ARE 5.0

# Project Development & Documentation

Study Guide



Brightwood
ARCHITECTURE EDUCATION

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PROJECT DEVELOPMENT & DOCUMENTATION 5.0



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# CONTENTS

# INTRODUCTION

## WELCOME

Thank you for choosing Brightwood Architecture Education for your ARE study needs. We wish you the best of luck in your pursuit of licensure.

## ARE OVERVIEW

Since the State of Illinois first pioneered the practice of licensing architects in 1897, architectural licensing has been increasingly adopted as a means to protect the public health, safety, and welfare. Today, the United States and Canadian provinces require licensing for individuals practicing architecture. Licensing requirements vary by jurisdiction; however, the minimum requirements are uniform and in all cases include passing the Architect Registration Exam (ARE). This makes the ARE a required rite of passage for all those entering the profession, and you should be congratulated on undertaking this challenging endeavor.

Developed by the National Council of Architectural Registration Boards (NCARB), the ARE is the only exam by which architecture candidates can become registered in the United States or Canada. The ARE assesses candidates' knowledge, skills, and abilities in six different areas of professional practice, including a candidate's competency in decision making and knowledge of various areas of the profession. The exam also tests competence in fulfilling an architect's responsibilities and in coordinating the activities of others while working with a team of design and construction specialists. In all jurisdictions, candidates must pass the six divisions of the exam to become registered.

The ARE is designed and prepared by architects, making it a practice-based exam. It is generally not a test of academic knowledge, but rather a means to test decision-making ability as it relates to the responsibilities of the architectural profession. For example, the exam does not expect candidates to memorize specific details of the building code, but it requires them to understand a model code's general requirements, scope, and purpose and to know the architect's responsibilities related to that code. As such, there is no substitute for a well-rounded internship to help prepare for the ARE.

### Exam Format

The six ARE 5.0 divisions are outlined in the table below.

**ARE 5.0 DIVISIONS**

| Division | Items |
|---|---|
| Practice Management | 80 |
| Project Management | 95 |
| Programming & Analysis | 95 |
| Project Planning & Design | 120 |
| Project Development & Documentation | 120 |
| Construction & Evaluation | 95 |

The exam presents multiple-choice questions, new hotspots, and drag-and-place, as well as incorporating case studies. Candidates may answer questions, skip questions, or mark questions for further review. Candidates may also move backward or forward within the exam using simple on-screen icons.

Appointment times for taking the exam are slightly longer than the actual exam time, allowing candidates to check in and out of the testing center. All ARE candidates are encouraged to review NCARB's *ARE 5.0 Guidelines* for further detail about the exam format. These guidelines are available via free download at NCARB's website (www.ncarb.org).

## EXAM PREPARATION

### Overview

There is little argument that preparation is key to passing the ARE. With this in mind, Brightwood has developed a learning system for each exam division, including study guides, QBanks, and flashcards. The study guides offer a condensed course of study and will best prepare you for the exam when utilized along with the other tools in the learning system. The system is designed to provide you with the general background needed to pass the exam and to provide an indication of specific content areas that demand additional attention.

In addition to the Brightwood learning system, materials from industry-standard documents may prove useful for the various divisions.

### Preparation Basics

The first step in preparation should be a review of the exam specifications and reference materials published by NCARB. The ARE 5.0 Handbook is available for download at www.ncarb.org.

Though no two people will have exactly the same ARE experience, the following are recommended best practices to adopt in your studies and should serve as a guide.

*Set aside scheduled study time.*

Establish a routine and adopt study strategies that reflect your strengths and mirror your approach in other successful academic pursuits. Most importantly, set aside a definite amount of study time each week, just as if you were taking a lecture course, and carefully read all of the material.

*Take—and retake—quizzes.*

After studying each lesson in the study guide, take the quiz found at its conclusion. The quiz questions are intended to be straightforward and objective. Answers and explanations can be found at the back of the book. If you answer a question incorrectly, see if you can determine why the correct answer is correct before reading the explanation. Retake the quiz until you answer every question correctly and understand why the correct answers are correct.

*Identify areas for improvement.*

The quizzes allow you the opportunity to pinpoint areas where you need improvement. Reread and take note of the sections that cover these areas and seek additional information from other sources. Use the question-and-answer handbook and online test bank as a final tune-up for the exam.

*Take the final exam.*

A final exam designed to simulate the ARE follows the last lesson of each study guide. Answers and explanations can be found on the pages following the exam. As with the lesson quizzes, retake the final exam until you answer every question correctly and understand why the correct answers are correct.

*Use the flashcards.*

If you've purchased the flashcards, go through them once and set aside any terms you know at first glance. Carry the rest with you throughout the day, reviewing them on the train, over lunch, or before bed. Remove cards as you become familiar with their terms until you know all the terms. Review all the cards a final time before taking the exam.

## Supplementary Study Materials

In addition to the Brightwood learning system, materials from industry-standard sources may prove useful in your studies. Candidates should consult the list of exam references in the NCARB guidelines for the council's recommendations and pay particular attention to the following publications, which are essential to successfully completing this exam:

International Code Council (ICC)
*International Building Code*

National Fire Protection Association
*Life Safety Code (NFPA 101)*

## Test-Taking Advice

Preparation for the exam should include a review of successful test-taking procedures—especially for those who have been out of the classroom for some time. Following is advice to aid in your success.

*Pace yourself.*

Each division allows candidates at least one minute per question. You should be able to comfortably read and reread each question and fully understand what is being asked before answering. Each vignette allows candidates ample time to complete a solution within the time allotted.

*Read carefully.*

Begin each question by reading it carefully and fully reviewing the choices, eliminating those that are obviously incorrect. Interpret language literally, and keep an eye out for negatively worded questions.

*Guess.*

All unanswered questions are considered incorrect, so answer every question. If you are unsure of the correct answer, select your best guess or mark the question for later review. If you continue to be unsure of the answer after returning the question a second time, it is usually best to stick with your first guess.

*Review difficult questions.*

The exam allows candidates to review and change answers within the time limit. Use this feature to mark troubling questions for review upon completing the rest of the exam.

*Choose the best answer.*

Many candidates fall victim to questions seeking the "best" answer. In these cases, it may appear at first glance as though several choices are correct. Remember the importance of reviewing the question carefully and interpreting the language literally. Consider the following example.

**1.** Which of these cities is located on the east coast of the United States?

**A.** Boston

**B.** Philadelphia

**C.** Washington, D.C.

**D.** Atlanta

At first glance, it may appear that all of the cities could be correct answers. However, if you interpret the question literally, you'll identify the critical phrase as "on the east coast." Although each of the cities listed is arguably an "eastern" city, only Boston sits on the Atlantic coast. All the other choices are located in the eastern part of the country but are not coastal cities.

## ABOUT BRIGHTWOOD

Thank you for choosing Brightwood Architecture Education as your source for ARE preparation materials. Brightwood brings its experience and history to the world of architectural education, pairing unparalleled resources with acknowledged experts in ARE content areas to bring you the very best in licensure study materials.

Only Brightwood Architecture offers a complete catalog of individual products and integrated learning systems to help you pass all six divisions of the ARE. Brightwood's ARE materials include study guides, QBanks, and flashcards. Products may be purchased individually or in division-specific learning systems to suit your needs. These systems are designed to help you better focus on essential information for each division, provide flexibility in how you study, and save you money.

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LESSON ONE

1

# INTEGRATION OF STRUCTURAL SYSTEMS



## INTRODUCTION

The Project Development & Documentation division explores how architectural design integrates materials and building systems into a coordinated solution that meets the project design requirements

This lesson examines how various structural systems and materials have influenced overall building design. It presents a quick review of notable buildings with innovative structural solutions, and then brief biographical sketches of several well-known engineers. Finally, it concludes with a discussion regarding recent high-tech architecture resulting from the collaboration of architects and structural engineers, and a short summary of structural failures.

## NOTABLE BUILDINGS

### Pantheon

This great concrete structure, the largest dome of the ancient world, was built by the Romans in the year 123 AD and still stands today (Figure 1.1). Its architects intuitively understood the nature of the stresses in a concrete dome: the lower part tends to crack because of circumferential tensile stresses. Since they had no materials that were strong in tension, their solution was to make the dome walls about 20 feet thick at the bottom in order to keep the unit tensile stresses low enough to be resisted by the concrete. To reduce the weight of the dome, its underside was coffered. The Pantheon remains to this day the most extraordinary example of Roman architecture and engineering.

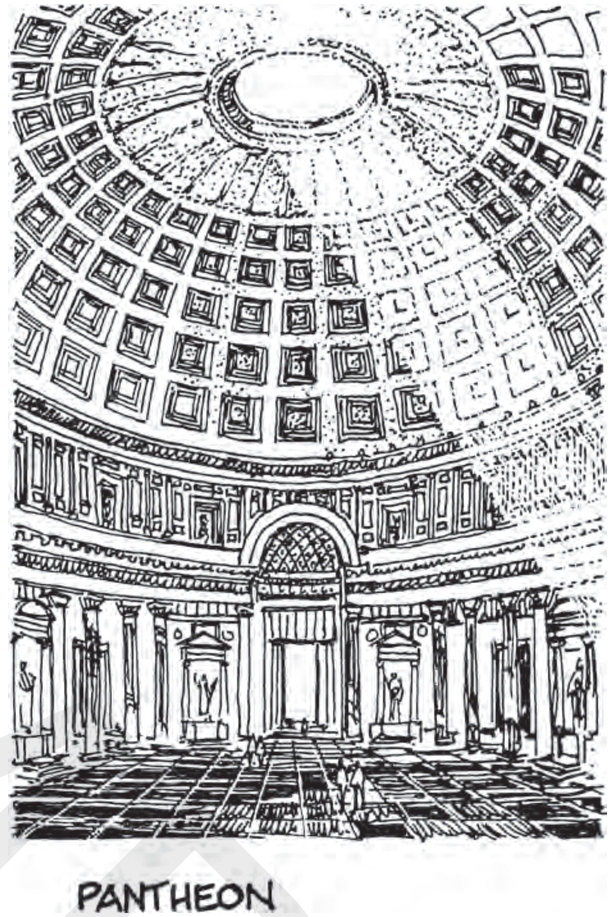


**Figure 1.1**

### Hagia Sophia

Hagia Sophia in Constantinople (now Istanbul), completed in 537 AD, is very interesting because of its architectural, engineering, historical, and religious significance (Figure 1.2). Its architects, Anthemius and Isidorus, created a magnificent edifice dedicated to the glory of both church and state. Its main dome was shallow and supported by four pillars, through pendentives and arches that rose from the pillars. The arches resisted both vertical forces and outward thrusts from the dome; unfortunately, however, the arches did not provide sufficient buttressing, and a portion of the dome collapsed in 558 A.D., while repairs were being made following an earthquake. The spherical dome was dismantled and rebuilt with a 20 foot greater rise, thus reducing the outward thrust. Through the years, more damage and reconstruction occurred,

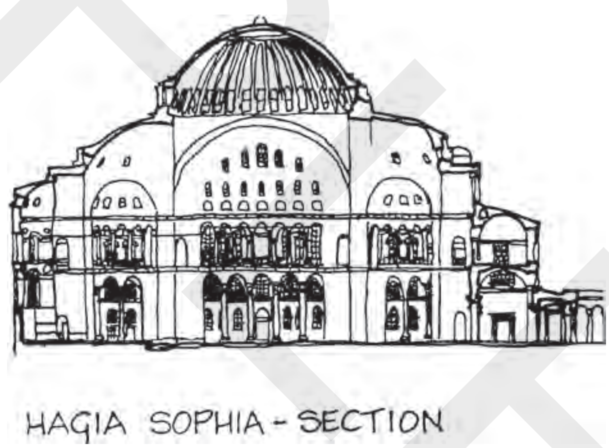


**Figure 1.2**

largely as a result of earthquakes, until in 1847, an iron tie was placed around the base of the dome. The outward thrust of the dome was now resisted by tension in the iron tie rather than by other elements of the structure. No further damage occurred, and the building still survives today, after 14 centuries.

## Dome of the Florence Cathedral

The dome of Santa Maria del Fiore in Florence, designed by the great Renaissance architect Filippo Brunelleschi and completed in 1436, is a masterpiece of aesthetic and structural design (Figure 1.3). There are actually two masonry domes: a thick inner shell and a thinner outer shell. Brunelleschi understood that a dome tends to spread apart and built in a series of circumferential iron chains to act as tension rings and hold the dome in equilibrium. His design permitted the dome to be constructed without the use of any temporary shoring, a feat unparalleled in its time.

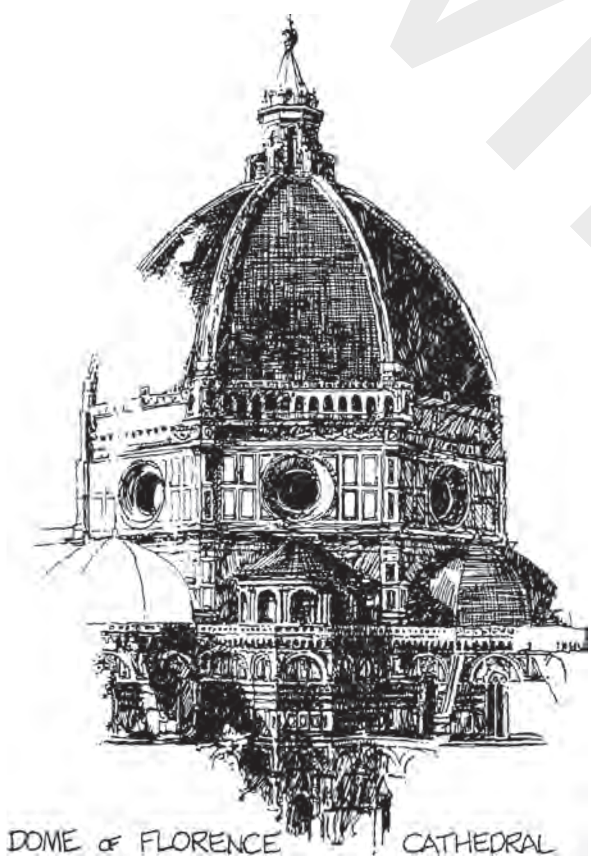


**Figure 1.3**

## Crystal Palace

The Great Exhibition of 1851, in London, was the largest display of man's progress ever assembled up to that time. It was housed in an immense prefabricated glass and cast iron structure, known as the Crystal Palace, that was without precedent (Figure 1.4). Designed by Joseph Paxton, it was more than a third of a mile long, enclosed nearly a million square feet, and was fabricated and erected in only six months. With its lightness and transparency, it influenced subsequent iron and glass buildings, and even today's steel and glass skyscrapers.


**Figure 1.4**

## Fallingwater

The Kaufmann House, completed in 1936 in Bear Run, Pennsylvania is popularly known as "Fallingwater" (Figure 1.5). It has become one of the best-known houses in the country and is widely considered one of the great houses of all time. Frank Lloyd Wright designed the striking three-story masonry structure, featuring six reinforced concrete terraces which cantilever over a natural waterfall and pool. Interior spaces open through large glass areas to the terraces, which offer breathtaking views of the waters below. Viewed from the exterior, Fallingwater seems to grow out of the natural site rather than being an addition to it.


**Figure 1.5**

## Nervi's Airplane Hangars

The great Italian engineer Pier Luigi Nervi designed buildings that achieved beauty through the bold and imaginative expression of structure. His airplane hangars built for the Italian Air Force between 1936 and 1939 had lamella roofs formed by short prefabricated reinforced concrete members connected at their joints (Figure 1.6). Towards the end of World War II, the retreating German army blew up the buttresses supporting the hangar roofs to prevent the hangars from falling into Allied hands. The roofs fell 40 feet to earth, yet remained almost entirely intact, a tribute to the excellence of their design and construction.

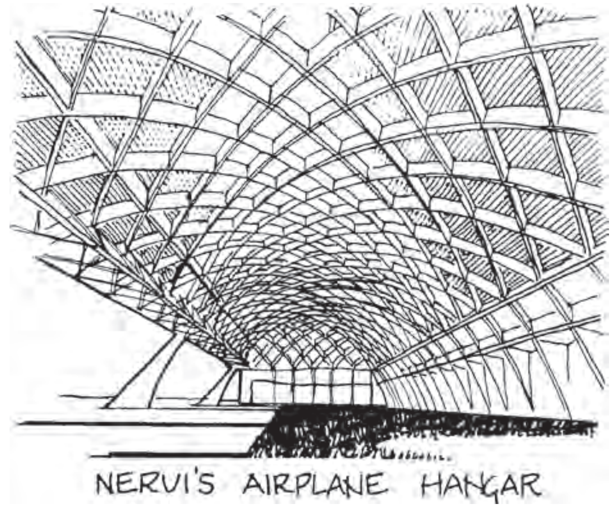


**Figure 1.6**

## Johnson Wax Building

In 1939, one of Frank Lloyd Wright's most famous structures, the Johnson Wax Building in Racine, Wisconsin was completed. The rounded exterior walls consist of horizontal bands of brick punctuated by strips of glass tubing. Perhaps the most interesting element of this building is a great work space with slender mushroom-shaped concrete columns that flare out at the top to support the roof (Figure 1.7). The structural columns, ceiling, and lighting form an integrated design and provide a space with virtually no sense of enclosure. The nearby multistoried laboratory tower, whose floors cantilever from a single central support, was built in 1950.

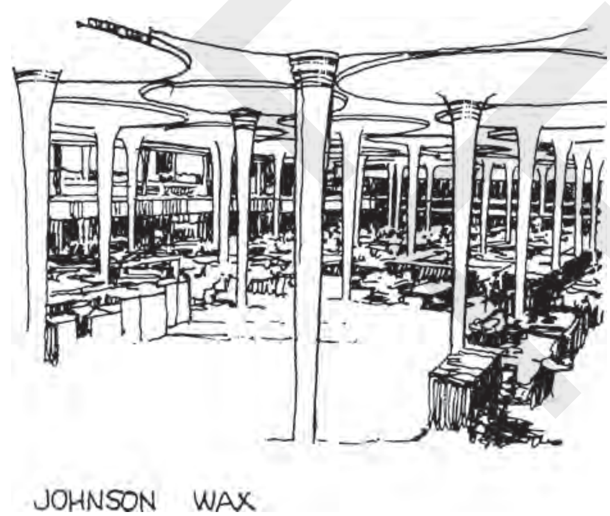


**Figure 1.7**

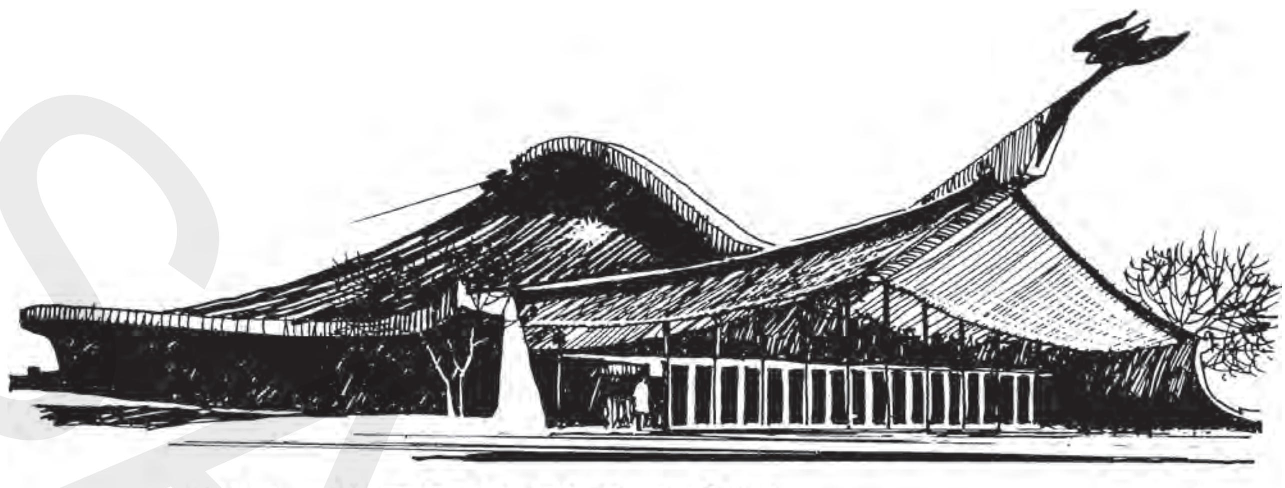


**Figure 1.8**

## Yale University Skating Rink

In recent years, a number of buildings have been constructed in which steel cables in tension are the essential structural element. In the Yale University Skating Rink, designed by Eero Saarinen and completed in 1958, steel cables are hung from a central reinforced concrete arch (Figure 1.8). The outer ends of the cables are anchored to heavy curved perimeter walls. The roof is wood, the weight of which partially stabilizes the cables. In this building, the merger of architecture and engineering creates a unified and dramatic expression.

## Palazzetto Dello Sport

In certain types of buildings, such as arenas, exhibition halls, and airplane hangars, the structure often determines the shape and character of the building. An outstanding example is the Palazzetto Dello Sport (Little Sports Palace) designed by Pier Luigi Nervi for the 1960 Rome Olympics. Its roof, a ribbed concrete shell dome, is supported by 36 Y-shaped concrete buttresses which resist the forces at the edge of the shell (Figure 1.9). In this building, the clearly expressed structure creates a pattern of unusual elegance and refinement.


**Figure 1.9**


Figure 1.10

## Dulles International Airport

In the terminal of Dulles Airport in suburban Washington, D.C., completed in 1962, Eero Saarinen was able to depart from the conventional finger plan airport terminal by using a mobile lounge, which separated the terminal from the airplanes. He was thus able to express the character of the terminal by a single compact building. The concrete roof is supported by steel cables that are suspended between huge concrete columns that lean outward to balance the inward pull of the cables (Figure 1.10). The result is a successful marriage of architecture and structure.

## CBS Building

Most very tall buildings are framed with structural steel, but a number of interesting reinforced concrete skyscrapers have also been built. An outstanding example is the CBS Building in New York, completed in 1964, which was designed by Eero Saarinen and engineered by Paul Weidlinger. This 42-story structure resists lateral forces by both an inner core and perimeter walls, which consist of concrete piers five feet long spaced five feet apart. The building's verticality is emphasized by the granite-clad triangular piers, which extend uninterrupted from below street level to the very top of the building (Figure 1.11).

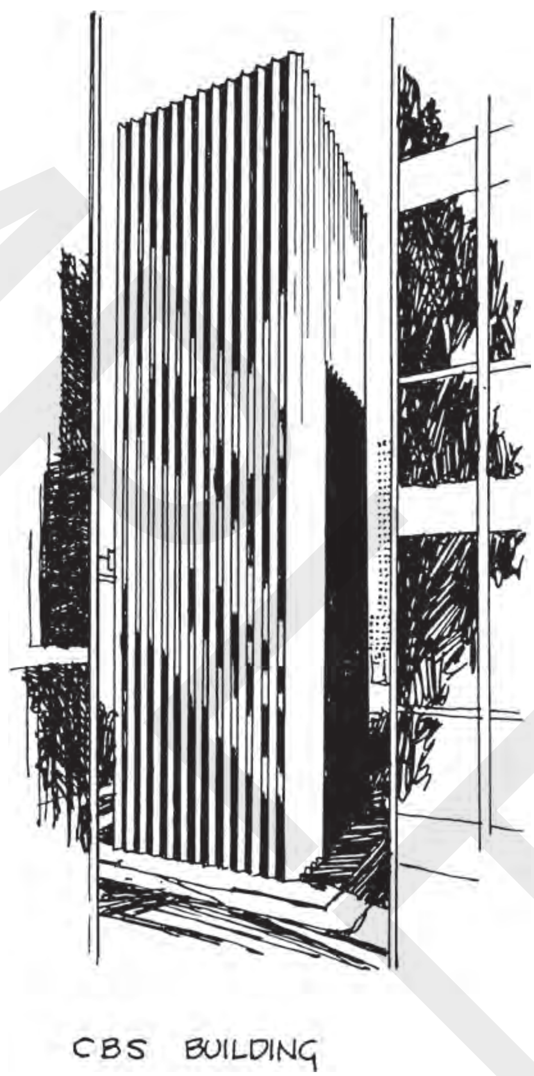


Figure 1.11

## Toronto City Hall

In 1958, the Finnish architect Viljo Revell won the competition for the Toronto City Hall, completed in 1965. The design is unique among high-rise public buildings: two curved office slabs surrounding a low circular city council chamber (Figure 1.12). Although the curved shape may seem arbitrary, it is efficient structurally; each office tower is a huge curved shell that provides strength and rigidity against the overturning forces caused by wind or earthquake.


**Figure 1.12**

## Houston Astrodome

Domes are not only the most dramatic and spectacular roof structures, they are also remarkably efficient. During the past 25 years, a number of enormous domed roofs have been built, enclosing stadiums seating up to 80,000 spectators. The first such structure, and still one of the most spectacular, is the Houston Astrodome. When it was completed in 1965, it was the largest enclosed stadium ever constructed, roofed by the largest dome ever built. Covering 9-1/2 acres, the steel lattice dome is 710 feet in diameter and rises 208 feet over the playing field (Figure 1.13). It weighs less than 30 pounds per square foot, one 20th of the weight of Brunelleschi's inner dome in Florence.

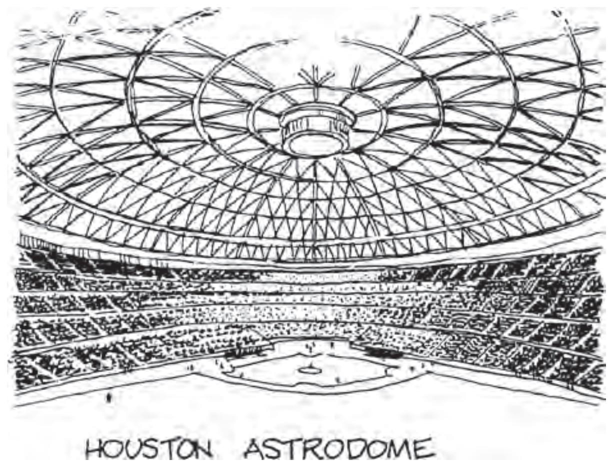


**Figure 1.13**

## First National Bank, Chicago

High rise buildings utilize a variety of structural systems to resist lateral forces from wind or earthquake, principally rigid frames, shear walls, braced frames, and tubular systems. A special type of rigid frame sometimes used in buildings over 50 stories is called a "superframe" or "mega-frame." This consists of a very deep, stiff horizontal truss or girder wherever a mechanical floor occurs, about 15 to 20 stories apart, connected at each end to a large exterior column. The interior columns and horizontal girders at the other levels form a secondary rigid frame. This type of system was used in the 60-story First National Bank Building in Chicago, which was designed by Perkins and Will with C.F. Murphy Associates and completed in 1966. This building has a slender profile that tapers gracefully to a wider base to resist wind overturning forces more effectively (Figure 1.14).

## John Hancock Building, Chicago

The familiar John Hancock Building, now a prominent part of the Chicago skyline, expresses its structure through its tapered form and enormous exposed exterior X-bracing (Figure 1.15).


**Figure 1.14**

Designed by Skidmore, Owings, and Merrill and completed in 1968, "Big John" is a gigantic trussed tube, which is very efficient in resisting wind forces. The overall dimension of the building is utilized to resist overturning forces, while the truss members resist shear by direct stress rather than by bending. For a time, this 100-story multi-use structure was the tallest building in Chicago, a distinction it has since relinquished to Willis Tower.

## Knights of Columbus Building

The 26-story Knights of Columbus Building in New Haven, Connecticut designed by Kevin Roche and John Dinkeloo and completed in 1969, makes a clear and powerful statement. Its four corner towers, constructed of concrete with dark brick veneer, support the main 80-foot long horizontal steel girders, which in turn support the steel floor structure

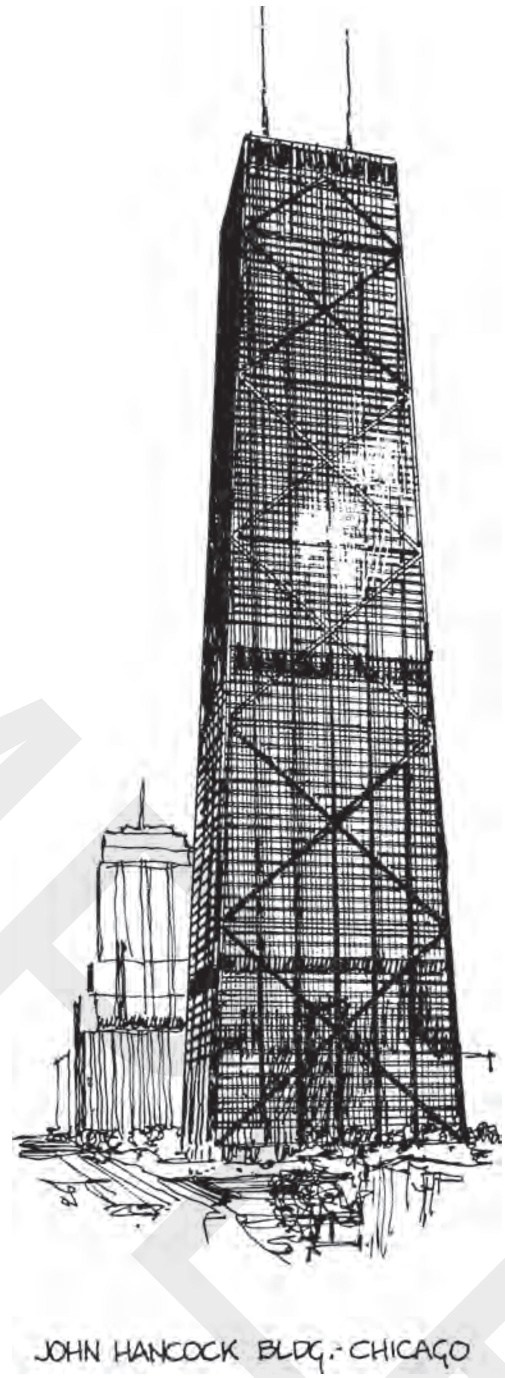


**Figure 1.15**

(Figure 1.16). The towers also resist horizontal wind or earthquake forces by acting as huge tubes that cantilever from the foundation. Within the towers are service elements such as stairs, toilets, and mechanical shafts, and the six elevators are contained in a core at the building's center.


**Figure 1.16**

## U.S. Pavilion at Expo '70

World's fairs and Olympic games have often been the background for exotic, state-of-the-art structures. The U.S. Pavilion at Expo '70 in Osaka, Japan, had an incredible 100,000 square foot inflatable roof made of a special vinyl membrane, with stiffening steel cables anchored to a concrete compression ring around the perimeter (Figure 1.17). The roof was designed to resist wind forces as well as the air pressure inside the pavilion. This building was a pioneering effort by engineer David Geiger in the field of pneumatic structures.

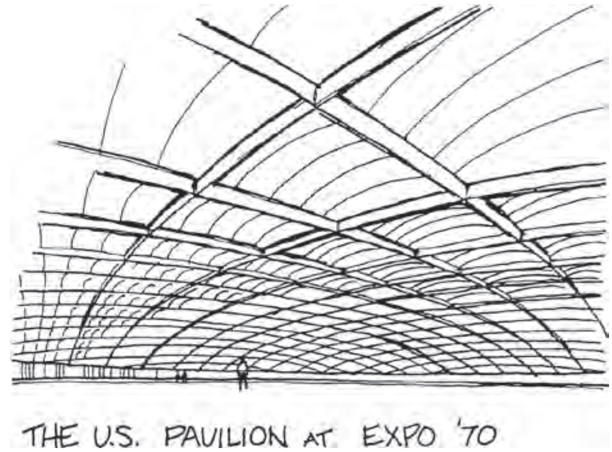


**Figure 1.17**

## Munich Olympic Stadium

The Munich Olympics of 1972 featured three new major arenas, the largest of which was the Olympic Stadium. Its roof design, by Frei Otto, was strikingly original—an immense high-tech tent. A series of steel cable nets was stretched between steel masts that were anchored to the ground by steel cables (Figure 1.18). The net surfaces, covered with plexiglass, were shapes of double curvature for stability. The design was bold, certainly controversial, and a giant step forward for tensile structures.

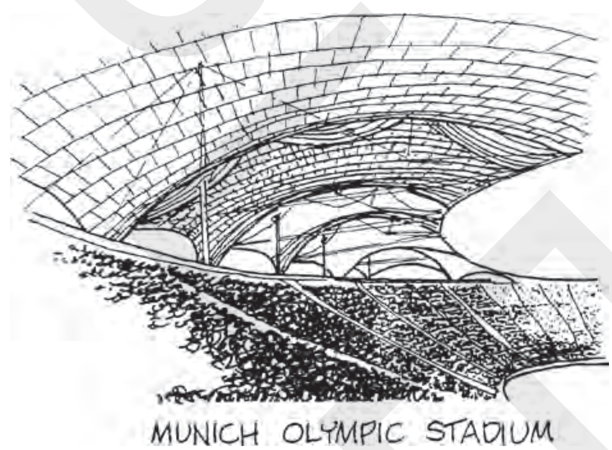


**Figure 1.18**


**Figure 1.19**

## Federal Reserve Bank Building, Minneapolis

The suspension bridge concept was used by Gunnar Birkerts in his design for the Federal Reserve Bank Building in Minneapolis, completed in 1972. In this 10-story office building, two sets of steel cables, draped in the shape of a catenary, support the building's vertical load and are anchored to a pair of concrete towers 275 feet apart (Figure 1.19). The façade expressed the structure dramatically by using glass on the inside face of the mullions above the catenary and on the outside face below.

## World Trade Center

The twin towers of the World Trade Center in New York, completed in 1972, were striking in scale, yet elegantly simple in design (Figure 1.20). Its statistics were staggering: 1,350 feet high, 110 stories, 9 million square feet, a working population of 50,000. As with all skyscrapers, two major obstacles that had to be overcome were the elevator system and the structural system to resist wind or earthquake forces. In this case, architect Minoru Yamasaki and his consulting engineers solved both problems imaginatively. The elevator system utilized a combination of express and local elevators, thus greatly increasing the area available for offices. The structural system comprised exterior columns only three feet apart connected by deep spandrels, so that the entire tower became an immense hollow cantilever tube. By any measure, the World Trade Center was an impressive part of the Manhattan skyline.

On September 11, 2001, the twin towers were tragically attacked by terrorists. The attack caused immense fires within the buildings and eventually compromised the buildings' steel structural system and resulted in their collapse. The strength and redundancy of the towers' innovative structural tube system did withstand the initial attack and withstood the blaze long enough for thousands of occupants to safely escape.


**Figure 1.20**

## Willis Tower

A recent innovation in the design of skyscrapers is the tubular concept, in which the structure acts like an immense, hollow, tubular column which cantilevers out of its foundation under the action of wind loads. Completed in 1976, the Willis Tower was originally named the Sears Tower. This Chicago structure is a bundle of nine tubes, each 75 feet square, placed next to each other to form a pattern of three squares in each direction (Figure 1.21). The square tubes end at varying heights, with only two of them extending the full 1,450-foot height of the building.

Designed by Skidmore, Owings, and Merrill, with Fazlur Kahn as chief engineer, the Willis Tower is one of the most notable achievements in skyscraper design and is currently the tallest building in the United States.

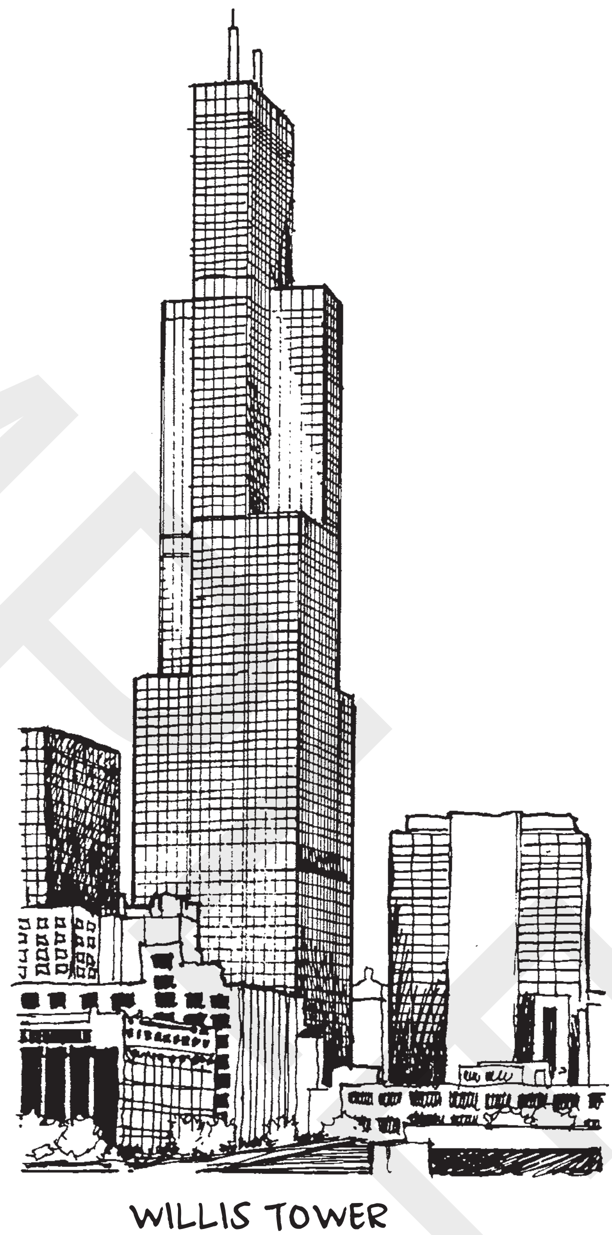


**Figure 1.21**

Taller buildings have been built in Malaysia, namely the Petronas Towers, designed by Cesar Pelli, with a measured height of 1,483 feet for each tower. The Taipei 101 building, located in Taipei, Taiwan, was completed in 2004 and reaches a height of 1,671 feet.

The Burj Dubai, recently constructed in Dubai, United Arab Emirates, was completed in 2010 and is currently the world's tallest building. The final height is 2,723 feet.

## NOTABLE ENGINEERS

Architectural candidates are expected to have some knowledge not only of structural concepts and actual structures, but also of structural engineers of distinction. Therefore, presented below are brief biographies of several engineers whose talent was exceptional, transcending technology to create true art.

### Felix Candela (1910–1997)

Born in Spain but a resident of Mexico for most of his life, Candela created thin-shell concrete roofs based on his experience and intuition, using mathematics only secondarily. His designs for hyperbolic paraboloids, such as the Xochimilco Restaurant roof, carried thinness of material to the ultimate.

### Gustave Eiffel (1832–1923)

Immortalized by the tower that bears his name, Eiffel was an extraordinary French engineer who believed that architectural beauty could be achieved only by structures whose form was determined rationally, based on the loads to be supported, rather than arbitrarily. His railroad stations and bridges used the new materials of 19th-century technology, rolled iron and steel, and were structures of great strength and beauty.

### Eugene Freyssinet (1879–1962)

The French engineer Freyssinet pioneered the development of prestressed concrete, which he used for a number of bridges that were visually and conceptually elegant. His most famous buildings were the two immense Orly Dirigible Hangars, near Paris, which were destroyed during World War II.

### Fazlur Khan (1930–1982)

A Pakistani by birth, Khan was a brilliant structural engineer and a partner in the Skidmore, Owings, and Merrill firm. In his buildings, such as the John Hancock Building and Willis Tower, both in Chicago, form evolved as a result of structural ideas rather than the other way around.

### Robert Maillart (1872–1940)

Maillart, a Swiss engineer, was among the first to recognize the aesthetic and technical potential of reinforced concrete. His designs for arched concrete bridges, originally accepted because of their economy, are now recognized as works of art.

### Pier Luigi Nervi (1891–1979)

The great Italian contractor and engineer Nervi created soaring concrete shell roofs to house sports event, exhibitions, and aircraft. Like Maillart, his work successfully combined technical excellence with a conscious aesthetic intent.

### John Roebling (1806–1869) and his son Washington Roebling (1837–1926)

The Roeblings were pioneers in the design and construction of suspension bridges. Their crowning achievement was the Brooklyn Bridge, which combined lightness with strength to create a structure of enduring beauty.

### Eduardo Torroja (1899–1961)

Although trained in his native Spain as an engineer, Torroja was a great creator of architectural form. His concrete shell structures, most notably the roof of the Zarzuela racetrack grandstand in Madrid, united rational engineering design with inspired creativity.

### Others

Others who are equally noteworthy include:

**Othmar Ammann**, the Swiss-American engineer, one of the greatest bridge designers of this century.

**Benjamin Baker**, designer of the Forth Bridge in Scotland.

**Santiago Calatrava,** Spanish-born architect and engineer, noted for engineering talent and artistic sensibility in designing contemporary bridges and buildings, including the Milwaukee Art Museum.

**Horst Berger and Frei Otto**, both specialists in the design of tent structures.

**James Eads**, whose greatest work was the Eads Bridge over the Mississippi, the first major structure built of steel.

**Buckminster Fuller**, the inventor of the geodesic dome.

**David Geiger**, pioneer designer of pneumatic structures.

**William Jenney**, the pioneer designer of steel frame buildings.

**T.Y. Lin**, the master of prestressed concrete.

**Elisha Graves Otis**, the inventor of the first safe passenger elevator, which helped make the skyscraper a reality.

**Auguste Perret**, the French architect and contractor, known as the father of reinforced concrete.

**Thomas Telford**, the great Scottish engineer of iron bridges.

## HIGH TECH

High-tech architecture intends to reduce structure and function to the most necessary elements. “Perfection can only be achieved if nothing can be taken away,” evokes the classic Modernist maxim that “less is more.” The manifestation of this high-tech philosophy ranges from super-rational and spare aesthetic to dazzling structural gymnastics that realize new achievements in engineering, material science, and building systems and the architect’s ability to integrate them.

Architects working in this idiom collaborate closely with engineering firms to achieve new structures that challenge expected limits of roof spans, floor cantilevers, and column supports. Evanescent cable-stayed curtain walls that use special insulating and tempered glass are commonly seen in high-tech architecture, as they allow maximum building performance for a (perceived) minimum use of material.

The equal marriage of technology, manufacturing, and architecture has always been a goal for some architects. Buckminster Fuller (b. 1895) was one of the iconic early pioneers, and the technologically rich ***Dymaxion House*** *(1945)* was one of his most famous works. Today’s high-tech architecture is a design practice that attempts to effectively remove the working separation between architect and engineer. Architect-engineer teams such as Helmut Jahn and Werner Sobek or Norman Foster and Ove Arup focus on utilizing the most current structural science and materials available to them in order to produce the most high-performing and structurally daring designs possible. Designer and engineer work together from the earliest sketches to create an integrated design. Invention and progress are requirements for the high-tech architects, placing them at an edge of a constantly changing and expanding architecture.

Functionalism, rationalism, and expression of industrial production are elements linking this style to early European Modernism and the International Style. Advances in steel, insulating glass, cable structures, and concrete all allow for more dramatic forms than were possible in previous generations. Modernist movements have tried to free themselves from historicity and regionalism to pursue new horizons of form and to embrace this architectural style that addresses an increasingly global society.

While much early Modernism worked in a populist philosophy, high-tech is more frequently synonymous with large-scale projects such as airports, train stations, convention centers, and skyscrapers. Due to the high budgets of the projects and typically high square foot costs of the architecture, it is often governments, corporations, and high-end developers that commission high-tech projects. As a result, many of these works are major landmarks that affect the skyline, transportation patterns, and commerce at the scale of entire cities or countries.

Critics of the style see it as cold, soulless, and impersonal. High-tech architecture rejects a broad color palette and any extraneous elements that might distract from the overall composition of structure and skin. All-glass exteriors with steel and concrete structure, and stainless steel fittings and cladding are ubiquitous material combinations. Yet its ambition and the eternally evocative drive toward invention give high-tech architecture its own humanity.

## Style/Mannerism

An early example of high-tech is Norman Foster's (b. 1935) ***Stansted Airport*** in London, built 1981-1991. Foster's consistent collaboration with Ove Arup and Partners has had a great impact on architecture. High-tech style often is a good match for transportation facilities because great efficiency is demanded for the large, open plans and building systems. The building is an efficient and simple continuous roof supported on large structural "trees." Daylight streams in from skylights in the roof as well as through the full-height glass walls at the perimeter. The transparency contributes to the successful organization of this very large building, and the visitor is able to see through the building from the roadway to the airplanes and is in no need of further orientation in the space.

Nicholas Grimshaw's (b. 1939), ***Waterloo International Terminal*** (1990–93) in London uses a long-span cable system as the main structural system. Grimshaw evokes the history and dynamics of the train shed with its immense volumes and diaphanous structures while making a serious statement about efficiency, cutting edge structural design, and responses to contingencies of a site. An asymmetrical, tapering, double cable-stayed truss supports the roof and is the main image of this project. The structure lends a sense of importance and lightness to an irregular and confined London rail station. The smaller western truss is placed on the outside of the building and supports glazing on the interior, achieving a continuous glazed interior with adequate clearance for the trains. This immense glass wall introduced daylight and also became a "public showcase for the trains." Due to the irregularity of the site and truss sizes, and movement due to climate and train vibration, standardized glass panels were designed to move over one another in response to slight movements in the structural system.

Richard Rogers' (b. 1933) ***Lloyd's Building*** (1984) in London is remarkable for the way that it boldly expresses function and the structural and building systems. The office areas are completely open while elevators, building systems, and other servant areas are clearly exposed at the rear of the building. These elements are clearly expressed on the exterior as individual elements that are hanging on the exposed structural system. This arrangement allows easy access for maintenance and allows easy upgrading of those elements that become obsolete through frequent use or advancing technology. Rogers' design recognizes that changing technology will require systems in the building to be significantly overhauled in the future. He designed even beyond the forefront of the technology of the era.

## Structure

Santiago Calatrava's (b. 1951) artful interpretations of natural elements into structural forms demonstrates a perfect equilibrium of architectonic and engineering principles. In his work asymmetry, dramatic cantilevers, graceful concrete forms, and operable exteriors serve to create a sense of wonder while the interiors and the site designs create a sense of architectural order. His ***Lyon Satolas Railway Station*** (1989–94) in Lyon, France utilizes a series of soaring steel arches that fan from a single vertex to create the central light-filled hall that provides clear orientation for the visitor and an easily defined landmark for the surrounding city. The height and airiness of the central hall is in distinct contrast to the low, linear tube created by Calatrava's trademark wishbone piers that cover the train platforms below.

Calatrava also draws inspiration from natural movement and human or animal structures and form. The ***Milwaukee Art Museum's*** (2001) wing-like operable sunshades draw a large crowd each time they open and close. Located just off downtown at the end of a long street, the museum complex is a magnificently sited yet unexpected midwestern landmark. The project features a cable-stayed footbridge hung from a graceful, inclined pylon. This bridge leads to the entrance and is the main organizing axis of the project's formal composition. The sunshades qualify as public sculpture when they are open and fully extended. But the museum is more than just a mechanical curiosity: the sunshades enclose a jewel-like interior space with a stunning view of Lake Michigan.

## Sustainability/Energy Conservation

One of the emerging tenets of the high-tech style is one of energy conservation. Although their palette of glass, steel, and concrete varies from that of other sustainable practitioners, these architects are working to bring the operational costs of a building down by using less energy. Also, the components of high-tech architecture are particular to a given project, and the architects frequently design these to be easily recycled or reused.

Nicolas Grimshaw's temporary ***British Pavilion*** for the 1992 Seville Exposition was entirely prefabricated and assembled in Seville, Spain. It was a showcase for the articulation of structure and the ability of a small palette of materials to capture and manipulate wind, light, and water. High-tech aesthetics and structure combined to showcase local traditions and environmentally conscious passive building systems. A water wall on one side of the building served as a sculpture and also provided passive cooling. Fabric sails and roof louvers helped to shade the building and softened the harsh sunlight. Solar panels on the roof provided energy to the Pavilion. The project was designed to be taken apart at the end of the Exposition, so all elements were discrete and easily recycled.

Helmut Jahn's ***Post Tower*** (1992) in Bonn, Germany, the headquarters for the German post office, is based on simple geometries resulting in sharp edges and elegant curves. These combine to form a handsome statement of corporate identity. The distinctive shingled façade is a double skin commonly found in European high-rise buildings. It offers a highly insulated envelope that also allows fresh air to circulate. The floor-to-ceiling glass and narrow floor plate allow a maximum amount of natural light to reach the interior. These considerations give the building a low operating cost and also give office staff a pleasant working environment. Helmut Jahn was educated in the pure Miesian style, and he typifies the high-tech architect. He collaborates with structural and environmental engineers from the beginning of the design process in a relationship Jahn refers to as "Archineering."

## TALL TOWERS

Ever since the very first steel high-rises were built at the end of the 19th century, the race to construct the world's tallest buildings has been a race for civic pride and stature. The names New York or Chicago immediately call to most people's mind an image of the Empire State Building or Willis Tower. Super-tall buildings define the visual identity of the cities that welcome them, the status of corporations who finance them, and the careers of the architects who design them.

Caesar Pelli's (b. 1926) 1.6 billion-dollar ***Petronas Towers*** (1998) in Kuala Lumpur, Malaysia, emphatically demonstrates the ability of the world's tallest building to become an international cultural and commercial landmark. The tower ushered a new continent and world capital market into global consciousness. The twin 88-story towers are capped with spires that soar to 1,483 feet. The towers are linked at the 41st and 42nd floors by a double-decker skybridge. Comprising more than 8 million square feet, Petronas Towers includes a shopping mall, an interactive petroleum discovery center, an 864-seat concert hall, a mosque, and a conference center. The floor plate is based on an eight-pointed star and is said to reference Malaysian Islamic motifs. This reinforces the project's connection with national, not merely corporate, identity. The façade is reminiscent of temple spires, especially the pattern that is created by the blue glass panels that are set in aluminum frames. Other stainless steel panels help deflect the forceful Malaysian heat.

C.Y. Lee and Partners' ***Taipei 101*** (2004) in Taipei, Taiwan, at 1671 feet (509 meters), was the first building to exceed the half-kilometer mark. Holding the record with the world's tallest occupied floor and observation deck until 2010, the project was also notable for the world's fastest elevators. Based on traditional Chinese design, the rhythm of the tower is distinctive and is a departure from the orthodox, smooth Modernist line found in most high-rise buildings. The interior is organized according to the principles of feng shui.

Skidmore, Owings and Merrill's *Burj Khalifa* (2010) in Dubai, United Arab Emirates, at 828 meters (2,717 feet) is currently the world's tallest occupied floor and observation deck. The overall construction cost of Burj Khalifa was approximately $1.5 billion.

## STRUCTURAL FAILURES

In recent years, a number of spectacular structural failures have occurred in the United States. Among them are the following:

1. **Hartford Civic Center Coliseum, Hartford, CT,** 1978. Steel space frame spanning 300 feet. No casualties.
2. **C.W. Post Auditorium**, Greenvale, NY, 1978. Steel and aluminum dome spanning 171 feet. No casualties.
3. **Kemper Memorial Arena,** Kansas City, MO, 1979. Steel truss roof suspended from steel space frame spanning 324 feet. No casualties.
4. **Rosemont Horizon Arena**, Rosemont, IL, 1979. Glued laminated arches spanning 290 feet. 5 dead, 19 injured.
5. **Hyatt Regency Hotel**, Kansas City, MO, 1981. Two suspended walkways. 113 dead, 186 injured. In terms of casualties, the most devastating structural collapse ever to take place in the United States.

The investigations and conferences that have taken place as a result of these failures have produced several general conclusions, which are summarized at the end of Lesson Thirteen.

# LESSON 1 QUIZ

1. Select the CORRECT statement about the terminal of Dulles Airport.

   **A.** The use of a mobile lounge allowed Saarrinen to depart from the conventional finger plan airport terminal.

   **B.** The huge concrete piers that support the roof lean outward to express the concept of flight rather than for any structural reason.

   **C.** The terminal was the first to use computerized subway trains.

   **D.** While the terminal building is compact and efficient, it does not lend itself readily to future expansion.

2. Select the CORRECT statement about the Pantheon.

   **A.** Circumferential iron chains were built in to act as tension rings.

   **B.** An iron tie was placed around the dome's base in the 19th century to resist the outward thrust of the dome.

   **C.** The hoop tension in the dome is resisted by very thick concrete walls.

   **D.** It remains to this day a masterpiece of Greek architecture.

3. The principal structural materials utilized by Wright in Fallingwater are

   **A.** wood and structural steel.

   **B.** structural steel and cast-in-place concrete.

   **C.** cast-in-place concrete and masonry.

   **D.** precast concrete and masonry.

4. Select the CORRECT statements about the John Hancock Building in Chicago.

   **A.** After its completion, its windows frequently broke loose from their frames and fell to the street below.

   **B.** It expresses its structure through its tapered form.

   **C.** Its enormous exposed cross-bracing is effective in resisting wind loads.

   **D.** It is the tallest building in Chicago.

5. What do the Palazzetto Dello Sport and the airplane hangars built for the Italian Air Force have in common?

   **I.** Both were designed by Nervi.

   **II.** Both were outstanding examples of elegant cast-in-place concrete construction.

   **III.** Both had dome roofs.

   **IV.** Both were destroyed during World War II.

   **V.** Both had ribbed concrete shell roofs.

   **A.** I, II, IV, and V  **C.** II and V

   **B.** I and V  **D.** I, III, and IV

6. Select the CORRECT statement about the Toronto City Hall.

   **A.** Its two huge shells are curved arbitrarily to achieve an aesthetic effect.

   **B.** Each of its towers acts as a huge circular tube to resist wind forces.

   **C.** Its floors are suspended from immense roof trusses.

   **D.** It comprises two huge shells which are curved to provide resistance to wind or earthquake forces.

**7.** What great structure partially collapsed because its dome was insufficiently buttressed?

**A.** Hagia Sophia
**B.** Palazzetto Dello Sport
**C.** Santa Maria del Fiore Cathedral
**D.** Munich Olympic Stadium

**8.** Which of the following buildings BEST exemplifies the bundled tube concept?

**A.** First National Bank, Chicago
**B.** John Hancock Building, Chicago
**C.** Willis Tower
**D.** World Trade Center

**9.** What building has a façade that clearly expresses its catenary suspension structure?

**A.** CBS Building
**B.** Dulles International Airport
**C.** Johnson Wax Building
**D.** Federal Reserve Bank, Minneapolis

**10.** Which of the buildings listed below has a cable-supported roof suspended between a central reinforced concrete arch and heavy perimeter walls?

**A.** Italian Air Force Hangars
**B.** Knights of Columbus Building
**C.** Toronto City Hall
**D.** Yale University Skating Rink