed before the project is bid, the owner starts construction with a well-defined scope of work and a high degree of 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 1.8, *right*). 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 conceptual 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 also places 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, cost control, construction scheduling, and similar matters. This delivery method also readily accommodates fast track construction, a scheduling technique for reducing construction time that is described later in this chapter.

Other delivery methods are possible: An owner may contract separately with a design team and a *construction manager* (*CM*) (Figure 1.9). As in design/build construction, the construction manager participates in the project prior to the onset of construction, introducing construction expertise during the design stage. Construction management project

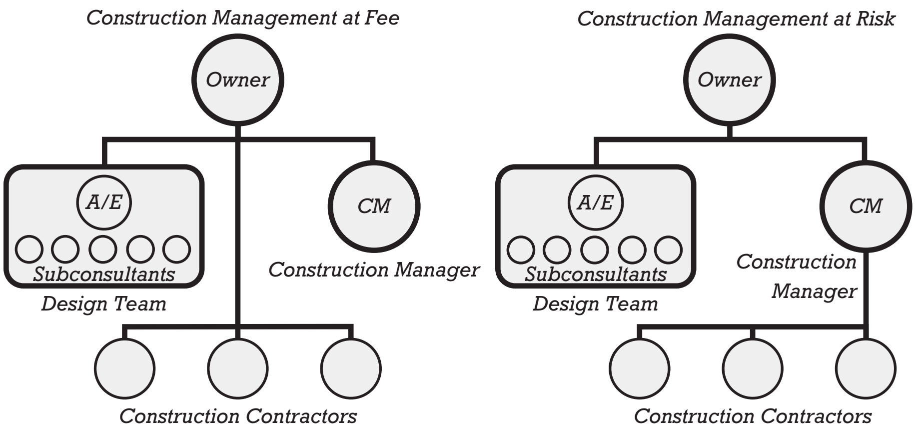


FIGURE 1.9
In its traditional role, a construction manager (CM) at fee (*left*) provides project management services to the owner and assists the owner in contracting directly for construction services with one or more construction entities. A CM at fee is not directly responsible for the construction work itself. A CM at risk (*right*) acts more like a general contractor and takes on greater responsibility for construction quality, schedule, and costs. In either case, the A/E design team also contracts separately with the owner.

delivery can take a variety of forms and is frequently associated with especially large or complex projects. 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. Or design and construction can be undertaken by a *single-purpose entity*, of which the owner, architect, and contractor are all joint members. Aspects of these and other project delivery methods can also be intermixed, allowing many possible organizational schemes for the delivery of design and construction services that are suitable to a 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 known 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 an incentive 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 noncompetitive 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 1.10), 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. 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 (Figure 1.10). By allowing construction to start sooner and by

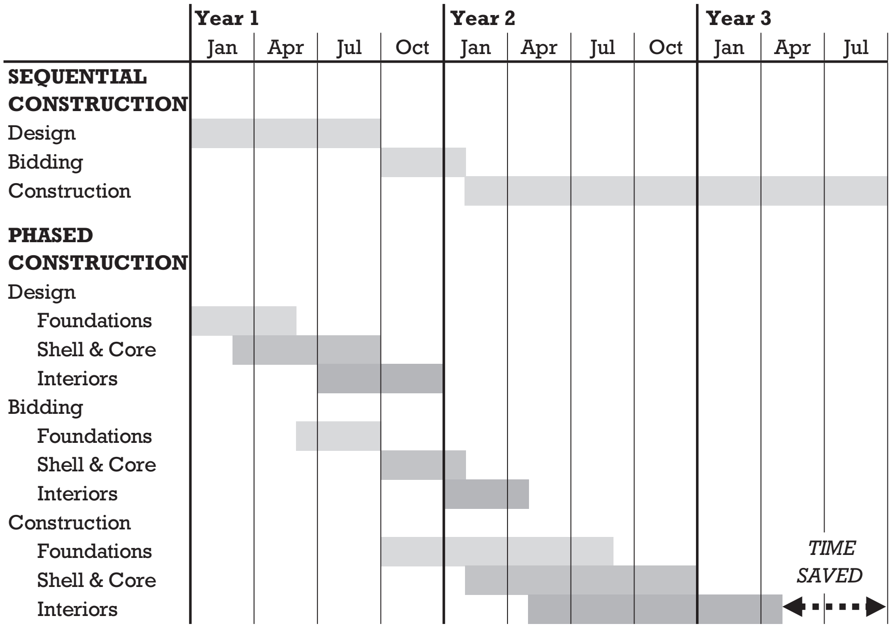


Figure 1.10
In sequential construction, construction does not begin until design is complete. In phased construction, design and construction activities overlap, with the goal of reducing the overall time required to complete a project.

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.

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 1.11 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 structures, which rely, in part, on the previously completed cores for support. Attachment of the exterior skin can follow only after the floor plates 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

Figure 1.11
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 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 1.10), or they can be expanded to represent a larger number of more narrowly defined tasks at greater levels of project detail (Figure 1.12).

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 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 1.13). 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

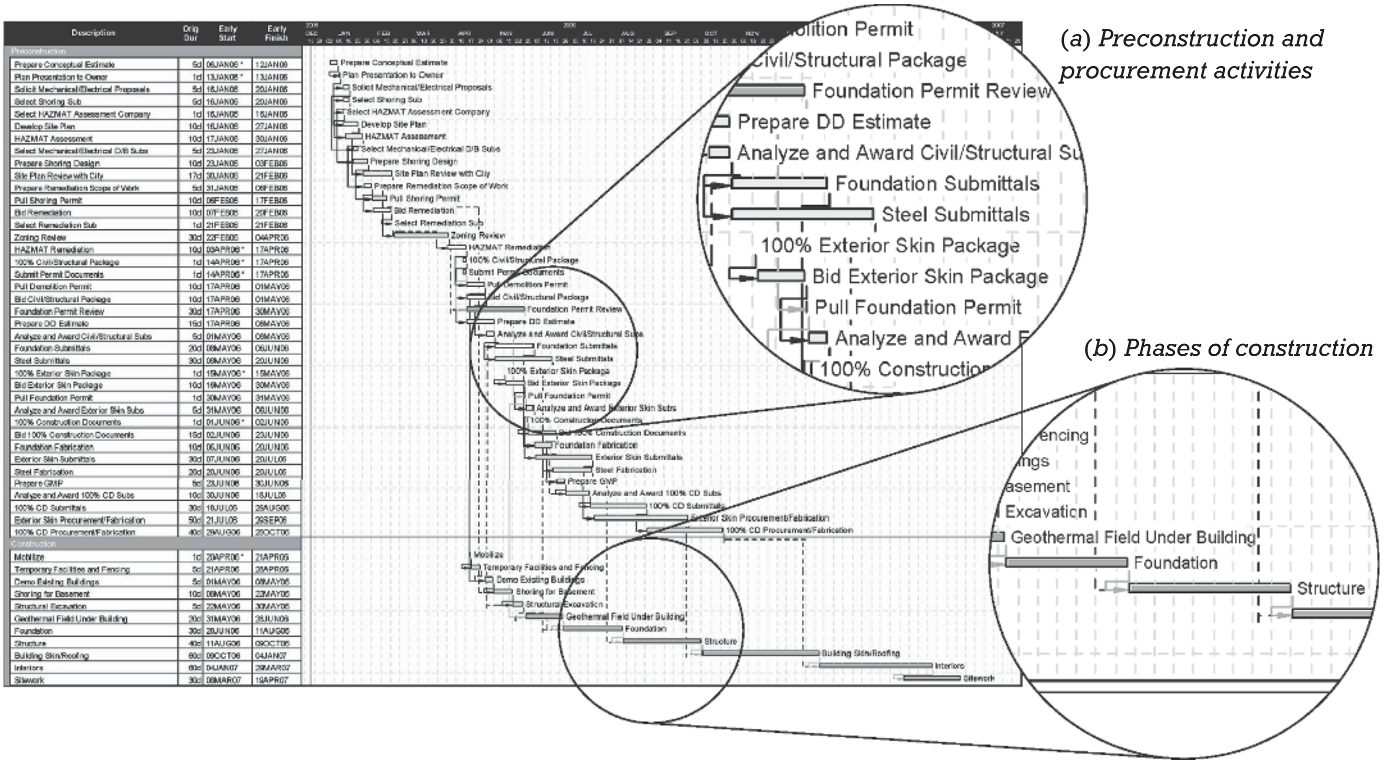


FIGURE 1.12

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*).

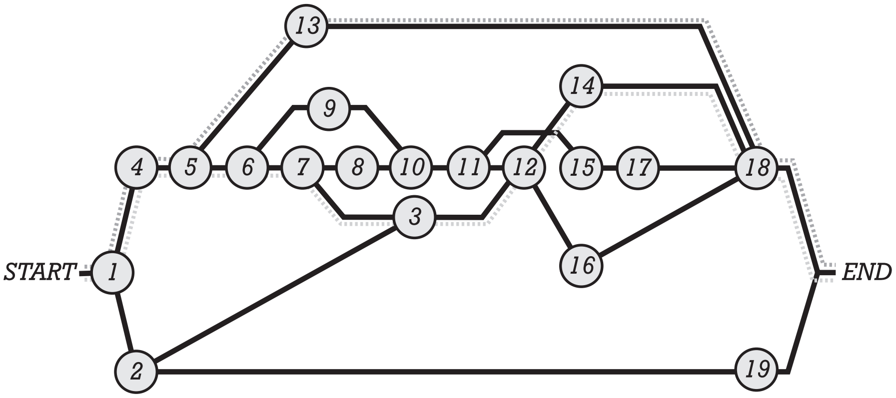


FIGURE 1.13
The critical path method depends on a detailed analysis of work tasks and their relationships to generate an optimal construction schedule. Shown here is a schematic network diagram representing task dependencies. For example, task 6 cannot begin until tasks 1, 4, and 5 are completed, and 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.

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 constructions 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 overall, 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 subtrades 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 changes to the work, protecting completed work, and more.

Trends in the Delivery of Design and Construction Services

Fostering Collaboration

The design and construction industry continues to test innovative organizational structures and project delivery methods in which designers, builders, and owners assume less adversarial and less compartmentalized roles. Such approaches share characteristics such as:

- Contractual relationships and working arrangements that foster collaboration between primary project participants—the designer, owner, and builder
- Early involvement of all parties, including participation of the construction entity during the design phases of a project
- Shared risk and reward

- Expanded project services to more fully address the full life of a project—from its original conception through planning, design, and construction to postconstruction occupancy—to best serve the needs of the building owner

The growth of design/build in the construction marketplace is one example of this trend: Between 1980 and the present, the share of private, nonresidential construction work performed as design/build construction has increased from roughly 5 percent of the total market to 45 percent.

The current state of the art in collaborative project delivery is *integrated project delivery* (*IPD*). In IPD, the major parties—including at least the design team, construction team, and owner group—share mutually the responsibilities, decision-making, and financial risks and rewards of the project. In its purest form, the parties share one agreement, for example, as a single-purpose entity, binding them all to the same goals and outcomes. In other cases, a shared joining agreement may be used to mutually bind parties contracted under separate agreements. The goal of IPD and similar efforts is to increase efficiency, improve project outcomes, and reduce conflict and litigation.

Improving Productivity

Industry efforts also focus on improvements in the efficiency of construction processes themselves. For example, a typical single-family home may be made of more than 100,000 separate pieces, assembled by as many as 1,000 workers. Estimates of inefficiency in the general construction market sector range as high as 50 percent or more, equating, in the U.S. market, to $400 to $600 billion wasted annually. And while U.S. nonfarm productivity has more than doubled since 1964, productivity in the construction sector has remained unchanged or even declined during the same period.

Unlike factory production, most building construction takes place outdoors, is performed within physically challenging work areas, and is executed by a highly fragmented workforce. Despite the differences in production environments, the construction industry is drawing lessons from factory production to improve its own processes. Sometimes called *lean construction*, such methods attempt to:

- Reduce complexity
- Eliminate wasteful activities
- Structure the supply of materials and methods of production to achieve the quickest and most reliable workflow
- Decentralize information and decision-making, to put control of processes into the hands of those most familiar with the work and most capable of improving it

Other efforts are focusing on a broader integration of the services that contribute to bringing buildings to market, including architectural and engineering design, the materials supply chain, manufacturing, prefabrication, and building construction. Such *vertical integration of construction services* into a single business entity opens up new possibilities for the streamlining of processes, application of new technologies, cost savings, elimination of waste, and control of building quality.

Advances in Information Technology

The adoption of *building information modeling* (*BIM*) and the influence of this technology on design and construction services continues to grow. Unlike the two-dimensional representation of building systems characteristic of *computer-aided design* (*CAD*), BIM is three-dimensional and intelligent. Components are not only represented geometrically and spatially but are linked to data describing their intrinsic properties and relationships to other components. In other words, the model is *object-based* and *parametric*. Originally developed for use in highly capital-intensive industries such as aerospace and automobile manufacturing, this technology is now the state-of-the-art design technology in the building construction sector.

BIM can impact all phases of the building life cycle. It can aid the design team in the effective communication of design concepts or the exploration of complex building geometries. It can improve coordination between disciplines, for example, performing *clash detection* to find spatial conflicts, or "collisions," between mechanical system ductwork, structural framing, and other systems designed by separate teams. It can facilitate the modeling of building energy use, daylighting design, and other performance criteria. For the builder, BIM can analyze project phasing, improve coordination of trades, drive the automated fabrication or preassembly of building components, and integrate cost and schedule data more closely with design and construction activities. For the building owner, information accumulated in the model during design and construction can be carried forward for use with post-occupancy operations and facilities planning. BIM has the potential to profoundly influence how buildings are designed, constructed, and operated, although the full transformative promise of this technology has yet to be realized in practice.

A key component to successful implementation of building information modeling is the *BIM execution plan*. This 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 1.14).

The influence of other information technologies on the design,

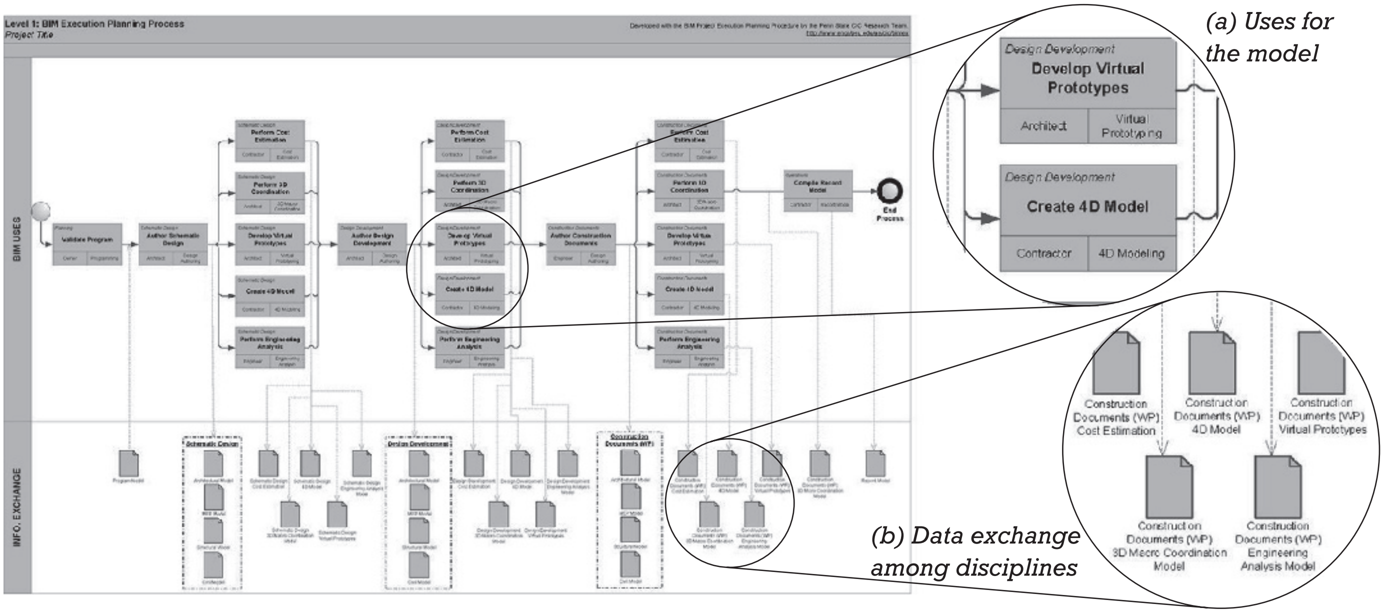


FIGURE 1.14

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*). *(Excerpted from the Building Information Modeling Execution Planning Guide (Version 2.1), 2011. State College, PA: Computer Integrated Construction Research Program, Pennsylvania State University. This work is licensed under the Creative Commons Attribution-Share Alike 3.0 United States License. To view a copy of this license, visit http://creativecommons.org/licenses/by-sa/3.0/us or send a letter to Creative Commons, 171 Second Street, Suite 300, San Francisco, California, 94105, USA.)*

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

construction, and operation of buildings is growing as well. Enterprise business analytics are being applied to the economics of manufacturing building components and building construction. Advanced computational methods and new 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. Big-data analysis is creating new opportunities for understanding the interactions of buildings both internally, with building occupants, and externally, with the environments within which they are placed. And robotics and 3D printing technologies are opening up new possibilities for the automated assembly and construction of building components and even complete buildings.

Key Terms

sustainable development
green building
integrated design process (IDP)
Leadership in Energy and Environmental Design, LEED
LEED prerequisite
LEED credit
Living Building Challenge
Living Building Challenge Imperative
Product Data Sheet (PDS)
environmental label, ecolabel
volatile organic compound (VOC)
product disclosure
Environmental Product Declaration (EPD)
global warming potential
Environmental Building Declaration (EBD)
ISO 14020 standards
life-cycle analysis (LCA)
cradle-to-grave analysis
environmental footprint
embodied energy
cradle-to-gate analysis
embodied water
health product declaration (HPD)
recycled materials content
preconsumer recycled material
postconsumer recycled material
bio-based material
rapidly renewable material
regional material, locally sourced material
Living Building Challenge Red List
building commissioning (Cx)
drawings
specifications
construction documents
zoning ordinance
building code
model code
National Building Code of Canada
International Building Code (IBC)
building code occupancy
building code construction type
fire resistance rating
bearing wall
nonbearing wall, partition
means of egress
International Residential Code (IRC)
Americans with Disabilities Act (ADA)
Fair Housing Act
equal access standard
Occupational Safety and Health Administration (OSHA)
ASTM International
Canadian Standards Association (CSA)
International Organization for Standardization (ISO)
American National Standards Institute (ANSI)
National Institute of Science and Technology (NIST)
Institute for Research in Construction (NRC-IRC)
trade association
Construction Specifications Institute (CSI)
Construction Specifications Canada (CSC)
MasterFormat
specification division
specification section
UniFormat
OmniClass Construction Classification System
OmniClass Tables
design/bid/build project delivery
general contractor
subcontractor
design/build project delivery
construction manager (CBA, CA)
turnkey project delivery
single-purpose entity
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)
schedule class
schedule level
rolling schedule, look-ahead schedule
integrated project delivery (IPD)
lean construction
vertical integration of construction services
building information modeling (BIM)
computer-aided design (CAD)
object-based modeling
parametric modeling
clash detection
BIM execution plan

Review Questions

1. What is sustainable building? Why is it important?

2. What is the difference between a product disclosure and an ecolabel?

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. 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? 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. Categorize the types of information available, such as product disclosures, ecolabels, EPDs, etc.

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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The model building code used as the basis for the majority of U.S. state, county, and municipal building codes.

International Living Future Institute. *Living Building Challenge* 3.1. Seattle, WA, updated regularly.

Describes the essential requirements for design of Living Building Certified, Petal Certified, or Net Zero Energy Certified buildings.

Kibert, Charles J. *Sustainable Construction: Green Building Design and Delivery*. Hoboken, NJ, John Wiley & Sons, 2016.

U.S. Green Building Council. *LEED v4 for Green 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: https://architecture2030.org

Athena Sustainable Materials Institute: www.athenasmi.org

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

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

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

International WELL Building Institute: www.wellcertified.com

Living Building Challenge: www.livingbuildingchallenge.org

Passive House Institute US: www.phius.org/home-page

Pharos: www.pharosproject.net

U.S. Environmental Protection Agency, Green Building: www.epa.gov/greenbuilding

U.S. Green Building Council: www.usgbc.org

Worldwatch Institute: www.worldwatch.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

Canadian Standards Association (CSA): www.csa.ca

Construction Specifications Canada (CSC): www.csagroup.org

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

International Code Council: www.iccsafe.org

International Codes, Public Access: https://codes.iccsafe.org/public/collections/I-Codes

National Institute of Building Sciences (NIBS): www.nibs.org

NRC Institute for Research in Construction: www.nrc-cnrc.gc.ca/eng/rd/construction

OmniClass: www.omniclass.org

UniFormat: www.csiresources.org/practice/standards/uniformat

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

Construction Management Association of America (CMAA): cmaanet.org

Design-Build Institute of America (DBIA): www.dbia.org

Engineers Joint Contract Documents Committee: www.ejcdc.org

Trends in the Delivery of Design and Construction Services

ConsensusDocs: www.consensusdocs.org

Construction Robotics: www.construction-robotics.com

Core Studio, Thornton Tomasetti: core.thorntontomasetti.com/core-studio

ICON: www.iconbuild.com

Integrated Project Delivery: A Guide: www.aiacontracts.org/resources/64146-integrated-project-delivery-a-guide

Katerra: katerra.com

Lean Construction Institute: www.leanconstruction.org

U.S. National BIM Standard: www.nationalbimstandard.org