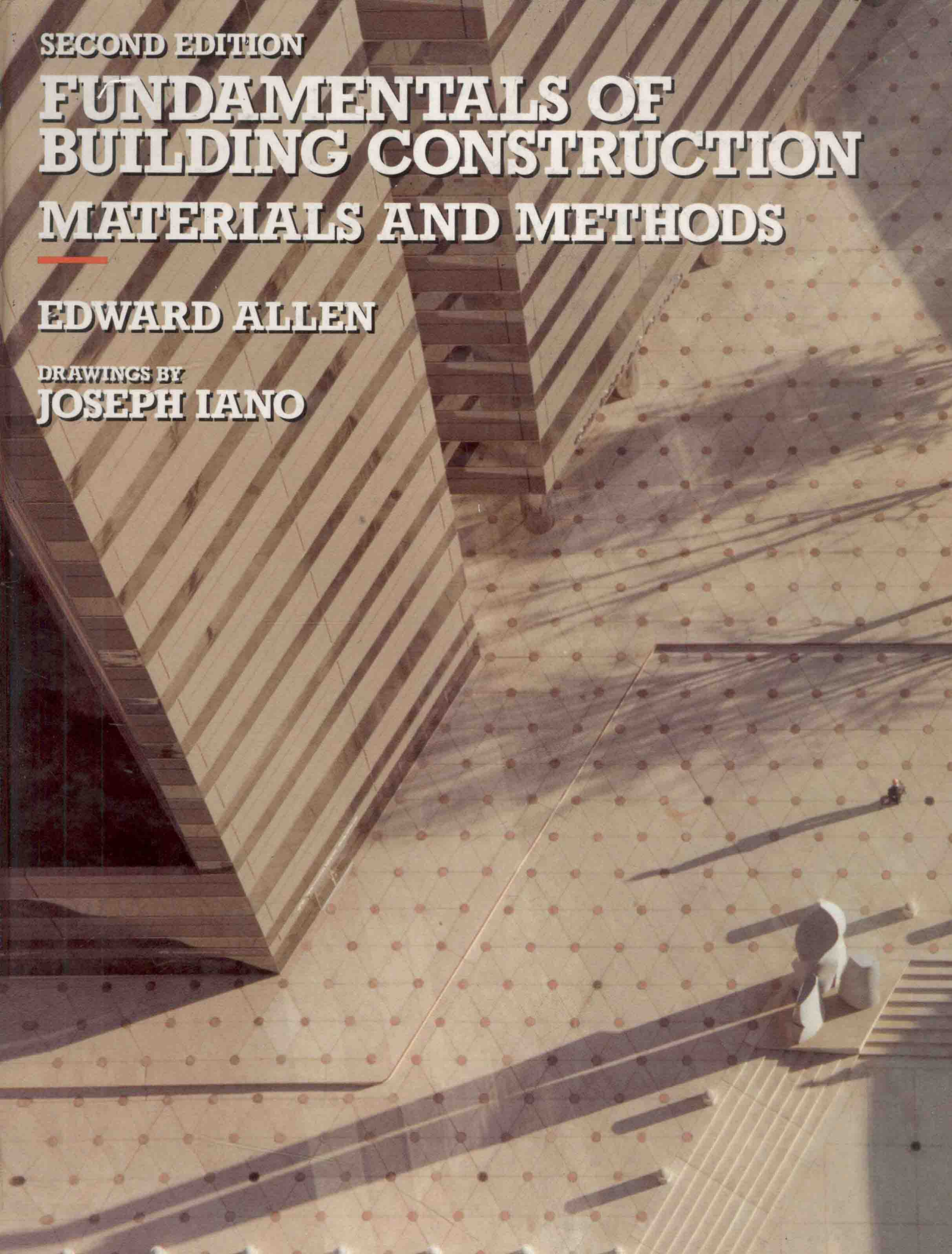


SECOND EDITION

# FUNDAMENTALS OF BUILDING CONSTRUCTION MATERIALS AND METHODS

EDWARD ALLEN

DRAWINGS BY  
JOSEPH IANO



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# PREFACE

This book is an introduction to the art of building. It begins by describing the simple but wondrously rich materials of the ancients—wood, stone, and brick—and the techniques by which they are made into buildings today, before proceeding to structural steel, reinforced and prestressed concrete, float glass, extruded aluminum, advanced gypsum products, synthetic rubber compounds, and plastics, the miraculous materials of construction developed over the past two centuries. Insofar as possible it deals with whole systems of building. The structural systems are those widely used today—heavy timber framing, wood platform framing, masonry loadbearing wall, structural steel framing, and concrete framing systems. The nonstructural systems are those that provide enclosure and interior finishes. Electrical and mechanical systems, which are treated in detail in other books, are considered here only to the extent that they interact with the fabric of a building.

The discussion of each building system begins with a brief summary of its historical development and continues with a review of how the major material is obtained and processed, an outline of the people and organizations who work with the material, a description of their tools and working methods, and a discussion of the role of the system in relation to alternative systems. The intent of this organization is to help the reader understand the evolutionary development of the system, the properties of its major materials, the possibilities and limitations of the building method, and the basis for choosing among systems.

At the end of each chapter is a

group of features designed to assist the student in reviewing, remembering, and learning to use the essential material. A listing of the key terms and concepts introduced in the chapter will be helpful in mastering the extensive technical terminology of the building field. The review questions relate to the most important ideas contained in the chapter, and the exercises encourage the application of the lessons of the chapter to real-life situations. Several carefully selected references point the way toward further reading for those who wish to delve more deeply into the topic.

The book contains three hundred drawings and nearly seven hundred photographs, a thousand illustrations in all. Each chapter includes three types of illustrations: line drawings to show in detail the major features of building assemblies, photographs of manufacturing and assembly operations to relate the drawings to everyday building practice, and photographs of finished buildings to exemplify the use of the materials and techniques described in the chapter. Key progressions of construction operations are illustrated with sequential drawings or photographs wherever possible.

At the back of the book there is a brief appendix containing tables of physical quantities that the student will find useful while studying any of the chapters: densities and thermal expansion coefficients of common construction materials, and metric and English units of conversion. This is followed by a glossary that defines the approximately nine hundred technical terms introduced in this book.

Several aids are available from the

publisher to the teacher who uses this as a textbook, including a workbook of student exercises, a set of black-and-white 35-mm slides excerpted from the illustrations in the book, and a teacher's manual that incorporates a script to accompany the slides. The teacher's manual also includes extensive suggestions on lecture topics and schedules, and further questions and exercises for use in homework problems, examinations, and the laboratory.

The student will soon recognize that full expertise in the materials and methods of construction can best be acquired through practice—in homework exercises, in the design studio, in the professional office, in the field. One must use the information in order to learn it, extend it, and shape it into a working methodology. This is all the more important because there are qualities of construction materials that cannot be conveyed adequately in graphic form: their colors, their fragrances, the sounds they make when struck or rubbed, the way they feel beneath the hand, the ways light plays off them, the ways they interact with tools, the manner in which they change with age. And there is a potential in construction methods that can be fully realized—whether aesthetically or technically—only by one who has observed firsthand, or better yet, labored beside, skilled construction artisans over many a season.

## ACKNOWLEDGMENTS

This book has many coauthors. Joseph Iano, while preparing his admirable drawings, shaped the book

in important ways through his ideas, criticism, and enthusiastic sharing of his extensive experience in construction. Clifford Boehmer, architect and craftsman, lent an expert hand with the inking of drawings and furnished valuable advice on many construction details. Carol Davidson, with efficiency, skill, and good humor, accomplished much of the heavy task of obtaining and organizing the photographs, edited the manuscript in a way that greatly enhanced its clarity and readability, and prepared the index. Mary M. Allen, as she has done so many times before, willingly and unstintingly gave every kind of support required to get the job done.

Merrill Smith, Margaret DePopolo, and Stewart Roberts gave special assistance in obtaining particular illustrations from outside sources. For the remainder of the illustrations I am indebted to several hundred representatives of the building industry in North America and Europe, the names of whose firms appear in the credit lines that accompany the figures.

A well-coordinated team of exceptionally patient, skilled, and creative professionals at John Wiley & Sons undertook the daunting task of converting a mountain of rough manuscript and pictures into a finished book. Judith R. Joseph, the acquiring editor, deftly guided the preparation of the book from earliest idea to bound volumes, with assistance from Cindy Zigmund. Ishaya Monokoff helped develop the graphic guidelines for the drawings. Elizabeth Doble ably coordinated the editorial and production functions. Tamara Lee and Richard Christopher edited the manuscript, and Lilly Kaufman and Janice Weisner managed the production process. Karin Kincheloe applied her exceptional talent to the design of the book and worked tirelessly to lay out its pages one by one. To all these people, and to those who worked still further in the background in the editing and production

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Finally I wish to thank Professor Albert G. H. Dietz, scientist, teacher, author, expert carpenter, longtime colleague, and friend, for his invaluable work in reviewing Chapters 3 through 7. It is to Al Dietz and his remarkable wife Ruth that I dedicate this volume.

E.A.

South Natick, Massachusetts  
May 1985

## ACKNOWLEDGMENTS FOR THE SECOND EDITION

The preparation of the second edition of this book began with the soliciting of comments and suggestions from all the teachers who have used the first edition in their classrooms. More than one hundred teachers responded with a flood of ideas, most of which are reflected in this new edition. Outstanding among these responses were those of Professor Jerry Bancroft of Montana State University, Professor Stephen Diamond of Wentworth Institute, Professor David Evan Glasser of the University

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E.A.

South Natick, Massachusetts  
February 1990

# DISCLAIMER

The drawings, tables, descriptions, and photographs in this book have been obtained from many sources, including trade associations, suppliers of building materials, governmental organizations, and architectural firms. They are presented in

good faith, but the author, illustrator, and publisher, while they have made every reasonable effort to make this book accurate and authoritative, do not warrant, and assume no liability for, its accuracy or completeness or its fitness for any particu-

lar purpose. It is the responsibility of users to apply their professional knowledge in the use of information contained in this book, to consult the original sources for additional information when appropriate, and to seek expert advice when appropriate.

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# **FUNDAMENTALS OF BUILDING CONSTRUCTION**





C H A P T E R   O N E

# MAKING BUILDINGS

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## Designing Buildings

### Choosing Building Systems: Constraints

Zoning Ordinances

Building Codes

Other Legal Constraints

### Choosing Building Systems: Information Resources

ASTM, CSA, and ANSI

Construction Trade and Professional Associations

Masterformat

### Choosing Building Systems: The Work of the Design Professional

Recurring Concerns

---

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

We build because little that we do can take place outdoors. We need shelter from sun, wind, rain, and snow. We need dry, level platforms for our activities. Often we need to stack these platforms to multiply available groundspace.

## DESIGNING BUILDINGS

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 of buildings, the next step for the owner of the prospective building is to engage, either directly or through a hired construction manager, the services of building design professionals. An architect helps to consolidate the owner's ideas about the new building, develops the form of the building, and assembles a group of engineering specialists to help work out concepts and details of foundations, structural support, and mechanical, electrical, and communications services. This team of designers, working with the owner, then develops the scheme for the building in progressively finer degrees of detail. Drawings and written specifications are produced by the architect-engineer design team to document how the building is to be made and of what. A general contractor is selected, either by negotiation or by competitive bidding, and it is the general contractor who hires subcontractors to carry out many specialized portions of the work. The drawings and specifications are submitted to the municipal inspector of buildings, who checks them for conformance with zoning ordinances and building codes before issuing a permit to build. Construction may then begin, with the building inspec-

tor, the architect, and the engineering consultants inspecting the work at frequent intervals to be sure it is carried out according to plan.

## CHOOSING BUILDING SYSTEMS: CONSTRAINTS

Although a building begins as an abstraction, it is built in a world of material realities. The designers of a building—the architects and engineers—work constantly from a knowledge of what is possible and what is not. They are able, on the one hand, to employ any of a limitless palette of building materials and any of a number of structural systems to produce a building of almost any desired form and texture. On the other hand, they are inescapably bound by certain physical limitations: how much land there is with which to work; how heavy a building the soil can support; how long a structural span is feasible; what sorts of materials will perform well in the given environment; and so on. They are also constrained by a construction budget and by a complex web of legal restrictions. Those who work in the building professions need a broad understanding of many things, including people, climate, the physical principles by which buildings work, the technologies available for utilization in buildings, the legal restrictions on building, and the contractual arrangements under

On these platforms, and within our shelter, 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, and water, and dispose of wastes. So we gather materials and assemble them into the constructions we call buildings in an attempt to satisfy these needs.

which buildings are built. This book is concerned primarily with the technologies of construction materials—what the materials are, how they are produced, what their properties are, and how they are crafted into buildings. But these must be studied with reference to many other factors that bear on the design of buildings, some of which require explanation here.

## Zoning Ordinances

The legal restrictions on building begin with local *zoning ordinances*, which govern such matters as what types of activities may take place on a given piece of land, how much of the land may be covered by the building or buildings, how far buildings must be set back from each of the property lines, how many parking spaces must be provided, how large a total floor area may be constructed, and how tall the building may be. In many cities, the zoning ordinances establish special center-city fire zones in which buildings must be built of noncombustible materials. Copies of the zoning ordinance for a municipality are available for purchase or reference at the office of the building inspector or the planning department, or they may be consulted at public libraries.

## Building Codes

In addition to its zoning ordinances, each local government also regulates building activity by means of a

**Table 501**  
**HEIGHT AND AREA LIMITATIONS OF BUILDINGS**  
 Height limitations of buildings (shown in upper figure as stories and feet above grade), and area limitations of one or two story buildings facing on one street or public space not less than 30 feet wide (shown in lower figure as area in square feet per floor). See Note a.

N.P. — Not permitted  
 N.L. — Not limited

Use Group  Note a	Type of construction									
	Noncombustible					Noncombustible/Combustible			Combustible	
	Type 1		Type 2			Type 3		Type 4	Type 5	
	Protected Note b		Protected		Unprotected	Protected	Unprotected	Heavy timber	Protected	Unprotected
	1A	1B	2A	2B	2C	3A	3B	4	5A	5B
A-1 Assembly, theaters	N.L.	N.L.	5 St. 65' 19,950	3 St. 40' 13,125	2 St. 30' 8,400	3 St. 40' 11,550	2 St. 30' 8,400	3 St. 40' 12,600	1 St. 20' 8,925	1 St. 20' 4,200
A-2 Assembly, night clubs and similar uses	N.L.	4 St. 50' 7,200	3 St. 40' 5,700	2 St. 30' 3,750	1 St. 20' 2,400	2 St. 30' 3,300	1 St. 20' 2,400	2 St. 30' 3,600	1 St. 20' 2,550	1 St. 20' 1,200
A-3 Assembly Lecture halls, recreation centers, terminals, restaurants other than night clubs	N.L.	N.L.	5 St. 65' 19,950	3 St. 40' 13,125	2 St. 30' 8,400	3 St. 40' 11,550	2 St. 30' 8,400	3 St. 40' 12,600	1 St. 20' 8,925	1 St. 20' 4,200
A-4 Assembly, churches	N.L.	N.L.	5 St. 65' 34,200	3 St. 40' 22,500	2 St. 30' 14,400	3 St. 40' 19,800	2 St. 30' 14,400	3 St. 40' 21,600	1 St. 20' 15,300	1 St. 20' 7,200
B Business	N.L.	N.L.	7 St. 85' 34,200	5 St. 65' 22,500	3 St. 40' 14,400	4 St. 50' 19,800	3 St. 40' 14,400	5 St. 65' 21,600	3 St. 40' 15,300	2 St. 30' 7,200
E Educational	N.L.	N.L.	5 St. 65' 34,200	3 St. 40' 22,500	2 St. 30' 14,400	3 St. 40' 19,800	2 St. 30' 14,400	3 St. 40' 21,600	1 St. 20' 15,300	1 St. 20' 7,200
F Factory and industrial	N.L.	N.L.	6 St. 75' 22,800	4 St. 50' 15,000	2 St. 30' 9,600	3 St. 40' 13,200	2 St. 30' 9,600	4 St. 50' 14,400	2 St. 30' 10,200	1 St. 20' 4,800
H High hazard	5 St. 65' 16,800	3 St. 40' 14,400	3 St. 40' 11,400	2 St. 30' 7,500	1 St. 20' 4,800	2 St. 30' 6,600	1 St. 20' 4,800	2 St. 30' 7,200	1 St. 20' 5,100	N.P.
I-1 Institutional, residential care	N.L.	N.L.	9 St. 100' 19,950	4 St. 50' 13,125	3 St. 40' 8,400	4 St. 50' 11,550	3 St. 40' 8,400	4 St. 50' 12,600	3 St. 40' 8,925	2 St. 35' 4,200
I-2 Institutional, incapacitated	N.L.	8 St. 90' 21,600	4 St. 50' 17,100	2 St. 30' 11,250	1 St. 20' 7,200	1 St. 20' 9,900	N.P.	1 St. 20' 10,800	1 St. 20' 7,650	N.P.
I-3 Institutional, restrained	N.L.	6 St. 75' 18,000	4 St. 50' 14,250	2 St. 30' 9,375	1 St. 20' 6,000	2 St. 30' 8,250	1 St. 20' 6,000	2 St. 30' 9,000	1 St. 20' 6,375	N.P.
M Mercantile	N.L.	N.L.	6 St. 75' 22,800	4 St. 50' 15,000	2 St. 30' 9,600	3 St. 40' 13,200	2 St. 30' 9,600	4 St. 50' 14,400	2 St. 30' 10,200	1 St. 20' 4,800
R-1 Residential, hotels	N.L.	N.L.	9 St. 100' 22,800	4 St. 50' 15,000	3 St. 40' 9,600	4 St. 50' 13,200	3 St. 40' 9,600	4 St. 50' 14,400	3 St. 40' 10,200	2 St. 35' 4,800
R-2 Residential, multi-family	N.L.	N.L.	9 St. 100' 22,800	4 St. 50' 15,000 Note i	3 St. 40' 9,600	4 St. 50' 13,200 Note i	3 St. 40' 9,600	4 St. 50' 14,400	3 St. 40' 10,200	2 St. 35' 4,800
R-3 Residential, one and two family	N.L.	N.L.	4 St. 50' 22,800	4 St. 50' 15,000	3 St. 40' 9,600	4 St. 50' 13,200	3 St. 40' 9,600	4 St. 50' 14,400	3 St. 40' 10,200	2 St. 35' 4,800
S-1 Storage, moderate	N.L.	N.L.	5 St. 65' 19,950	4 St. 50' 13,125	2 St. 30' 8,400	3 St. 40' 11,550	2 St. 30' 8,400	4 St. 50' 12,600	2 St. 30' 8,925	1 St. 20' 4,200
S-2 Storage, low	N.L.	N.L.	7 St. 85' 34,200	5 St. 65' 22,500	3 St. 40' 14,400	4 St. 50' 19,800	3 St. 40' 14,400	5 St. 65' 21,600	3 St. 40' 15,300	2 St. 30' 7,200
U Utility, miscellaneous	N.L.	N.L.								

**Note a.** See the following sections for general exceptions to Table 501:

Section 501.4 Allowable area reduction for multi-story buildings.

Section 502.2 Allowable area increase due to street frontage.

Section 502.3 Allowable area increase due to automatic fire suppression system installation.

Section 503.1 Allowable height increase due to automatic fire suppression system installation.

Section 504.0 Unlimited area one-story buildings.

**Note b.** Buildings of Type 1 construction permitted to be of unlimited tabular heights and areas are not subject to special requirements that allow increased heights and areas for other types of construction (see Section 501.5).

**Note c.** For tabular area increase in buildings of Use Group E, see Section 502.4.

**Note d.** For height exceptions for auditoriums in buildings of Use Groups A-4 and E, see Section 503.2.

**Note e.** For exceptions to height and area limitations for buildings of Use Group H, see Article 6 governing the specific use. For other special fire-resistive requirements governing specific uses, see Section 905.0.

**Note f.** For exceptions to height of buildings for Use Group R-2 of Types 2B and 3A construction, see Section 905.2.

**Note g.** For height and area exceptions for open parking structures, see Section 607.0.

**Note h.** For exceptions to height and area limitations for special industrial uses, see Section 501.1.1.

**Note i.** 1 foot = 304.8 mm; 1 square foot = 0.093 m<sup>2</sup>.

**FIGURE 1.1**

*Height and area limitations of buildings of various types of construction, as defined in the BOCA National Building Code/1987.*



**Table 501.4**  
**PERCENT REDUCTION OF AREA LIMITS**

No. of stories	Type of construction		
	1A & 1B	2A	2B, 2C, 3A, 3B, 4, 5A, 5B
1	None	None	None
2	None	None	None
3	None	5%	20%
4	None	10%	20%
5	None	15%	30%
6	None	20%	40%
7	None	25%	50%
8	None	30%	60%
9	None	35%	70%
10	None	40%	80%

**FIGURE 1.2**

*For a building more than two stories in height, the area permitted by the BOCA Code for each story of the building must be reduced in accordance with this table.*

*building code.* The intent of a building code is to protect public health and safety by setting a minimum standard of construction quality. Most building codes in the United States are based on one of three *model building codes*. These are standardized codes prepared by national organizations of local building code officials. In the western United States and parts of the Midwest, most codes are modeled after the *Uniform Building Code*. In the East and other areas of the Midwest, the *BOCA National Building Code* is the model in most states. The *Standard Building Code* has been adopted by many southern and southeastern states. Canada publishes its own model code, the *National Building Code of Canada*. While these four codes differ in detail, they are similar in their approach. Each begins by defining *use groups* for buildings: buildings of assembly, business, industry, high-hazard industry (such as plants working with highly flammable or explosive substances), institutional buildings, mercantile buildings, residential buildings, and simple buildings used only for storage or agricultural purposes.

These definitions are followed by a set of definitions of *construction types*. At the head of this list are highly fire-resistive types of construction such as reinforced concrete and fire-protected steel. At the foot of it are types of construction that are relatively combustible because they are framed with small wood members. In between are a range of construction types with varying levels of resistance to fire.

With use groups and construction types carefully defined, the code proceeds to match the two, setting forth in a table which use groups may be housed in which types of construction, and under what limitations. Figure 1.1 is reproduced from the model code prepared by the Building Officials and Code Administrators International, Incorporated (BOCA). This table concentrates a great deal of useful information into a very small space. A designer may enter it with a particular use group in mind—an electronics plant, for example—and find out very quickly what types of construction will be permitted and what shape the plant may take. An electronics plant obviously fits under Use Group F, Fac-

tory and Industrial. Reading across the chart, one finds immediately that this factory may be built to any desired size, without limit, using Type 1 construction.

Type 1 construction is defined in a nearby table in the BOCA Code, reproduced here as Figure 1.3. Looking down this table under Type 1 construction, one finds a rather detailed listing of the required *fire resistance ratings*, measured in hours, of the various parts of either a Type 1A or a Type 1B building. In a Type 1A building, for example, one finds on line 11 that floor beams must be rated at 3 hours, and on line 9 that lower-story columns must be rated at 4 hours. For the required fire resistances of exterior walls (line 1) one is referred to another section of the BOCA Code, not reproduced in this book. Lines 2 and 3 refer to a Table 902 for fire walls and party walls, which is reproduced as Figure 16.6 of this book.

Fire resistance ratings of actual construction components are not found in the BOCA Code (although the Standard Building Code and Uniform Building Code do contain partial listings). Instead, they are tabu-



lated in a variety of 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 full-scale laboratory fire tests of building components carried out in accordance with Standard E-119 of the American Society for Testing and Materials, to assure uniformity of results. (This fire test is described more fully in Chapter 16 of this book.) Figures 1.4 through 1.6 reproduce small sections of tables from catalogs and handbooks to illustrate how this type of information is presented.

It is not possible in this book to reproduce a comprehensive listing of fire resistance ratings for every type of building component, but what can be said in a very general way (and with many exceptions) is that the higher the degree of fire resistance, the higher the cost. In general, therefore, buildings are built with the least level of fire resistance that is permitted by the applicable building code. The hypothetical electronics plant could be built using Type 1 construction, but does it really need to be built to this standard?

Let us suppose that the owners want the electronics plant to be a two-story building with 10,000 square feet on each floor. The table in Figure 1.1 makes it clear that it cannot be built of unprotected metal (Type 2C), unprotected joisted construction (Type 3B), or unprotected wood frame (Type 5B), because none of these types will allow construction of floors as large as 10,000 square feet. But it can be built of steel with a relatively small amount of applied fire protective material (Type 2B), of protected wood joists with exterior walls either of masonry or of wood (Type 3A), or of Heavy Timber construction (Type 4). (The names associated with the various construction types are defined in later chapters of this book.)

Often the situation is more compli-

cated than this. Figure 1.1 applies only to one- and two-story buildings; for taller buildings, the BOCA Code applies the reduction factors shown in Figure 1.2 (each of the model building codes does this slightly differently). The presence or absence of an automatic sprinkler system for suppression of fires also affects the choice of a construction system under all the building codes. Under the BOCA Code, for example, a fully sprinklered building belonging to a nonhazardous use group is allowed to have floor areas three times those shown in Figure 1.1 if it is one or two stories tall, and twice the tabulated areas if it is more than two stories tall. In addition, BOCA allows the building to be a story taller than the height limitation indicated in Figure 1.1 if it is fully sprinklered. Further increases are granted by all the model codes for buildings that front on streets or open spaces on more than one side. Additionally, if a building is divided by fire walls having the fire resistance ratings specified in Table 902 (Figure 16.6 of this book), each portion of the building that is separated from the remainder of the building by fire walls may be considered as a separate building for purposes of computing its allowable area, which effectively permits the architect to create a building many times larger than Figure 1.1 would indicate.

A building code goes far beyond what is illustrated here. A typical code also establishes standards for natural light, ventilation, means of emergency egress, structural design, floor, wall, ceiling, and roof con-

struction, chimney construction, and energy efficiency.

The building code is not the only code with which a new building must comply. There are also health codes, fire codes, plumbing codes, and electrical codes in force in most communities. Some of these are locally written, but most are model national codes that have been adopted locally.

## Other Legal Constraints

Other types of legal restrictions must also be observed in the design and construction of buildings. *Access standards* regulate the design of entrances, stairs, doorways, elevators, and toilet facilities to assure that they are usable by physically handicapped members of the population. The U.S. *Occupational Safety and Health Act (OSHA)* controls the design of workplaces to minimize threats to the health and safety of workers. OSHA sets safety standards under which a building may be constructed and also has an important effect on the design of industrial and commercial buildings. Many states have established standards of *energy efficiency* for 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 through their rate structures for building insurance coverage, which offer strong financial incentives for more fire-resistant construction. Building contractors and construction labor unions also have standards, both formal and informal, that affect the ways in which buildings are built. Unions have work rules and safety rules that must be observed; contractors have particular types of equipment, certain kinds of skills, and customary ways of going about things. All of these vary significantly from one place to another.

... 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