# Construction and Building

## (Types and Elements)

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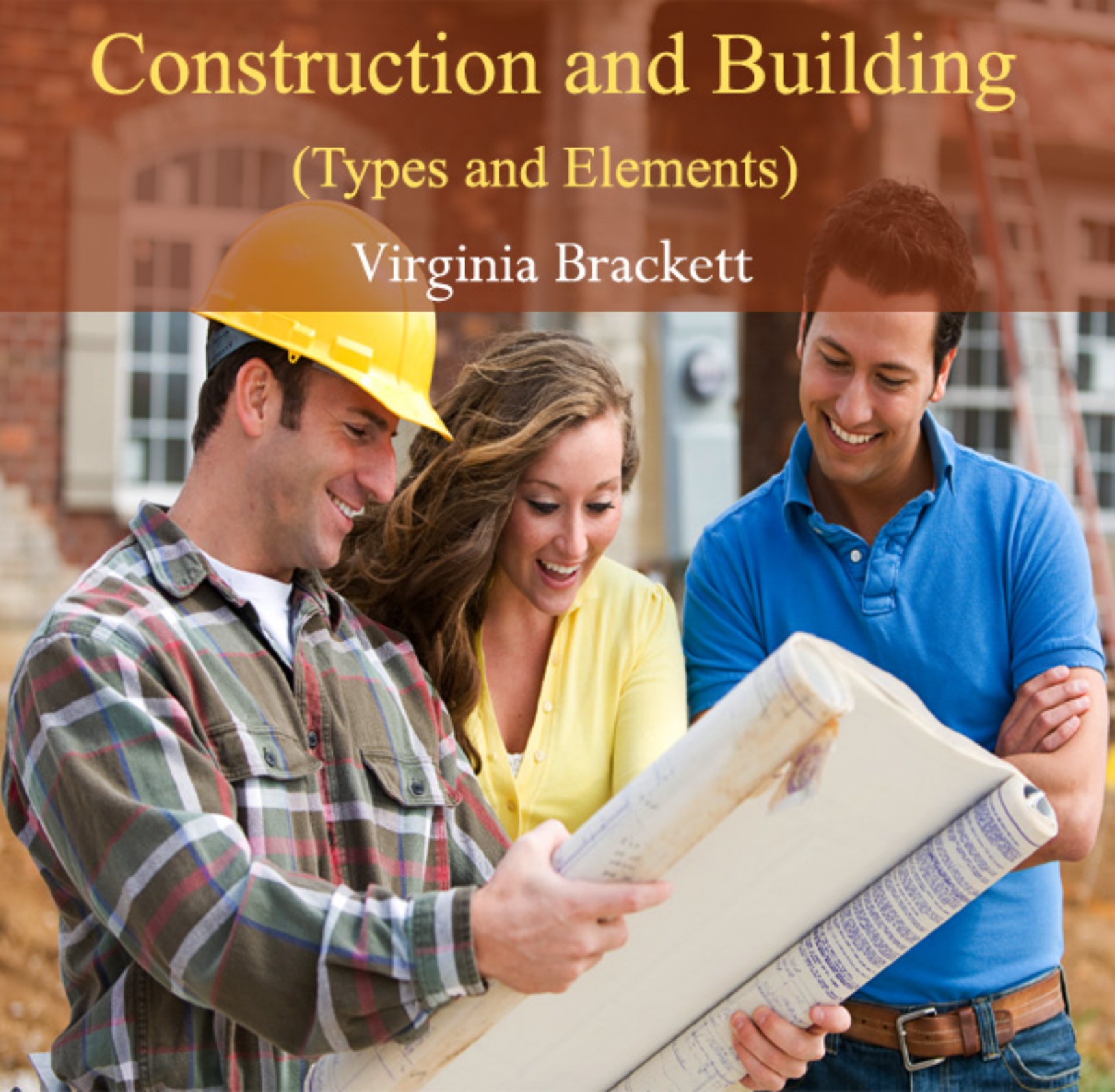

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# Construction

In large construction projects, such as this skyscraper in Melbourne, cranes are essential.

In the fields of architecture and civil engineering, **construction** is a process that consists of the **building** or assembling of infrastructure. Far from being a single activity, large scale construction is a feat of human multitasking. Normally, the job is managed by a

project manager, and supervised by a construction manager, design engineer, construction engineer, or project architect.

For the successful execution of a project, effective planning is essential. Those involved with the design and execution of the infrastructure in question must consider the environmental impact of the job, the successful scheduling, budgeting, construction site safety, availability of building materials, logistics, inconvenience to the public caused by construction delays, and bidding, etc.

# Types of construction projects

Construction of a prefabricated home

In general, there are three types of construction:

1. Building construction
2. Heavy / civil construction
3. Industrial construction

Each type of construction project requires a unique team to plan, design, construct, and maintain the project.

## Building construction

A building site for a row of riverside apartment blocks in Cambridge


A large unfinished building

Building construction is the process of adding structure to real property. The vast majority of building construction projects are small renovations, such as addition of a room, or renovation of a bathroom. Often, the owner of the property acts as laborer, paymaster, and design team for the entire project. However, all building construction projects include some elements in common - design, financial, and legal considerations. Many projects of varying sizes reach undesirable end results, such as structural collapse, cost overruns, and/or litigation reason, those with experience in the field make detailed plans and maintain careful oversight during the project to ensure a positive outcome.

Building construction is procured privately or publicly utilizing various delivery methodologies, including hard bid, negotiated price, traditional, management contracting, construction management-at-risk, design & build and design-build bridging.

Residential construction practices, technologies, and resources must conform to local building authority regulations and codes of practice. Materials readily available in the area generally dictate the construction materials used (e.g. brick versus stone, versus timber). Cost of construction on a per square metre (or per square foot) basis for houses can vary dramatically based on site conditions, local regulations, economies of scale (custom designed homes are always more expensive to build) and the availability of

skilled tradespeople. As residential (as well as all other types of construction) can generate a lot of waste, careful planning again is needed here.

The most popular method of residential construction in the United States is wood framed construction. As efficiency codes have come into effect in recent years, new construction technologies and methods have emerged. University Construction Management departments are on the cutting edge of the newest methods of construction intended to improve efficiency, performance and reduce construction waste.

## Heavy / civil construction

Civil engineering deals with the design, construction and maintenance of the physical and naturally built environment, including works such as bridges, roads, canals, dams and buildings.

## Industrial construction

Industrial construction, though a relatively small part of the entire construction industry, is a very important component. Owners of these projects are usually large, for-profit, industrial corporations. These corporations can be found in such industries as medicine, petroleum, chemical, power generation, manufacturing, etc. Processes in these industries require highly specialized expertise in planning, design, and construction. As in building and heavy/highway construction, this type of construction requires a team of individuals to ensure a successful project. Industrial construction is very important.Sometimes it may cause or harm the environment.

# Construction processes

## Design team

Shasta Dam under construction in June 1942

In the modern industrialized world, construction usually involves the translation of designs into reality. A formal design team may be assembled to plan the physical proceedings, and to integrate those proceedings with the other parts. The design usually consists of drawings and specifications, usually prepared by a design team including surveyors, civil engineers, cost engineers (or quantity surveyors), mechanical engineers, electrical engineers, structural engineers, and fire protection engineers. The design team is most commonly employed by (i.e. in contract with) the property owner. Under this system, once the design is completed by the design team, a number of construction companies or construction management companies may then be asked to make a bid for the work, either based directly on the design, or on the basis of drawings and a bill of quantities provided by a quantity surveyor. Following evaluation of bids, the owner will typically award a contract to the most cost efficient bidder.

The modern trend in design is toward integration of previously separated specialties, especially among large firms. In the past, architects, interior designers, engineers,

developers, construction managers, and general contractors were more likely to be entirely separate companies, even in the larger firms. Presently, a firm that is nominally an "architecture" or "construction management" firm may have experts from all related fields as employees, or to have an associated company that provides each necessary skill. Thus, each such firm may offer itself as "one-stop shopping" for a construction project, from beginning to end. This is designated as a "design Build" contract where the contractor is given a performance specification, and must undertake the project from design to construction, while adhering to the performance specifications.

Several project structures can assist the owner in this integration, including design-build, partnering, and construction management. In general, each of these project structures allows the owner to integrate the services of architects, interior designers, engineers, and constructors throughout design and construction. In response, many companies are growing beyond traditional offerings of design or construction services alone, and are placing more emphasis on establishing relationships with other necessary participants through the design-build process.

The increasing complexity of construction projects creates the need for design professionals trained in all phases of the project's life-cycle and develop an appreciation of the building as an advanced technological system requiring close integration of many sub-systems and their individual components, including sustainability. **Building engineering** is an emerging discipline that attempts to meet this new challenge.

## Financial advisors

### Trump International Hotel and Tower (Chicago)

May 23, 2006

September 14, 2007 (3 months before completion)

Many construction projects suffer from preventable financial problems. **Underbids** ask for too little money to complete the project. Cash flow problems exist when the present amount of funding cannot cover the current costs for labour and materials, and because they are a matter of having sufficient funds at a specific time, can arise even when the overall total is enough. Fraud is a problem in many fields, but is notoriously prevalent in the construction field. Financial planning for the project is intended to ensure that a solid plan, with adequate safeguards and contingency plans, is in place before the project is started, and is required to ensure that the plan is properly executed over the life of the project.

Mortgage bankers, accountants, and cost engineers are likely participants in creating an overall plan for the financial management of the building construction project. The presence of the mortgage banker is highly likely even in relatively small projects, since the owner's equity in the property is the most obvious source of funding for a building project. Accountants act to study the expected monetary flow over the life of the project, and to monitor the payouts throughout the process. Cost engineers apply expertise to relate the work and materials involved to a proper valuation. Cost overruns with government projects have occurred when the contractor was able to identify change orders or changes in the project resulting in large increases in cost, which are not subject to competition by other firm as they have already been eliminated from consideration after the initial bid.

Large projects can involve highly complex financial plans. As portions of a project are completed, they may be sold, supplanting one lender or owner for another, while the logistical requirements of having the right trades and materials available for each stage of the building construction project carries forward. In many English-speaking countries, but not the United States, projects typically use quantity surveyors.

## Legal considerations

Construction along Ontario Highway 401, widening the road from six to twelve travel lanes

A construction project must fit into the legal framework governing the property. These include governmental regulations on the use of property, and obligations that are created in the process of construction.

The project must adhere to zoning and building code requirements. Constructing a project that fails to adhere to codes will not benefit the owner. Some legal requirements come from malum in se considerations, or the desire to prevent things that are indisputably bad - bridge collapses or explosions. Other legal requirements come from malum prohibitum considerations, or things that are a matter of custom or expectation, such as isolating businesses to a business district and residences to a residential district. An attorney may seek changes or exemptions in the law governing the land where the building will be built, either by arguing that a rule is inapplicable (the bridge design will not collapse), or that the custom is no longer needed (acceptance of live-work spaces has grown in the community).

A construction project is a complex net of contracts and other legal obligations, each of which must be carefully considered. A contract is the exchange of a set of obligations between two or more parties, but it is not so simple a matter as trying to get the other side to agree to as much as possible in exchange for as little as possible. The time element in construction means that a delay costs money, and in cases of bottlenecks, the delay can be extremely expensive. Thus, the contracts must be designed to ensure that each side is capable of performing the obligations set out. Contracts that set out clear expectations and clear paths to accomplishing those expectations are far more likely to result in the project flowing smoothly, whereas poorly drafted contracts lead to confusion and collapse.

Legal advisors in the beginning of a construction project seek to identify ambiguities and other potential sources of trouble in the contract structure, and to present options for preventing problems. Throughout the process of the project, they work to avoid and resolve conflicts that arise. In each case, the lawyer facilitates an exchange of obligations that matches the reality of the project.

## Interaction of expertise

Apartment complex under construction in Daegu, South Korea

Design, finance, and legal aspects overlap and interrelate. The design must be not only structurally sound and appropriate for the use and location, but must also be financially possible to build, and legal to use. The financial structure must accommodate the need for building the design provided, and must pay amounts that are legally owed. The legal structure must integrate the design into the surrounding legal framework, and enforce the financial consequences of the construction process.

## Procurement

**Procurement describes the merging** of activities undertaken by the client to obtain a building. There are many different methods of construction procurement; however the three most common types of procurement are:

1. Traditional (Design-bid-build)
2. Design and Build
3. Management Contracting

There is also a growing number of new forms of procurement that involve relationship contracting where the emphasis is on a co-operative relationship between the principal and contractor and other stakeholders within a construction project. New forms include partnering such as Public-Private Partnering (PPPs) aka Private Finance Initiatives (PFIs) and alliances such as "pure" or "project" alliances and "impure" or "strategic" alliances. The focus on co-operation is to ameliorate the many problems that arise from the often highly competitive and adversarial practices within the construction industry.

**Traditional**

This is the most common method of construction procurement and is well established and recognized. In this arrangement, the architect or engineer acts as the project coordinator. His or her role is to design the works, prepare the specifications and produce construction drawings, administer the contract, tender the works, and manage the works from inception to completion. There are direct contractual links between the architect's client and the main contractor. Any subcontractor will have a direct contractual relationship with the main contractor.

**Design and build**

Construction of the *Phase-1* (first two towers) of the Havelock City Project, Sri Lanka.

This approach has become more common in recent years and includes an entire completed package, including fixtures, fittings and equipment where necessary, to produce a completed fully functional building. In some cases, the Design and Build (D & B) package can also include finding the site, arranging funding and applying for all necessary statutory consents.

The owner produces a list of requirements for a project, giving an overall view of the project's goals. Several D&B contractors present different ideas about how to accomplish these goals. The owner selects the ideas he likes best and hires the appropriate contractor. Often, it is not just one contractor, but a consortium of several contractors working together. Once a contractor (or a consortium/consortia) has been hired, they begin building the first phase of the project. As they build phase 1, they design phase 2. This is in contrast to a design-bid-build contract, where the project is completely designed by the owner, then bid on, then completed.

Kent Hansen, director of engineering for the National Asphalt Pavement Association (NAPA), pointed out that state departments of transportation (DOTs) usually use design build contracts as a way of getting projects done when states don't have the resources. In DOTs, design build contracts are usually used for very large projects.

**Management procurement systems**

In this arrangement the client plays an active role in the procurement system by entering into separate contracts with the designer (architect or engineer), the construction manager, and individual trade contractors. The client takes on the contractual role, while the construction or project manager provides the active role of managing the separate trade contracts, and ensuring that they all work smoothly and effectively together.

Management procurement systems are often used to speed up the procurement processes, allow the client greater flexibility in design variation throughout the contract, the ability to appoint individual work contractors, separate contractual responsibility on each individual throughout the contract, and to provide greater client control.

# Authority having jurisdiction

Construction on a building in Kansas City, Missouri

In construction, the **authority having jurisdiction** (AHJ) is the governmental agency or sub-agency which regulates the construction process. In most cases, this is the municipality in which the building is located. However, construction performed for

supra-municipal authorities are usually regulated directly by the owning authority, which becomes the AHJ.

During the planning of a building, the zoning and planning boards of the AHJ will review the overall compliance of the proposed building with the municipal General Plan and zoning regulations. Once the proposed building has been approved, detailed civil, architectural, and structural plans must be submitted to the municipal **building department** (and sometimes the public works department) to determine compliance with the building code and sometimes for fit with existing infrastructure. Often, the municipal fire department will review the plans for compliance with fire-safety ordinances and regulations.

Before the foundation can be dug, contractors are typically required to notify utility companies, either directly or through a company such as Dig Safe to ensure that underground utility lines can be marked. This lessens the likelihood of damage to the existing electrical, water, sewage, phone, and cable facilities, which could cause outages and potentially hazardous situations. During the construction of a building, the municipal building inspector inspects the building periodically to ensure that the construction adheres to the approved plans and the local **building code**. Once construction is complete and a final inspection has been passed, an **occupancy permit** may be issued.

An operating building must remain in compliance with the **fire code**. The fire code is enforced by the local fire department.

Changes made to a building that affect safety, including its use, expansion, structural integrity, and fire protection items, usually require approval of the AHJ for review concerning the building code.

# Construction careers

Ironworkers erecting the steel frame of a new building at Massachusetts General Hospital, Boston

There are many routes to the different careers within the construction industry which vary by country. However, there are three main tiers of careers based on educational background which are common internationally:

- Unskilled and Semi-Skilled - General site labour with little or no construction qualifications.

- Skilled - On-site managers whom possess extensive knowledge and experience in their craft or profession.
- Technical and Management - Personnel with the greatest educational qualifications, usually graduate degrees, trained to design, manage and instruct the construction process.

Skilled occupations in the UK require further education qualifications, often in vocational subject areas. These qualifications are either obtained directly after the completion of compulsory education or through "on the job" apprenticeship training. In the UK, 8500 construction-related apprenticeships were commenced in 2007. Skills in the United States and abroad differ very little: the very simple change that can be obviously perceived is language: some of the latest skills required in the United States can be interpreted by contacting Construction Citizen s in America and abroad.

Technical and specialised occupations require more training as a greater technical knowledge is required. These professions also hold more legal responsibility. A short list of the main careers with an outline of the educational requirements are given below:

- Architect - Typically holds at least a 5 to 6-year degree in architecture. To use the title "architect" the individual must hold chartered status with the Royal Institute of British Architects and be on the Architects Registration Board.
- Civil Engineer - Typically holds a degree in a related subject. The Chartered Engineer qualification is controlled by the Institution of Civil Engineers. A new university graduate must hold a master's degree to become chartered, persons with bachelor's degrees may become an Incorporated Engineer.
- Building Services Engineer - Often referred to as an "M&E Engineer" typically holds a degree in mechanical or electrical engineering. Chartered Engineer status is governed by the Chartered Institution of Building Services Engineers.
- Project Manager - Typically holds a 4-year or greater higher education qualification, but are often also qualified in another field such as quantity surveying or civil engineering.
- Quantity Surveyor - Typically holds a master's degree in quantity surveying. Chartered status is gained from the Royal Institution of Chartered Surveyors.
- Structural Engineer - Typically holds a bachelors or master's degree in structural engineering, new university graduates must hold a master's degree to gain chartered status from the Institution of Structural Engineers.

# History

The first buildings were huts and shelters, constructed by hand or with simple tools. As cities grew during the Bronze Age, a class of professional craftsmen, like bricklayers and carpenters, appeared. Occasionally, slaves were used for construction work. In the Middle Ages, these were organized into guilds. In the 19th century, steam-powered machinery appeared, and later diesel- and electric powered vehicles such as cranes, excavators and bulldozers. Modern-day Construction involves creating awesome structures that can show the beauty and creativity of the human intellect. Some great

examples of art in buildings or architecture include the London Shard, which can be viewed on Construction Citizen, a website updated daily for increasing construction labor.

## Chapter- 2

# Building


A building and skybridge in Munich, Germany

Example of a religious building : the Great Mosque of Kairouan, founded in 670, dates in its present state from the 9th century; situated in Kairouan, Tunisia.

In architecture, construction, engineering and real estate development the word **building** may refer to one of the following:

1. Any human-made structure used or intended for supporting or sheltering any use or continuous occupancy, or
2. An act of construction (i.e. the activity of building)

Buildings come in a wide amount of shapes and functions, and have been adapted throughout history for a wide number of factors, from building materials available, to weather conditions, to land prices, ground conditions, specific uses and aesthetic reasons.

Buildings serve several needs of society – primarily as shelter from weather and as general living space, to provide privacy, to store belongings and to comfortably live and work. A building as a shelter represents a physical division of the human habitat (a place of comfort and safety) and the *outside* (a place that at times may be harsh and harmful).

Ever since the first cave paintings, buildings have also become objects or canvasess of artistic expression. David found in recent years, interest in sustainable planning and building practices has also become part of the design process of many new buildings.

# Definitions

Building is defined in many aspects as:

- As a Civil Engineering structures such as a house,worship center,Factories etc. that has a foundation,wall,roof etc. that protect human being and their properties from direct harsh effect of weather like rain,wind,sun etc.
- The act of constructing, erecting, or establishing.
- The art of constructing edifices, or the practice of civil architecture.
- That which is built; a fabric or edifice constructed, as a house, a church, castle, arena/ stadium, etc.
- The act of constructing or building something; "during the construction we had to take a detour"; "his hobby was the building of boats"
- The commercial activity involved in constructing buildings; "their main business is home construction"; "workers in the building trades"
- A structure that has a roof and walls and stands more or less permanently in one place; "there was a three-storey building on the corner"; "it was an imposing edifice"
- The occupants of a building; "the entire building complained about the noise"

*Structural height* in technical usage is the height to the highest architectural detail on building from street-level. Depending on how they are classified, spires and masts may or may not be included in this height. Spires and masts used as antennas are not generally included.

The definition of a *low-rise vs. a high-rise* building is a matter of debate, but generally three stories or less is considered low-rise.

# History

The first shelter on Earth constructed by a relatively close ancestor to humans is believed to be built 500,000 years ago by an early ancestor of humans, Homo erectus.

# Types

A timber framing house in Marburg, Germany.

## Residential

Residential buildings are called houses/homes, though buildings containing large numbers of separate dwelling units are often called apartment buildings / blocks to differentiate them from the more 'individual' house.

Building types may range from one-room wood-framed, masonry, or adobe dwellings to multi-million dollar high-rise buildings able to house thousands of people. Increasing settlement density in buildings (and closer distances between buildings) is usually a response to high ground prices resulting from many people wanting to live close to work or similar attractors.

**Multi-storey**

Some of Denver's multi-storey buildings.

A multi-storey building is a building that has multiple floors above ground in the building.

Multi-storey buildings aim to increase the area of the building without increasing the area of the land the building is built on, hence saving land and, in most cases, money (depending on material used and land prices in the area).

# Creation

The practice of designing, constructing, and operating buildings is most usually a collective effort of different groups of professionals and trades. Depending on the size, complexity, and purpose of a particular building project, the project team may include:

- A real estate developer who secures funding for the project;
- One or more financial institutions or other investors that provide the funding
- Local planning and code authorities
- A Surveyor who performs an ALTA/ACSM and construction surveys throughout the project;
- Construction managers who coordinate the effort of different groups of project participants;
- Licensed architects and engineers who provide building design and prepare construction documents;
- Landscape architects;

- Interior designers;
- Other consultants;
- Contractors who provide construction services and install building systems such as climate control, electrical, plumbing, Decoration, fire protection, security and telecommunications;
- Marketing or leasing agents;
- Facility managers who are responsible for operating the building.

Regardless of their size or intended use, all buildings in the US must comply with zoning ordinances, building codes and other regulations such as fire codes, life safety codes and related standards.

Vehicles—such as trailers, caravans, ships and passenger aircraft—are treated as "buildings" for life safety purposes.

### Ownership and funding

- Mortgage loan
- Real estate developer

### Planning and design

- Architecture
- Building construction
- Civil engineering
- Mechanical, electrical, and plumbing design
- Quantity surveying
- Structural engineering
- Urban planning

## Building services

### Physical plant

Any building requires a certain amount of internal infrastructure to function, which includes such elements like heating / cooling, power and telecommunications, water and wastewater etc. Especially in commercial buildings (such as offices or factories), these can be extremely intricate systems taking up large amounts of space (sometimes located in separate areas or double floors / false ceilings) and constitute a big part of the regular maintenance required.

### Conveying systems

Systems for transport of people within buildings:

- Elevator
- Escalator
- Moving sidewalk (horizontal and inclined)

Systems for transport of people between interconnected buildings:

- Skyway
- Underground city

# Building damage

A building in Massueville, Quebec, Canada engulfed by fire.

Buildings may be damaged during the construction of the building or during maintenance. There are several other reasons behind building damage like accident. Buildings also may suffer from fire damage and flooding in special circumstances.

Chapter- 3

# Agricultural Buildings

## Barn

A barn in Pennsylvania, U.S.

A **barn** is an agricultural building used for storage and as a covered workplace. It may sometimes be used to house livestock or to store farming vehicles and equipment. Barns are most commonly found on a farm or former farm.

A barn meant for keeping cattle may be known as a **byre**.

# Construction

The skeleton of a post and beam horse barn just after raising

Thomas Ranck Round Barn in Fayette County, Indiana, U.S.

Older barns were usually built from lumber sawn from timber on the farm, although stone barns were sometimes built in areas where stone was a cheaper building material.

Modern barns are more typically steel buildings. Prior to the 1900s, most barns were timber framed (also known as post and beam) forming very strong structures to withstand storms and heavy loads of animal feed. From about 1900 to 1940, many large dairy barns were built in northern USA. These commonly have gambrel or hip roofs to maximize the size of the hayloft above the dairy roof, and have become associated in the popular image of a dairy farm. The barns that were common to the wheatbelt held large numbers of pulling horses such as Clydesdales or Percherons. These large wooden barns, especially when filled with hay, could make spectacular fires that were usually total losses for the farmers. With the advent of balers it became possible to store hay and straw outdoors in stacks surrounded by a plowed fireguard. Many barns in the northern United States are painted red with a white trim. One possible reason for this is that ferric oxide, which is used to create red paint, was the cheapest and most readily available chemical for farmers in New England and nearby areas. Another possible reason is that ferric oxide acts a preservative and so painting a barn with it would help to protect the structure.

With the popularity of tractors following World War II many barns were taken down or replaced with modern Quonset huts made of plywood or galvanized steel. Beef ranches and dairies began building smaller loftless barns often of Quonset huts or of steel walls

on a treated wood frame (old telephone or power poles). By the 1960s it was found that cattle receive sufficient shelter from trees or wind fences (usually wooden slabs 20% open).

# Stable

The interior of a stable built for horses

A horse in a box stall, inside a stable

Stables of the Einsiedeln Abbey in Switzerland

A horse stable, over 100 years old, still in use

Traditional style barn, built 1802, still used as a horse stable

A modest stable with a few stalls

A shed row-style stable at a riding club in Panama

A **stable** is a building in which livestock, especially horses, are kept. It most commonly means a building that is divided into separate stalls for individual animals. There are many different types of stables in use today such as the American barn which is a large barn with a door each end and individual stalls inside or free standing stables with the classic top and bottom opening doors. The term "stable" is also used to describe a group of animals kept by one owner, regardless of housing or location.

The exterior design of a stable can vary widely, based on climate, building materials, historical period, and cultural styles of architecture. A wide range of building materials can be used, including masonry (bricks or stone), wood, and steel. Stables can range widely in size, from a small building to house only one or two animals, to facilities used at agricultural shows or at race tracks, which can house hundreds of animals.

# Other uses

Historically, the headquarters of a unit of cavalry, not simply their horses' accommodation, would be called a stable.

Used metaphorically from this origin, a stable is a collection of people (e.g. professional wrestlers) working under a single manager.

Historical stables in Great Britain had a hayloft on the first floor and a pitching door at the front. Doors and windows were symmetrically arranged. Interior was divided into stalls - a large stall was for a foaling mare or sick horse. The floors were cobbled, and later of brick, with drainage channels laid across the floors. Outside steps to the first floor were common for farm hands to live in the building.

The stable is typically historically the second oldest building type on the farm. Free-standing stables began to be built from the 16th century. They were well built and placed near the house due to the value that the horses had as draught animals. High-status examples could have plastered ceilings to prevent dust falling through into the horses' eyes. Complete interiors – with stalls, mangers and feed racks – of the 19th century and earlier are rare.

**Chapter- 4**

# Tower Block

A high-rise residential apartment building in Hong Kong

A 16 floor tower block in Charlestown, Greater Manchester, United Kingdom

A **tower block**, **high-rise**, **apartment tower**, **office tower**, **apartment block**, or **block of flats**, is a tall building or structure used as a residential and/or office building. In some areas they may be referred to as "MDU" standing for "Multi Dwelling Unit".

High-rise buildings became possible with the invention of the elevator (lift) and cheaper, more abundant building materials. The materials used for the structural system of high-rise buildings are reinforced concrete and steel. Most North American style skyscrapers have a steel frame, while residential blocks are usually constructed out of concrete.

High-rise structures pose particular design challenges for structural and geotechnical engineers, particularly if situated in a seismically active region or if the underlying soils

have geotechnical risk factors such as high compressibility or bay mud. They also pose serious challenges to firefighters during emergencies in high-rise structures. New and old building design, building systems like the building standpipe system, HVAC systems (Heating, Ventilation and Air conditioning), fire sprinkler system and other things like stairwell and elevator evacuations pose significant problems.

Apartment blocks have technical and economic advantages in areas with high population density. They have become a distinguished form of housing accommodation in virtually all densely populated urban areas around the world. In contrast with low-rise and single-family houses, apartment blocks accommodate more inhabitants per unit of area of land they occupy and also decrease the cost of municipal infrastructure.

# History

These tower blocks were built in Shibam, Yemen in the 16th century, and are the tallest mudbrick buildings in the world

High-rise apartment buildings had already appeared in antiquity: the insulae in ancient Rome and several other cities in the Roman Empire, some of which might have reached up to 10 or more stories, one reportedly having 200 stairs. Because of the destruction caused by poorly-built high-rise insulae collapsing, several Roman emperors, beginning with Augustus (r. 30 BC - 14 AD), set limits of 20–25 metres for multi-story buildings, but met with limited success, as these limits were often ignored despite the likelihood of taller insulae collapsing. The lower floors were typically occupied by either shops or wealthy families, while the upper stories were rented out to the lower classes. Surviving Oxyrhynchus Papyri indicate that seven-storey buildings even existed in provincial towns, such as in 3rd century AD Hermopolis in Roman Egypt.

In Arab Egypt, the initial capital city was Fustat. It housed many high-rise residential buildings, some seven stories tall that could reportedly accommodate hundreds of people. Al-Muqaddasi in the 10th century described them as resembling minarets, while Nasir Khusraw in the early 11th century described some of them rising up to 14 stories, with roof gardens on the top storey complete with ox-drawn water wheels for irrigating them. By the 16th century, Cairo also had high-rise apartment buildings where the two lower floors were for commercial and storage purposes and the multiple stories above them were rented out to tenants.

The skyline of many important medieval cities was dominated by large numbers of high-rising urban towers which fulfilled defensive, but also representative purposes. The residential Towers of Bologna numbered between 80 to 100 at a time, the largest of which still rise to 97.2 m. In Florence, a law of 1251 decreed that all urban buildings should be reduced to a height of less than 26 m, the regulation immediately put into effect. Even medium-sized towns such as San Gimignano are known to have featured 72 towers up to 51 m height.

Tower blocks were built in the Yemeni city of Shibam in the 16th century. The houses of Shibam are all made out of mud bricks, but about 500 of them are tower houses, which rise 5 to 16 stories high, with each floor having one or two apartments. This technique of building was implemented in order to protect residents from Bedouin attacks. While Shibam has existed for around 2,000 years, most of the city's houses come mainly from the 16th century. The city has the tallest mud buildings in the world, with some of them over 30 meters (100 feet) high. Shibam has been called "one of the oldest and best examples of urban planning based on the principle of vertical construction" or "Manhattan of the desert".

Currently, the tallest high-rise apartment building in the world is Chicago's John Hancock Center, constructed under the supervision of Skidmore, Owings & Merrill and completed in 1969. The building has 100 stories and stands at 344 meters tall.

# Modern development

## United Kingdom

The three tower blocks of the Crossways Estate in Bow, London, United Kingdom

Tower blocks were built in the UK after the Second World War. The first residential tower block, "The Lawn" was constructed in Harlow, Essex in 1951; it is now a Grade II listed building. In many cases Tower Blocks were seen as a "quick-fix" to cure problems caused by crumbling and unsanitary 19th century dwellings or to replace buildings destroyed by German aerial bombing. Initially, they were welcomed, and their excellent views made them popular living places. Later, as the buildings themselves deteriorated,

they grew a reputation for being undesirable low cost housing, and many tower blocks saw rising crime levels, increasing their unpopularity. One response to this was the great increase in the number of housing estates built, which in turn brings its own problems. In the UK, tower blocks particularly lost popularity after the partial collapse of Ronan Point in 1968. Glasgow, the largest city in Scotland, is believed to contain the highest concentration of tower blocks in the UK - examples include the Hutchesontown C blocks in the Gorbals, the 20-storey blocks in Sighthill, and the 31-storey Red Road flats in the city's north east. However, on the whole, London has the largest number of high-rise residential buildings in the UK.

The post-war British tower block vision

Post-war Britain was the stage for a tower block building ‘boom’; from the 1950s to the late 1970s there was a dramatic increase in tower block construction. During this time, local authorities desired to impress their voters by building futuristic and imposing tower blocks, which would signify post-war progress. Both Patrick Dunleavy and Lynsey Hanley agree that architects and planners were influenced by Le Corbusier’s promotion of high-rise architecture. The modern tower blocks were to include features that would foster desired forms of resident interaction, an example being the inclusion of Le Corbusier’s streets in the sky in some estates.

As well as inspiring residents, local authority planners believed that the way tower blocks were constructed would save money. Generally, the tower blocks were built on cheap greenfield land skirting established cities. Although the property prices for these periphery sites were markedly cheaper than their inner city counterparts, they often had little access to public amenities, such as public transport. It was thought that the implementation of industrialised building techniques would lower costs too, as similar tower blocks would be replicated over many sites. Uniform and standardised parts, such as toilet fittings and door handles, would be fitted throughout many tower blocks – planners deemed that buying in bulk would reduce overall costs.

Another key aspect of the tower block vision was the 'Brutalist' architectural method, popular with architects and planners at the time. The Brutalist emphasis led to the construction of stark and striking tower blocks with large sections of exposed concrete. Concrete was to be an integral part of the tower block designs; it could be poured on site, offering boundless flexibility to the building designers. To the planners, concrete was a silver bullet for the construction process – it was economical, and 'was vaunted as being long-lasting, if not indestructible'.

The post war British tower block reality

Elmet Towers in Swarcliffe, Leeds, showing the dereliction that led to its demolition

Coleman's 1985 work argues that in trying to emulate Le Corbusier's ideas, the tower block planners only succeeded in encouraging social problems. Although architects and local authorities intended the opposite, tower blocks quickly became, as Hanley sharply stated, 'slums in the sky'. Due to demanding deadlines, complicated construction practices were rushed and many tower blocks experienced structural decay as a result – roofs leaked, concrete suffered spalling, steel corroded, and damp penetrated the buildings. Unfortunately, by replicating tower blocks across the nation, planners 'disastrously' replicated design faults. In many tower blocks, concrete quickly exhibited signs of decay; cracks soon formed and destabilised the buildings. The partial collapse of the Ronan Point tower block is an infamous example of the hasty and substandard construction that occurred in a number of the towers. The tower blocks quickly lost their 'futuristic' look; concrete turned from the crisp white the designers had imagined to a dull grey, stained by pollution.

Poor design decisions ruined the anticipated benefits of the buildings. Open spaces, which were supposed to benefit the residents, were instead unattractive, unused and inadequately supervised. Residents felt it was difficult to maintain the large open spaces around the blocks because they realistically belonged to no one. Social problems increased as the tower blocks quickly degraded through poor maintenance and an insecure communal environment. Apart from frequent break-downs, communal lifts were a source of fear for people travelling alone. It was a rarity to 'enter a clean-smelling, undefaced lift'. The tower blocks, many of which were located on the periphery of the city, made residents feel isolated and cut off from society. Outsiders and newcomers were

also affected; they felt the overbearing design of the tower blocks made them fearsome and unsociable.

Power argues that as a direct consequence of their design and construction, security problems were prevalent in many of the tower blocks. Break-ins, vandalism and muggings were common, which were aided by the buildings' concealed areas, the mazes of internal corridors, and dark corners. Police were often required in the tower blocks, but their infrequent presence did little to pacify towers rife with delinquency. In order to contain disruptive behaviour, local authorities began to place 'problem families' in the same blocks; Hanley argues that this policy only led to 'further alienation …nihilism and a creeping sense of lawlessness'. Dunleavy seconds this, suggesting that the mental health of long term tower block residents may have been detrimentally affected.

While local authorities and their architects intended to create tower blocks that encouraged harmonious and vibrant communities, often the results were far from ideal. Post-war tower blocks were compromised from the outset by a combination of faults: local authorities advocated impractical architectural methods; design and construction faults were frequently reproduced; and there appeared to be a lack of understanding about the social consequences of certain design features. Collectively, these oversights transformed many tower blocks into undesirable places to live.

Towards the present day

In recent years, some council or ex-council high-rises in the United Kingdom, including Trellick Tower, Keeling House, Sivill House and The Barbican Estate, have become popular with young professionals due to their excellent views, desirable locations and architectural pedigrees, and now command high prices. There are plans to redevelop the Little London and Lovell Park areas on the fringes of Leeds city centre into luxury flats for 'Young Urban Professionals'. The plans entail demolishing all of the council housing and refurbishing the highrise flats. This demand has led to many councils rethinking plans regarding their demolition.

After a gap of around 30 years, new high-rise flats are once again being built in Belfast, Birmingham, Cardiff, Glasgow, Leeds, Liverpool, London, Manchester and Newcastle; but this time for wealthy professionals, rather than the `lower classes`. Their developers market these properties by using the American term 'apartment buildings', perhaps in an effort to distance these newer buildings from the older tower blocks from the 1950s and 1960s. These are usually taller than their older counterparts and generally built in and around these provincial city centres. They are often glass and aluminum clad. Tonight with Trevor McDonald highlighted that in Leeds and Manchester (perhaps the cities that had seen most development) only approximately half were occupied and with owner occupation often being as low as 10%.

Tower blocks in Northern Ireland were never built to the frequency as they were in other cities in Britain and Ireland. Most tower blocks and flat complexes are found in Belfast and Derry, although many of these have been demolished in recent years and replaced

with traditional public housing units. The Divis flats complex in west Belfast was built in between 1968 and 1972 was demolished in the early 1990s as the residents demanded new houses due to mounting problems with the flats. Divis Tower, built separately in 1966, still stands, however; and, in 2007, work began to convert the former British Army base at the top two floors into new dwellings.

In the north of the City, the iconic 7 towers complex in the New Lodge remains, although so too the problems that residents face, such as poor piping and inadequate sanitation. Farther north, the 4 tower blocks in Rathcoole still dominate the local skyline, while in south Belfast, the tower blocks in Seymour Hill also remain standing.

## Ireland

Flats in Ballymun, Dublin, Ireland

Most of the tower blocks in Northern Ireland are in Belfast. All of Belfast's flat complexes were built by Belfast Corporation as part of Belfast slum clearances and to solve the housing problem. The Ballymun Flats were built between 1966 and 1969

consisting of seven 15-storey towers, nineteen 8 storey blocks and ten 4 storey blocks. Inner Dublin flat complexs include Sheriff Street (demolished), Fatima Mansions (demolished and redeveloped), St. Joseph's Gardens (demolished; replaced by Killarney Court flat complex), St. Teresa's Gardens, Dolphin House, Liberty House, St. Michael's Estate and O'Devaney Gardens and a lot more mainly throughout the North and South Inner City of Dublin. Suburban flat complexes were built exclusively on the northside of the city in Ballymun, Coolock and Kilbarrack. These flats were badly affected by a heroin epidemic that hit working-class areas of Dublin in the 1980s and early 90s.

Over the last five years the largest cities such as Dublin, Cork, Limerick and Galway have witnessed new large apartment building. Some large towns such as Navan, Drogheda, Dundalk and Mullingar have also witnessed lots of modern apartments being built.

## Eastern Europe

Russia is currently undergoing a dramatic buildout, growing a commercially-shaped skyline. Russians, both poor and wealthy, from Soviet time had conserved the impression of prestige about tower blocks.

## East Asia

The unpopularity of tower blocks in Europe is in marked contrast to many Asian countries.


Typical Tower block apartment in South Korea

In South Korea the tower blocks are called "Apartment Complex *(Apartment Danji)*". The first residential towers began to be built after the Korean War. The South Korean government needed to build many apartment complexes in the cities to be able to accommodate the citizens. In the 60 years since, as the population increased considerably, tower blocks have become more common. This time however the new tower blocks integrated shopping malls, parking system and other convenient facilities.

In Singapore and urban Hong Kong, land prices are so high that almost the entire population lives in high-rise apartments. In fact, over 60% of Hong Kong residents live in apartments, many of them condominiums. Tower Palace in Seoul, South Korea, is the tallest apartment complex in Asia.

## Canada

In Canada tower blocks are usually known as *apartment buildings* or *apartment blocks*. Toronto contains the second largest concentration of high-rise apartment buildings in North America. Many were built in the 1950s and 1960s to provide modern affordable housing in what was then the periphery of the city, following what had become popular in many European nations; notably France. Today, many lie isolated from amenities and rapid transit corridors, and a few have become plagued by crime such as those around Jane and Finch, Malvern, and Regent Park neighbourhoods. Except for public housing, the construction of apartment blocks has declined in Toronto since the 1970s, and most multi-unit buildings since then have been built as condominiums. Furthermore, public housing is increasingly being combined with private condominium development, such as with the redevelopment of Regent Park.

"Residential high-rises" are also extensively used in Vancouver downtown, leading to very high population downtown. Many of the newly built high-rises are luxury apartments that command prices higher than those than detached housing in the area.

## United States

In the United States tower blocks are commonly referred to as "midrise" or "highrise apartment buildings", depending on their height, while buildings that house fewer flats (apartments), or are not as tall as the tower blocks, are called "lowrise apartment buildings".

Some of the first residential towers were the Castle Village towers in New York City completed in 1939. Their cross-shaped design was copied in towers in Parkchester and Stuyvesant Town residential developments.

The government's experiments in the 1960s and 70s to use high-rise apartments as a means of providing the housing solution for the poor resulted in a spectacular failure. All but a few high-rise housing projects in the nation's largest cities, such as Cabrini–Green and Robert Taylor Homes in Chicago, Penn South in New York and the Desire projects in New Orleans, fell victim to the "ghettofication" and are now being torn down, renovated, or replaced.

In contrast to their public housing cousins, commercially developed high-rise apartment buildings continue to flourish in cities around the country largely due to high land prices and the housing boom of the 2000s. The Upper East Side in New York City and Chicago's Gold Coast, both featuring high-rise apartments, are the wealthiest urban neighborhoods in the United States.

Currently, the tallest high-rise apartment building and tower block in the world is Chicago's John Hancock Center, constructed by Bangladeshi engineer Fazlur Khan in 1969. The building has 100 stories and stands at 344 meters tall.

## Australia

Housing commission towers in Waterloo, Sydney, Australia

High-rise living in Australia was limited to small pockets of bohemian inner Sydney until the 1960s, where a short-lived fashion saw public housing tenants located in new high-rise developments, especially in Sydney and Melbourne. Due to the stigma these enormous and impersonal developments gained, high-rise living fell out of favour until a new wave of developments aimed at the affluent inner urban middle class began from the 1970s onwards. Developers have enthusiastically adopted the term 'apartment' for these new high-rise blocks, perhaps to avoid the stigma still attached to housing commission flats.

# Definition

Although there is no precise definition that is universally accepted, various bodies have tried to define what 'high-rise' means:

- Emporis Standards defines a high-rise as "A multi-story structure between 35-100 meters tall, or a building of unknown height from 12-39 floors."
- According to the building code of Hyderabad, India, a high-rise building is one with four floors or more, or one 15 meters or more in height.
- The *New Shorter Oxford English Dictionary* defines a high-rise as "a building having many stories".
- The *International Conference on Fire Safety in High-Rise Buildings* defined a high-rise as "any structure where the height can have a serious impact on evacuation"
- Massachusetts, United States General Laws define a high-rise as being higher than 70 feet (21 m).
- Most building engineers, inspectors, architects and similar professions define a high-rise as a building that is at least 75 feet (23 m) tall.

# Streets in the sky

"Street in the sky" at Park Hill

Streets in the sky is a term used to describe a style of architecture that emerged in Britain in the 1960s and 1970s. Generally built to replace run-down terraced housing, the new designs included not only modern improvements such as inside toilets, but also shops and other community facilities within high-rise blocks. Examples of the buildings and developments are Trellick Tower, Balfron Tower, Robin Hood Gardens and Keeling House in London, Hunslet Grange in Leeds and Park Hill, Sheffield. These were an attempt to develop a new architecture, differentiated from earlier large housing estates, such as Quarry Hill flats in Leeds.

Alison and Peter Smithson were the architects of Robin Hood Gardens. Another large example, the Aylesbury Estate in South London, built in 1970, is about to be demolished.

## Deck access

Deck access is a term used to describe flats that are accessed from a walkway that is open to the elements, as opposed to flats that are accessed from fully enclosed internal corridors. Deck access blocks of flats are usually fairly low-rise structures. The decks can vary from simple walkways, which may be covered or uncovered, to decks wide enough for small vehicles. The best known example of deck-access flats in the UK is Park Hill, Sheffield, where the decks are wide enough to allow electric vehicles, however the design is inspired by French Modernist architect Le Corbusier, particularly his Unite D'Habitation in Marseilles.

## Chapter- 5

# Skyscraper

A **skyscraper** is a tall, continuously habitable building. There is no official definition or height above which a building may clearly be classified as a skyscraper. Most cities define the term empirically; even a building of 80 meters (262 feet) may be considered a skyscraper if it protrudes above its built environment and changes the overall skyline.

## Definition

The Burj Khalifa in Dubai, UAE is currently the tallest skyscraper in the world

The word "skyscraper" originally was a nautical term referring to a small triangular sail set above the skysail on a sailing ship. The term was first applied to buildings in the late 19th century as a result of public amazement at the tall buildings being built in Chicago and New York City. The first skyscraper was for many years thought to be the Home Insurance Building built in Chicago, Illinois in 1885. More recent arguments point to New York's seven floor Equitable Life Assurance Building built in 1870 and it was arguably the first office building built using a kind of skeletal frame but it depends on what factors are chosen and even the scholars making the argument find it academic.

The structural definition of the word *skyscraper* was refined later by architectural historians, based on engineering developments of the 1880s that had enabled construction of tall multi-storey buildings. This definition was based on the steel skeleton—-as opposed to constructions of load-bearing masonry, which passed their practical limit in 1891 with Chicago's Monadnock Building. Philadelphia's City Hall, completed in 1901, still holds claim as the world's tallest load-bearing masonry structure at 167 m (548 ft). The steel frame developed in stages of increasing self-sufficiency, with several buildings in Chicago and New York advancing the technology that allowed the steel frame to carry a building on its own. Today, however, many of the tallest skyscrapers are built almost entirely with reinforced concrete. Pumps and storage tanks maintain water pressure at the top of skyscrapers.

**Skyscraper and supertall**

A loose convention in the United States and Europe now draws the lower limit of a skyscraper at 150 meters (~500 ft). A skyscraper taller than 300 meters (~1000 ft) may be referred to as *supertall*. Shorter buildings are still sometimes referred to as skyscrapers if they appear to dominate their surroundings.

The somewhat arbitrary term *skyscraper* should not be confused with the also ill-defined term *high-rise*. The Emporis Standards Committee defines a high-rise building as "a multi-story structure between 35-100 meters tall, or a building of unknown height from 12-39 floors" and a skyscraper as "a multi-story building whose architectural height is at least 100 meters." Some structural engineers define a highrise as any vertical construction for which wind is a more significant load factor than earthquake or weight. Note that this criterion fits not only high rises but some other tall structures, such as towers.

The word *skyscraper* often carries a connotation of pride and achievement. The skyscraper, in name and social function, is a modern expression of the age-old symbol of the world center or *axis mundi*: a pillar that connects earth to heaven and the four compass directions to one another.

# History

## Before the 19th century

The Great Pyramid of Giza, *circa* 2560 BC, was 146 m tall and its height was unsurpassed until at least the 14th century AD.

The Two Towers of Bologna in the 12th century reached 97.2 m in height.

The 16th-century city of Shibam consisted entirely of over 500 high-rise tower houses.

Modern skyscrapers are built with materials such as steel, glass, reinforced concrete and granite, and routinely utilize mechanical equipment such as water pumps and elevators. Until the 19th century, buildings of over six stories were rare, as having great numbers of stairs to climb was impractical for inhabitants, and water pressure was usually insufficient to supply running water above 50 m (164 ft).

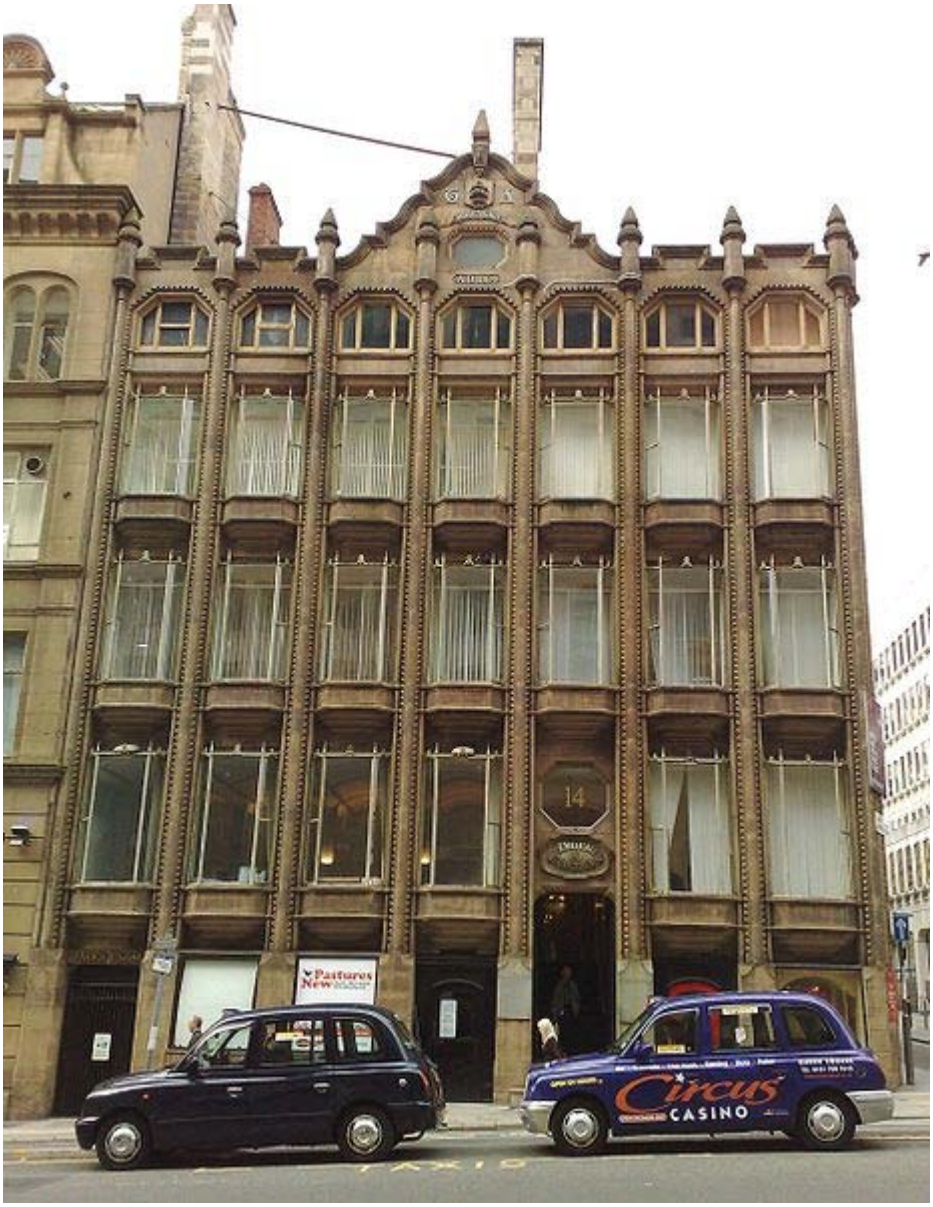
The tallest building in ancient times was the Great Pyramid of Giza in ancient Egypt, which was 146 metres (479 ft) tall and was built in the 26th century BC. Its height was not surpassed for thousands of years, possibly until the 14th century AD with the construction of Lincoln Cathedral (though its height is disputed), which in turn was not surpassed in height until the Washington Monument in 1884. However, being uninhabited buildings, none of these buildings actually complies with the definition of a skyscraper.

High-rise apartment buildings already flourished in classical antiquity: ancient Roman insulae in Rome and other imperial cities reached up to 10 and more stories. Several emperors, beginning with Augustus (r. 30 BC-14 AD), attempted to establish limits of 20–25 m for multi-storey buildings, but met with only limited success. The lower floors were typically occupied by either shops or wealthy families, while the upper stories were rented out to the lower classes. Surviving Oxyrhynchus Papyri indicate that seven-storey buildings even existed in provincial towns, such as in 3rd century AD Hermopolis in Roman Egypt.

The skylines of many important medieval cities had large numbers of high-rise urban towers. Wealthy families built these towers for defensive purposes and as status symbols. The residential Towers of Bologna in the 12th century, for example, numbered between 80 to 100 at a time, the largest of which (known as the "Two Towers") rise to 97.2 metres (319 ft). In Florence, a law of 1251 decreed that all urban buildings should be reduced to a height of less than 26 m, the regulation immediately put into effect. Even medium-sized towns at the time such as San Gimignano are known to have featured 72 towers up to 51 m height.

The medieval Egyptian city of Fustat housed many high-rise residential buildings, which Al-Muqaddasi in the 10th century described as resembling minarets. Nasir Khusraw in the early 11th century described some of them rising up to 14 stories, with roof gardens on the top floor complete with ox-drawn water wheels for irrigating them. Cairo in the 16th century had high-rise apartment buildings where the two lower floors were for commercial and storage purposes and the multiple stories above them were rented out to tenants. An early example of a city consisting entirely of high-rise housing is the 16th-century city of Shibam in Yemen. Shibam was made up of over 500 tower houses, each one rising 5 to 11 storeys high, with each floor being an apartment occupied by a single family. The city was built in this way in order to protect it from Bedouin attacks. Shibam still has the tallest mudbrick buildings in the world, with many of them over 100 feet (30 m) high.

An early modern example of high-rise housing was in 17th-century Edinburgh, Scotland, where a defensive city wall defined the boundaries of the city. Due to the restricted land area available for development, the houses increased in height instead. Buildings of 11 stories were common, and there are records of buildings as high as 14 stories. Many of the stone-built structures can still be seen today in the old town of Edinburgh. The oldest iron framed building in the world, although only partially iron framed, is The Flaxmill (also locally known as the "Maltings"), in Shrewsbury, England. Built in 1797, it is seen as the "grandfather of skyscrapers", since its fireproof combination of cast iron columns and cast iron beams developed into the modern steel frame that made modern skyscrapers possible. Unfortunately, it lies derelict and needs much investment to keep it standing.




Oriel Chambers, Liverpool. The world's first glass curtain walled building. The stone mullions are decorative.

Built in 1931, The Empire State Building in New York City is one of the oldest, yet tallest skyscrapers.

## Early skyscrapers

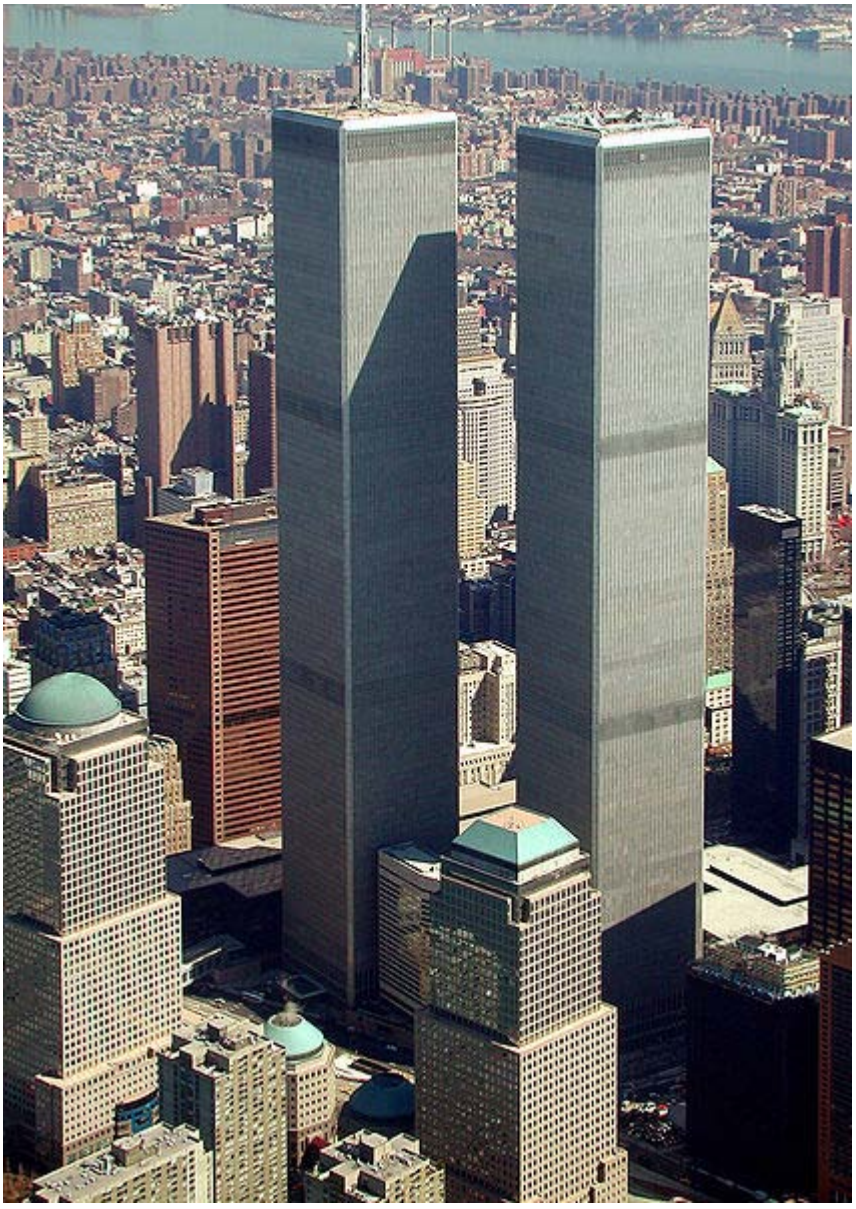
An early development was Oriel Chambers in Liverpool. Designed by local architect Peter Ellis in 1864, the building was the world's first iron-framed, glass curtain-walled office building. It was only 5 floors high as the elevator had not yet been invented. Further developments led to the world's first skyscraper, the ten-storey Home Insurance Building in Chicago, built in 1884–1885. While its height is not considered very impressive today, it was at that time. The architect, Major William Le Baron Jenney, created a load-bearing structural frame. In this building, a steel frame supported the entire

weight of the walls, instead of load-bearing walls carrying the weight of the building. This development led to the "Chicago skeleton" form of construction.

Louis Sullivan's Wainwright Building in St. Louis, 1891, was the first steel-framed building with soaring vertical bands to emphasize the height of the building and is therefore considered by some to be the first true skyscraper.

Most early skyscrapers emerged in the land-strapped areas of Chicago, London, and New York toward the end of the 19th century. A land boom in Melbourne, Australia between 1888-1891 spurred the creation of a significant number of early skyscrapers, though none of these were steel reinforced and few remain today. Height limits and fire restrictions were later introduced. London builders soon found building heights limited due to a complaint from Queen Victoria, rules that continued to exist with few exceptions until the 1950s. Concerns about aesthetics and fire safety had likewise hampered the development of skyscrapers across continental Europe for the first half of the twentieth century (with the notable exceptions of the 17-storey Kungstornen *(Kings' Towers)* in Stockholm, Sweden, which were built 1924-25, probably the first skyscrapers in Europe , the 15-storey Edificio Telefónica in Madrid, Spain, built in 1929; the 26-storey Boerentoren in Antwerp, Belgium, built in 1932; and the 31-storey Torre Piacentini in Genoa, Italy, built in 1940). After an early competition between Chicago and New York City for the world's tallest building, New York took the lead by 1895 with the completion of the American Surety Building, leaving New York with the title of tallest building for many years. New York City developers competed among themselves, with successively taller buildings claiming the title of "world's tallest" in the 1920s and early 1930s, culminating with the completion of the Chrysler Building in 1930 and the Empire State Building in 1931, the world's tallest building for forty years. The first completed World Trade Center tower became the world's tallest building in 1972. However, it was soon overtaken by the Sears Tower (now Willis Tower) in Chicago within two years. The Sears Tower stood as the world's tallest building for 24 years, from 1974 until 1998, until it was edged out by Petronas Twin Towers in Kuala Lumpur, which held the title for six years.

Taipei 101, formerly the world's tallest skyscraper, was the first to exceed the half-kilometer mark.



The iconic World Trade Center twin towers were destroyed in 2001.

The Willis Tower in Chicago was the world's tallest building from 1974 to 1998, and remains the tallest in the Western Hemisphere

The Petronas Twin Towers, the world's tallest twin buildings

Tower 2 of the International Finance Centre in Hong Kong is one of the 20 tallest buildings in the world.

The Commerzbank Tower in Frankfurt/Germany is the tallest completed skyscraper in the European Union.

30 St Mary Axe in London, United Kingdom is an example of a modern environmentally friendly skyscraper.

## Modern skyscrapers

From the 1930s onwards, skyscrapers also began to appear in Latin America (São Paulo, Santiago, Caracas, Bogotá, Mexico City) and in Asia (Tokyo, Shanghai, Hong Kong, Manila, Singapore, Mumbai, Jakarta, Seoul, Kuala Lumpur, Taipei, Bangkok). Immediately after World War II, the Soviet Union planned eight massive skyscrapers dubbed "Stalin Towers" for Moscow; seven of these were eventually built. The rest of Europe also slowly began to permit skyscrapers, starting with Madrid, during the 1950s. Finally, skyscrapers also began to be constructed in cities of Africa, the Middle East and Oceania (mainly Australia) from the late 1950s.

In the early 1960s structural engineer Fazlur Khan realized that the rigid steel frame structure that had "dominated tall building design and construction so long was not the only system fitting for tall buildings", marking "the beginning of a new era of skyscraper revolution in terms of multiple structural systems." His central innovation in skyscraper design and construction was the idea of the "tube" structural system, including the "framed tube", "trussed tube", and "bundled tube". These systems allowed far greater economic efficiency, and also allowed efficient skyscrapers to take on various shapes, no longer needing to be box-shaped. Over the next fifteen years, many towers were built by Khan and the "Second Chicago School", including the massive 442-meter (1,451-foot) Willis Tower. Chicago is currently undergoing an epic construction boom that will greatly add to the city's skyline. Since 2000, at least 40 buildings at a minimum of 50 stories high have been built or planned. The Trump International Hotel and Tower, Waterview Tower, Mandarin Oriental Tower, 29-39 South LaSalle, Park Michigan, and Aqua are some of the more notable projects currently underway in the city. Chicago, Hong Kong, and New York City, otherwise known as "the big three," are recognized in architectural circles as having especially compelling skylines. A landmark skyscraper can inspire a boom of new high-rise projects in its city, as Taipei 101 has done in Taipei since its opening in 2004.

## History of tallest skyscrapers

At the beginning of the 20th century, New York City was a center for the Beaux-Arts architectural movement, attracting the talents of such great architects as Stanford White and Carrere and Hastings. As better construction and engineering technology became available as the century progressed, New York and Chicago became the focal point of the competition for the tallest building in the world. Each city's striking skyline has been composed of numerous and varied skyscrapers, many of which are icons of 20th century architecture:

- The **Flatiron Building**, designed by Daniel Hudson Burnham and standing 285 ft (87 m) high, was one of the tallest buildings in the city upon its completion in 1902, made possible by its steel skeleton. It was one of the first buildings designed with a steel framework, and to achieve this height with other construction methods of that time would have been very difficult. (The 1889 Tower Building, designed by Bradford Gilbert and considered by some to be New York's first skyscraper, may have been the first building to use a skeletal steel frame.) Subsequent buildings such as the **Singer Building**, the **Metropolitan Life Tower** were higher still.
- The **Woolworth Building**, a neo-Gothic "Cathedral of Commerce" overlooking City Hall, was designed by Cass Gilbert. At 792 feet (241 m), it became the world's tallest building upon its completion in 1913, an honor it retained until 1930, when it was overtaken by 40 Wall Street.
- That same year, the **Chrysler Building** took the lead as the tallest building in the world, scraping the sky at 1,046 feet (319 m). Designed by William Van Alen, an art deco masterpiece with an exterior crafted of brick, the Chrysler Building continues to be a favorite of New Yorkers to this day.

- The **Empire State Building**, the first building to have more than 100 floors (it has 102), was completed the following year. It was designed by Shreve, Lamb and Harmon in the contemporary Art Deco style. The tower takes its name from the nickname of New York State. Upon its completion in 1931 at 1,250 feet (381 m), it took the top spot as tallest building, and towered above all other buildings until 1972. The antenna mast added in 1951 brought pinnacle height to 1,472 feet (449 m), lowered in 1984 to 1,454 feet (443 m).
- The **World Trade Center** officially reached full height in 1972, was completed in 1973, and consisted of two tall towers and several smaller buildings. For a short time, the first of the two towers was the world's tallest building. Upon completion, the towers stood for 28 years, until the September 11, 2001 attacks destroyed the structures. Various governmental entities, financial firms, and law firms called the towers home.
- The **Willis Tower** (formerly Sears Tower) was completed in 1974, one year after the World Trade Center, and surpassed it as the world's tallest building. It was the first building to employ the "bundled tube" structural system, designed by Fazlur Khan. The building was not surpassed in height until the Petronas Towers were constructed in 1998, but remained the tallest in some categories until Burj Khalifa surpassed it in all categories. It is currently the tallest building in the United States.

Momentum in setting records passed from the United States to other nations with the opening of the **Petronas Twin Towers** in Kuala Lumpur, Malaysia, in 1998. The record for world's tallest building remained in Asia with the opening of **Taipei 101** in Taipei, Taiwan, in 2004. A number of architectural records, including those of the world's tallest building and tallest free-standing structure, moved to the Middle East with the opening of the **Burj Khalifa** in Dubai, UAE.

This geographical transition is accompanied by a change in approach to skyscraper design. For much of the twentieth century large buildings took the form of simple geometrical shapes. This reflected the "international style" or modernist philosophy shaped by Bauhaus architects early in the century. The last of these, the Willis Tower and World Trade Center towers in New York, erected in the 1970s, reflect the philosophy. Tastes shifted in the decade which followed, and new skyscrapers began to exhibit postmodernist influences. This approach to design avails itself of historical elements, often adapted and re-interpreted, in creating technologically modern structures. The Petronas Twin Towers recall Asian pagoda architecture and Islamic geometric principles. Taipei 101 likewise reflects the pagoda tradition as it incorporates ancient motifs such as the ruyi symbol. The Burj Khalifa draws inspiration from traditional Arabic art. Architects in recent years have sought to create structures that would not appear equally at home if set in any part of the world, but that reflect the culture thriving in the spot where they stand.

The following list measures height of the **roof**. The more common gauge is the **highest architectural detail**; such ranking would have included Petronas Towers, built in 1998.

| Built | Building | City | Country | Roof | | Floors | Pinnacle | | Current status |
|---|---|---|---|---|---|---|---|---|---|
| 1873 | Equitable Life Building | New York City | United States | 142 ft | 43 m | 8 | | | Demolished in 1912 |
| 1889 | Auditorium Building | Chicago | United States | 269 ft | 82 m | 17 | 349 ft | 106 m | Standing |
| 1890 | New York World Building | New York City | United States | 309 ft | 94 m | 20 | 349 ft | 106 m | Demolished in 1955 |
| 1894 | Manhattan Life Insurance Building | New York City | United States | 348 ft | 106 m | 18 | | | Demolished in 1930 |
| 1895 | Milwaukee City Hall | Milwaukee | United States | 353 ft | 108 m | 15 | | | Standing |
| 1899 | Park Row Building | New York City | United States | 391 ft | 119 m | 30 | | | Standing |
| 1901 | Philadelphia City Hall | Philadelphia | United States | 511 ft | 155.8 m | 9 | 548 ft | 167 m | Standing |
| 1908 | Singer Building | New York City | United States | 612 ft | 187 m | 47 | | | Demolished in 1968 |
| 1909 | Met Life Tower | New York City | United States | 700 ft | 213 m | 50 | | | Standing |
| 1913 | Woolworth Building | New York City | United States | 792 ft | 241 m | 57 | | | Standing |
| 1930 | 40 Wall Street | New York City | United States | | | 70 | 927 ft | 283 m | Standing |
| 1930 | Chrysler Building | New York City | United States | 927 ft | 282.9 m | 77 | 1,046 ft | 319 m | Standing |
| 1931 | Empire State Building | New York City | United States | 1,250 ft | 381 m | 102 | 1,454 ft | 443 m | Standing |
| 1972 | World Trade Center (North tower) | New York City | United States | 1,368 ft | 417 m | 110 | 1,727 ft | 526.3 m | Destroyed in 2001 |
| 1974 | Willis Tower (formerly Sears Tower) | Chicago | United States | 1,450 ft | 442 m | 108 | 1,729 ft | 527 m | Standing |
| 2004 | Taipei 101 | Taipei | Taiwan | 1,474 ft | 449 m | 101 | 1,671 ft | 509 m | Standing |
| 2010 | Burj Khalifa | Dubai | United Arab Emirates | 2,717 ft | 828 m | 160 | 2,717 ft | 828 m | Standing |

## Today


Skyscrapers can serve as a city's identifier like Auckland's Sky Tower at 328 meters (1,076 feet). Visitors can rappell from the top.

Today, skyscrapers are an increasingly common sight where land is expensive, as in the centres of big cities, because they provide such a high ratio of rentable floor space per unit area of land. They are built not just for economy of space; like temples and palaces of the past, skyscrapers are considered symbols of a city's economic power. Not only do they define the skyline, they help to define the city's identity.

### Supertall towers

At the time Taipei 101 broke the half-kilometer mark in height, it was already technically possible to build structures towering over a kilometer above the ground. Proposals for such structures have been put forward, including the Mile-High Tower to be built in Jeddah, Saudi Arabia and Burj Mubarak Al Kabir in Kuwait. Kilometer-plus structures present architectural challenges that may eventually place them in a new architectural category.

## Future skyscrapers

The following skyscrapers are either approved or due to be completed in the near future:

- The **Lotte Super Tower 123**, a mixed-use skyscraper in Seoul, South Korea, will stand 555 meters (1,821 feet) in height (123 floors) upon completion (originally scheduled for 2014 after construction started in 2005, although the project is currently on hold). The tower will house retail space, residences, and a luxury hotel.
- Construction of the 133-floor, 640m supertall **Digital Media City Landmark Building** in Digital Media City, Seoul, South Korea, started in 2009, which will be the second-tallest building in the world when it is completed in 2015, housing the world's tallest observatory and hotels. Being constructed at the fastest speed among major skyscraper projects by South Korea's Samsung C&T (who also built Burj Khalifa), the supertall is the first skyscraper to contain an entire city inside a building, including the world's largest aquarium, a luxury department store, shopping malls, clinic center, high-tech offices, first-class apartments, six to eight-star hotels, a concert restaurant, a broadcasting studio and an art center.
- Construction of the **Shanghai Tower** started on 29 November 2008. The tower will be 632 m (2,073 ft) high and have 127 floors. The building will feature a glass curtain wall and nine indoor gardens when it is completed in 2014.
- Construction of the 151-floor, 610m supertall **151 Incheon Tower** in Songdo International City, Incheon, South Korea, started in 2008, which will be the tallest twin towers in the world when it is completed in 2014.
- The **Abraj Al-Bait Towers**, also known as the "Mecca Royal Clock Hotel Tower" is a complex under construction in Mecca, Saudi Arabia by the Saudi Binladin Group. The complex consists of seven towers, and the tallest tower (Hotel Tower) will have a height of 601 m (1,972 ft). Upon completion in 2011, the structure will have the largest floor area of any structure in the world, at 1,500,000 square metres (16,137,600 sq ft).
- Construction of the 110-floor, 510m supertall in **Busan Lotte World**, Busan, South Korea, started in 2009, which will be the third tallest building world when it is completed in 2013.
- **1 World Trade Center** is now under construction and is the tallest tower comprising the redevelopment of the site of the former World Trade Center following the attacks of September 11, 2001. Its pinnacle will reach a height of

541.4 m (1,776 ft), a height representing the year of the United States Declaration of Independence.
- The 528 m (1,732 ft), 102 floors **PVN Tower** locale in Hanoi, Vietnam, which was approved, scheduled to construct in 2011 and completed in 2014.The building costs almost $1.2 billions. Upon completion, it will be the tallest and most expensive building in Vietnam and South East Asia.
- **India Tower** (720 metres) is a supertall skyscraper proposed for construction in Mumbai, Maharashtra State, India. In January 2010, the Brihanmumbai Municipal Corporation gave the official go ahead for its construction on a site located at Charni Road, Marine Lines, just north of the city's historical district.
- **World One** is a residential skyscraper (442 metres) under construction in Mumbai,India. It will be located in Upper Worli of Mumbai on the plot of a 17.5 acre site, which Lodha obtained for 250 crore (US$ 56.75 million). The project will cost 2,000 crore (US$ 454 million), be completed by 2014, and will have the world's second tallest residential tower once completed.
- The **Port Tower** is a building planned for Karachi, the financial capital of Pakistan, with the collaboration of local and foreign investors, in association with the Karachi Port Trust. When completed, the new structure will be 1,947 ft (593 m) high. The height of the tower has a special significance, representing the year Pakistan gained independence.
- The 308 m (1,010 ft) **Tour Generali** in Paris La Défense, scheduled to be completed in 2013, is an entirely green building office skyscraper that is set to be the tallest building in Paris and the second tallest in the European Union after the Shard of Glass in London.
- Construction of London's **Shard of Glass** started in March 2009, and is scheduled to be completed in May 2012, in time for the London Olympics. At 310 m (1,017 ft), it is set to be the tallest building in the European Union.

A growing interest exists in a concept adapted from skyscraper, called seascraper. This is a proposed large building which will function as a floating city.

# Sustainability

The skyscraper as a concept is a product of the industrialized age, made possible by cheap energy and raw materials. The amount of steel, concrete and glass needed to construct a skyscraper is vast, and these materials represent a great deal of embodied energy. Tall skyscrapers are very heavy, which means that they must be built on a sturdier foundation than would be required for shorter, lighter buildings. Building materials must also be lifted to the top of a skyscraper during construction, requiring more energy than would be necessary at lower heights. Furthermore, a skyscraper consumes a lot of electricity because potable and non-potable water must be pumped to the highest occupied floors, skyscrapers are usually designed to be mechanically ventilated, elevators are generally used instead of stairs, and natural lighting cannot be utilized in rooms far from the windows and the windowless spaces such as elevators, bathrooms and stairwells.

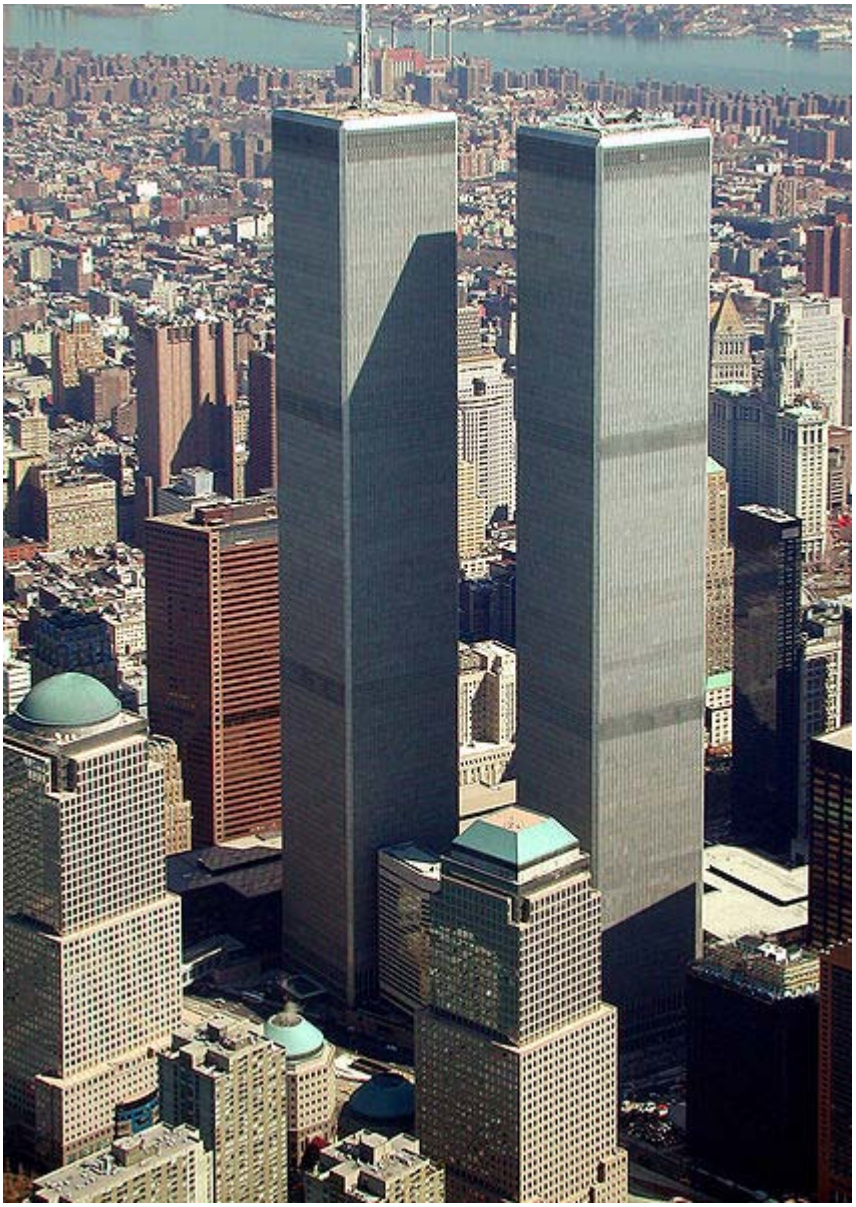
Despite these costs, the size of skyscrapers allows for high-density work and living spaces, reducing the amount of land given over to human development. Mass transit and commercial transport are economically and environmentally more efficient when serving high-density development than suburban or rural development. Also, the total energy expended towards waste disposal and climate control is relatively lower for a given number of people occupying a skyscraper than that same number of people occupying modern housing. Indeed, though the city of Paris, for example, has almost the population density of Manhattan, Paris' stringent building codes and unchanging borders have made it difficult to create the larger buildings and utilities needed for a growing population within the actual city limits. This inflexibility has led many important institutions and departments to locate outside of city limits (such as the La Défense business district).

# Quotations

> “What is the chief characteristic of the tall office building? It is lofty. It must be tall. The force and power of altitude must be in it, the glory and pride of exaltation must be in it. It must be every inch a proud and soaring thing, rising in sheer exaltation that from bottom to top it is a unit without a single dissenting line.”
>
> —Louis Sullivan's *The Tall Office Building Artistically Considered* (1896)

Chapter- 6

# Construction of the World Trade Center



The completed World Trade Center in March 2001

The **construction of the World Trade Center** was conceived as an urban renewal project, spearheaded by David Rockefeller, to help revitalize Lower Manhattan. The project was developed by the Port Authority of New York and New Jersey, which hired architect Minoru Yamasaki who came up with the specific idea for twin towers. After extensive negotiations, the New Jersey and New York State governments, which oversee the Port Authority, agreed to support the World Trade Center project at the Radio Row site on the lower-west side of Manhattan. To make the agreement acceptable to New Jersey, the Port Authority agreed to take over the bankrupt Hudson & Manhattan Railroad (renamed as PATH), which brought commuters from New Jersey to the Lower Manhattan site.

The towers were designed as framed tube structures, which provided tenants with open floor plans, uninterrupted by columns or walls. This was accomplished using numerous closely spaced perimeter columns to provide much of the strength to the structure, along with gravity load shared with the core columns. The elevator system, which made use of sky lobbies and a system of express and local elevators, allowed substantial floor space to be freed up for use as office space by making the structural core smaller. The design and construction of the World Trade Center twin towers involved many other innovative techniques, such as the slurry wall for digging the foundation, and wind tunnel experiments. Construction of the World Trade Center's North Tower began in August 1968, and the South Tower in 1969. Extensive use of prefabricated components helped to speed up the construction process. The first tenants moved into the North Tower in December 1970 and into the South Tower in January 1972. Four other low-level buildings were constructed as part of the World Trade Center in the 1970s, and a seventh building was constructed in the mid-1980s.

# Planning

In 1942, Austin J. Tobin became the Executive Director of the Port Authority, beginning a 30-year career during which he oversaw the planning and development of the World Trade Center. The concept of establishing a "world trade center" was conceived during the post-World War II period, when the United States thrived economically and international trade was increasing. In 1946, the New York State Legislature passed a bill that called for a "world trade center" to be established. The World Trade Corporation was founded, and a board was appointed by New York Governor Thomas E. Dewey to develop plans for the project. Architect John Eberson and his son Drew devised a plan that included 21 buildings over a ten-block area, at an estimated cost of $150 million. In 1949, the World Trade Corporation was dissolved by the New York State Legislature, and plans for a "world trade center" were put on hold.

## Original plans

Architect's model for the proposed World Trade Center on the East River

During the post-war period, economic growth was concentrated in Midtown Manhattan, in part stimulated by the Rockefeller Center, which was developed in the 1930s. Meanwhile, Lower Manhattan was left out of the economic boom. One exception was the construction of One Chase Manhattan Plaza in the Financial District by David Rockefeller, who led urban renewal efforts in Lower Manhattan. In 1958, Rockefeller established the Downtown-Lower Manhattan Association (DLMA), which commissioned Skidmore, Owings and Merrill to draw up plans for revitalizing Lower Manhattan. The plans, made public in 1960, called for a World Trade Center to be built on a 13-acre (53,000 $m^2$) site along the East River, from Old Slip to Fulton Street and between Water Street and South Street. The complex would include a 900-foot (275 m) long exhibition hall, and a 50–70 story building, with some of its upper floors used as a hotel. Other amenities would include a theater, shops, and restaurants. The plan also called for a new securities exchange building, which the Downtown-Lower Manhattan Association hoped would house the New York Stock Exchange.

David Rockefeller suggested that the Port Authority would be a logical choice for taking on the project, and argued that the Trade Center would provide great benefits in facilitating and increasing volume of international commerce coming through the Port of

New York. Given the importance of New York City in global commerce, Port Authority director Austin J. Tobin remarked that the proposed project should be *the* World Trade Center, and not just *a* "world trade center". After a year-long review of the proposal, the Port Authority formally backed the project on 11 March 1961.

## Agreement


Location of World Trade Center and originally proposed site

The States of New York and New Jersey also needed to approve the project, given their control and oversight role of the Port Authority. Objections to the plan came from New Jersey Governor Robert B. Meyner, who resented that New York would be getting this $335 million project. Meanwhile, ridership on New Jersey's Hudson and Manhattan Railroad (H&M) had declined substantially from a high of 113 million riders in 1927 to 26 million in 1958, after new automobile tunnels and bridges opened across the Hudson River. Toward the end of 1961, negotiations with outgoing New Jersey Governor Meyner regarding the World Trade Center project reached a stalemate. In December 1961, Tobin met with newly elected New Jersey Governor Richard J. Hughes, and made a proposal to shift the World Trade Center project to a west side site where the Hudson Terminal was located. In acquiring the Hudson & Manhattan Railroad, the Port Authority would also

acquire the Hudson Terminal and other buildings which were deemed obsolete. On 22 January 1962, the two states reached an agreement to allow the Port Authority to take over the railroad and to build the World Trade Center on Manhattan's lower west side. The shift in location for the World Trade Center to a site more convenient to New Jersey, together with Port Authority acquisition of the H&M Railroad, brought New Jersey to agreement in support of the World Trade Center project.

## Controversy

Even once the agreement between the states of New Jersey, New York, and the Port Authority was finalized, the World Trade Center plan faced continued controversy. The site for the World Trade Center was the location of Radio Row, which was home to hundreds of commercial and industrial tenants, property owners, small businesses, and approximately 100 residents. The World Trade Center plans involved evicting these business owners, some of whom fiercely protested the forced relocation. In June 1962, a group representing approximately 325 shops and 1,000 other affected small businesses filed an injunction, challenging the Port Authority's power of eminent domain. The dispute with local business owners worked its way through the court system, up to the New York State Court of Appeals, which in April 1963 upheld the Port Authority's right of eminent domain, saying that the project had a "public purpose." On 12 November 1963, the United States Supreme Court refused to accept the case. Under the state law, the Port Authority was required to assist business owners in relocating, though many business owners regarded what the Port Authority offered as inadequate. Questions continued while the World Trade Center was constructed, as to whether the Port Authority really ought to take on the project, described by some as a "mistaken social priority."

Private real estate developers and members of the Real Estate Board of New York also expressed concerns about this much "subsidized" office space going on the open market, competing with the private sector when there was already a glut of vacancies. An especially vocal critic was Lawrence A. Wien, owner of the Empire State Building, which would lose its title of tallest building in the world. Wien organized a group of builders into a group called the "Committee for a Reasonable World Trade Center" to demand that the project be scaled down.

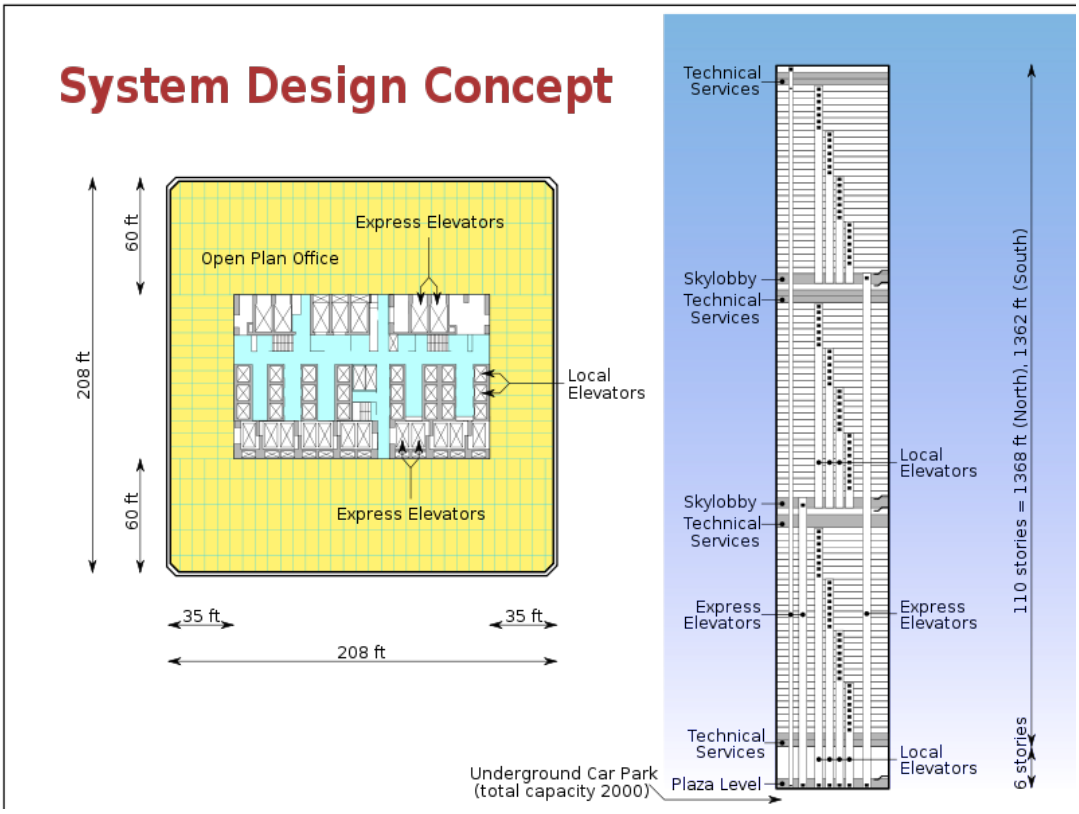
In January 1964, the Port Authority inked a deal with the State of New York to locate government offices at the World Trade Center. The Port Authority began signing commercial tenants in the spring and summer of 1964, including several banks. In 1965, the Port Authority signed the United States Customs Service as a tenant.

A final obstacle for the Port Authority was getting approval from New York City Mayor John Lindsay and the New York City Council, who raised concerns about the limited extent that the Port Authority involved the city in the negotiations and deliberations. Negotiations between The City of New York and the Port Authority were centered on tax issues. A final agreement was made on 3 August 1966, that the Port Authority would make annual payments to the City, in lieu of taxes, for the portion of the World Trade

Center leased to private tenants. In subsequent years, the payments would rise as the real estate tax rate increased.

## Design

On 20 September 1962, the Port Authority announced the selection of Minoru Yamasaki as lead architect, and Emery Roth & Sons as associate architects. Originally, Yamasaki submitted to the Port Authority a concept incorporating twin towers, but with each building only 80 stories tall. Yamasaki remarked that the "obvious alternative, a group of several large buildings, would have looked like a housing project."




A typical floor layout and elevator arrangement of the WTC towers

To meet the Port Authority's requirement to build 10 million square feet (930,000 m²) of office space, the buildings would each need to be 110 stories tall. A major limiting factor in building heights is elevators; the taller the building, the more elevators are needed to service the building, requiring more space-consuming elevator banks. Yamasaki and the engineers decided to use a new system that included sky lobbies, which are floors where people can switch from a large-capacity express elevator, which goes only to the sky lobbies, to a local elevator that goes to each floor in a section (the local elevators can be stacked within the same elevator shaft). Located on the 44th and 78th floors of each tower, the sky lobbies enabled the elevators to be used efficiently, while also increasing the amount of usable space on each floor from 62 to 75 percent by reducing the number

of required elevator shafts. The World Trade Center towers were the second supertall buildings to use sky lobbies, after the John Hancock Center in Chicago. This system was inspired by the New York City Subway system, whose lines include local stations where local trains stop and express stations where all trains stop.

Original architectural and engineering model

Yamasaki's design for the World Trade Center was unveiled to the public on 18 January 1964, with an eight-foot model. The towers had a square plan, approximately 207 feet (63 m) in dimension on each side. The buildings were designed with narrow office windows, only 18 inches (45 cm) wide, which reflected on Yamasaki's fear of heights and desire to make building occupants feel secure. Yamasaki's design called for the

building facades to be sheathed in aluminum-alloy. In all, the World Trade Center complex contained six buildings within the 16-acre (65,000 $m^2$) superblock.

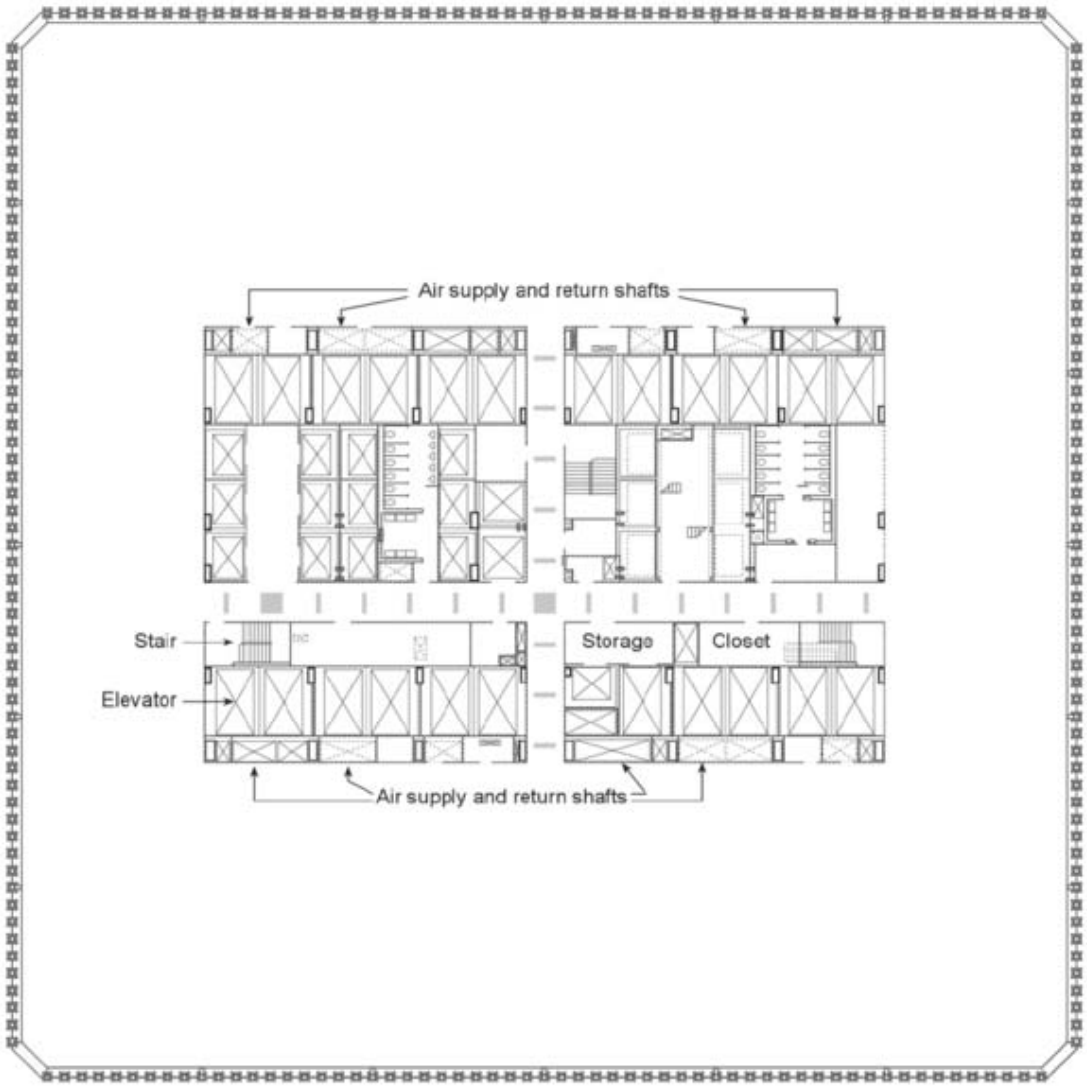
The World Trade Center design brought criticism of its aesthetics from the American Institute of Architects and other groups. Lewis Mumford, author of *The City in History* and other works on urban planning, criticized the project and described it and other new skyscrapers as "just glass-and-metal filing cabinets." Television broadcasters raised concerns that the World Trade Center twin towers would cause interference in television reception for viewers in the New York City area. In response to these concerns, the Port Authority offered to provide new television transmission facilities at the World Trade Center. The Linnaean Society of the American Museum of Natural History also opposed the Trade Center project, citing hazards the buildings would impose on migrating birds.

The structural engineering firm Worthington, Skilling, Helle & Jackson worked to implement Yamasaki's design, developing the tube-frame structural system used in the buildings. The Port Authority's Engineering Department served as foundation engineers, Joseph R. Loring & Associates as electrical engineers, and Jaros, Baum & Bolles as mechanical engineers. Tishman Realty & Construction Company was the general contractor on the World Trade Center project. Guy F. Tozzoli, director of the World Trade Department at the Port Authority, and the Port Authority's Chief Engineer, Rino M. Monti, oversaw the project.

## Structural design

As an interstate agency, the Port Authority was not subject to local laws and regulations of the City of New York, including building codes. Nonetheless, the Port Authority required architects and structural engineers to follow the New York City building codes. At the time when the World Trade Center was planned, new building codes were being devised to replace the 1938 version that was still in place. The structural engineers ended up following draft versions of the new 1968 building codes, which incorporated "advanced techniques" in building design.

The World Trade Center towers included many structural engineering innovations in skyscraper design and construction, which allowed the buildings to reach new heights and become the tallest in the world. Traditionally, skyscrapers used a skeleton of columns distributed throughout the interior to support building loads, with interior columns disrupting the floor space. The tube-frame concept, earlier introduced by Fazlur Khan, was a major innovation, allowing open floor plans and more space to rent. The buildings used high-strength, load-bearing perimeter steel columns called Vierendeel trusses that were spaced closely together to form a strong, rigid wall structure. There were 59 perimeter columns, narrowly spaced, on each side of the buildings. In all, the perimeter walls of the towers were 210 feet (64 m) on each side, and the corners were beveled. The perimeter columns were designed to provide support for virtually all lateral loads (such as wind loads) and to share the gravity loads with the core columns. Structural analysis of major portions of the World Trade Center were computed on an IBM 1620.




Typical WTC architectural floor plan

The perimeter structure was constructed with extensive use of prefabricated modular pieces, which consisted of three columns, three stories tall, connected by spandrel plates. The perimeter columns had a square cross section, 14 inches (36 cm) on a side, and were constructed of welded steel plate. The thickness of the plates and grade of structural steel varied over the height of the tower, ranging from 36,000 to 100,000 pounds per square inch (260 to 670 MPa). The strength of the steel and thickness of the steel plates decreased with height because they were required to support lesser amounts of building mass on higher floors. The tube-frame design required 40 percent less structural steel than conventional building designs. From the 7th floor to the ground level, and down to the foundation, the columns were spaced 10 feet (3 m) apart. All columns were placed on bedrock, which, unlike that in Midtown Manhattan, where the bedrock is shallow, is at 65–85 feet (20–26 m) below the surface.

The spandrel plates were welded to the columns to create the modular pieces off-site at the fabrication shop. The modular pieces were typically 52 inches (1.3 m) deep, and extended for two full floors and half of two more floors. Adjacent modules were bolted together, with the splices occurring at mid-span of the columns and spandrels. The spandrel plates were located at each floor, transmitting shear stress between columns, allowing them to work together in resisting lateral loads. The joints between modules were staggered vertically, so the column splices between adjacent modules were not at the same floor.

The building's core housed the elevator and utility shafts, restrooms, three stairwells, and other support spaces. The core of each tower was a rectangular area 87 by 135 feet (27 by 41 m), and contained 47 steel columns running from the bedrock to the top of the tower. The columns tapered after the 66th floor, and consisted of welded box-sections at lower floors and rolled wide-flange sections at upper floors. The structural core in 1 WTC was oriented with the long axis east to west, while that of 2 WTC was oriented north to south. All elevators were located in the core. Each building had three stairwells, also in the core, except on the mechanical floors where they were located outside the core.

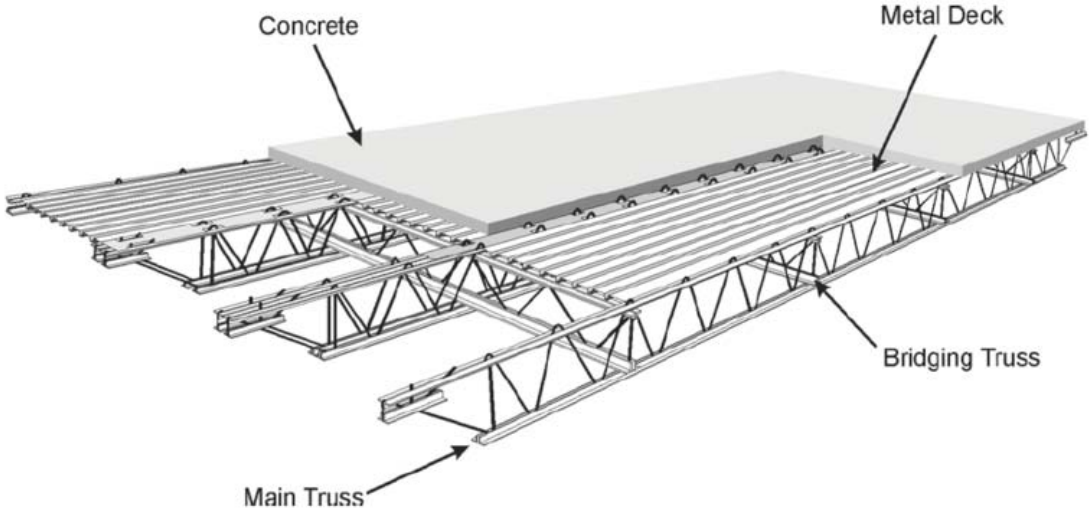


**Figure 1–6. Schematic of composite floor truss system.**

Schematic of composite floor truss system

The large, column-free space between the perimeter and core was bridged by prefabricated floor trusses. The floors supported their own weight, as well as live loads, provided lateral stability to the exterior walls, and distributed wind loads among the exterior walls. The floors consisted of 4-inch (10 cm) thick lightweight concrete slabs laid on a fluted steel deck with shear connections for composite action. A grid of lightweight bridging trusses and main trusses supported the floors. The trusses had a span of 60 feet (18 m) in the long-span areas and 35 feet (11 m) in the short span area. The trusses connected to the perimeter at alternate columns, and were on 6-foot-8-inch (2.03 m) centers. The top chords of the trusses were bolted to seats welded to the spandrels on

the exterior side and a channel welded to the core columns on the interior side. The floors were connected to the perimeter spandrel plates with viscoelastic dampers, which helped reduce the amount of sway felt by building occupants.

Hat trusses (or "outrigger truss") located from the 107th floor to the top of the buildings were designed to support a tall communication antenna on top of each building. Only 1 WTC (north tower) actually had an antenna fitted, which was added in 1978. The truss system consisted of six trusses along the long axis of the core and four along the short axis. This truss system allowed some load redistribution between the perimeter and core columns and supported the transmission tower.

## Wind effects

The tube frame design using steel core and perimeter columns protected with sprayed-on fire resistant material created a relatively lightweight structure that would sway more in response to the wind, compared to traditional structures such as the Empire State Building that have thick, heavy masonry for fireproofing of steel structural elements. During the design process, wind tunnel tests were done at Colorado State University and at the National Physical Laboratory in the United Kingdom to establish design wind pressures that the World Trade Center towers could be subjected to and structural response to those forces. Experiments were also done to evaluate how much sway occupants could tolerate. Subjects were recruited for "free eye exams," while the real purpose of the experiment was to subject them to simulated building sway and find out how much they could comfortably tolerate. Many subjects did not respond well, experiencing dizziness and other ill effects. One of the chief engineers Leslie Robertson worked with Canadian engineer Alan G. Davenport to develop viscoelastic dampers to absorb some of the sway. These viscoelastic dampers, used throughout the structures at the joints between floor trusses and perimeter columns, along with some other structural modifications reduced the building sway to an acceptable level.

## Aircraft impact

The structural engineers on the project also considered the possibility that an aircraft could crash into the building. In July 1945, a B-25 bomber that was lost in the fog had crashed into the 79th floor of the Empire State Building. A year later, another airplane nearly crashed into the 40 Wall Street building, and there was another near-miss at the Empire State Building. In designing the World Trade Center, Leslie Robertson considered the scenario of the impact of a jet airliner, the Boeing 707, which might be lost in the fog, seeking to land at JFK or at Newark airports. The National Institute of Standards and Technology (NIST) found a three page white paper that mentioned another aircraft impact analysis, involving impact of a jet at 600 mph (970 km/h), was indeed considered, but the original documentation of the study was lost when Port Authority offices were destroyed in the collapse of the World Trade Center.

## Fire protection

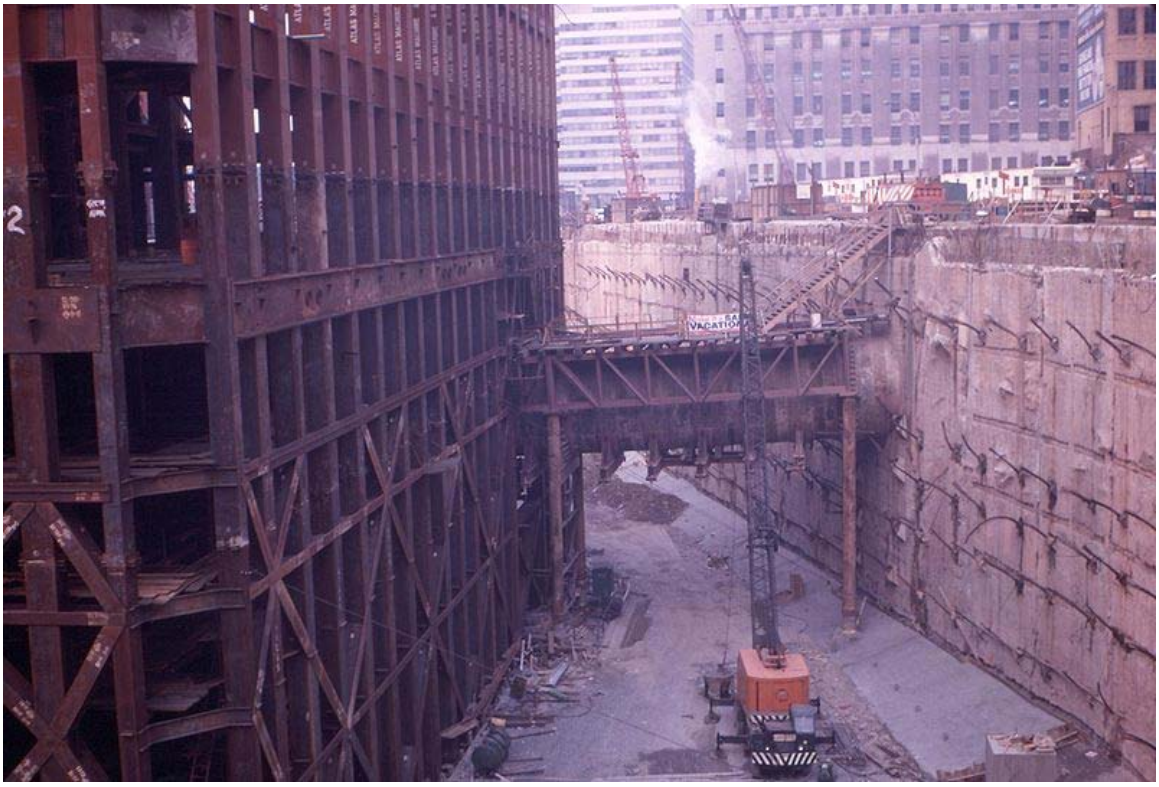
Sprayed-fire resistant materials (SFRMs) were used to protect some structural steel elements in the towers, including all floor trusses and beams. Gypsum wallboard in combination with SFRMs, or in some cases gypsum wallboard alone, was used to protect core columns. Vermiculite plaster was used on the interior-side and SFRMs on the other three sides of the perimeter columns for fire protection. The 1968 New York City building codes were more lenient in some aspects of fire protection, such as allowing three exit stairwells in the World Trade Center towers, instead of six as required under older building codes.

In April 1970, the New York City Department of Air Resources ordered contractors building the World Trade Center to stop the spraying of asbestos as an insulating material.

More fireproofing was added after a fire in February 1975 that spread to six floors before being extinguished. After the 1993 bombing, inspections found fireproofing to be deficient. The Port Authority was in the process of replacing it, but replacement had been completed on only 18 floors in WTC 1, including all the floors affected by the aircraft impact and fires on September 11, and on 13 floors in WTC 2, although only three of these floors (77,78, and 85) were directly affected by the aircraft impact.

The 1968 New York City building codes did not require sprinklers for high-rise buildings, except for underground spaces. In accordance with building codes, sprinklers were originally installed only in the underground parking structures of the World Trade Center. Following a major fire in February 1975, the Port Authority decided to start installing sprinklers throughout the buildings. By 1993, nearly all of 2 WTC and 85 percent of 1 WTC had sprinklers installed, and the entire complex was retrofitted by 2001.

# Construction



South Tower and slurry wall "bathtub" under construction in 1969

In March 1965, the Port Authority began acquiring property at the World Trade Center site. The Ajax Wrecking and Lumber Corporation was hired for the demolition work, which began on 12 March 1966 to clear the site for construction of the World Trade Center.

Groundbreaking was on 5 August 1966, marking the beginning of construction of the World Trade Center's foundations. The site of the World Trade Center was located on landfill, with the bedrock located 65 feet (20 m) below grade. In order to construct the World Trade Center, it was necessary to build the "bathtub", with the slurry wall along the West Street side of the site, to keep water from the Hudson River out. This method was used in place of conventional dewatering methods because lowering the groundwater table would cause large settlements of nearby buildings not built on deep foundations. The slurry method involves digging a trench, and as excavation proceeds, filling the space with a "slurry" mixture, composed of bentonite which plugs holes and keeps water out. When the trench was dug out, a steel cage was inserted, with concrete poured in, forcing the "slurry" out. The "slurry" method was devised by Port Authority chief engineer John M. Kyle, Jr. Towards the end of 1966, work began on building the slurry wall, led by Montreal-based Icanda, a subsidiary of an Italian engineering firm, Impresa Costruzioni Opere Specializzate (I.C.O.S.). It took fourteen months for the slurry wall to be completed, which was necessary before excavation of material from the interior of the

site could begin. The original Hudson Tubes, which carried PATH trains into Hudson Terminal, remained in service as elevated tunnels until 1971 when a new PATH station was built.

Construction work began on the North Tower in August 1968 with construction beginning on the South Tower by January 1969. In January 1967, $74 million in contracts were awarded to the Pacific Car and Foundry Company, Laclede Steel Company, Granite City Steel Company, and Karl Koch Erecting Company to supply steel for the project. The Port Authority chose to use many different steel suppliers, bidding on smaller portions of steel, rather than buy larger amounts from a single source such as Bethlehem Steel or U.S. Steel as a cost-saving measure. Karl Koch was also hired to do all the work of erecting the steel, and a contract for work on the aluminum facade was awarded to the Aluminum Company of America. Tishman Realty & Construction was hired in February 1967 to oversee construction of the project.

World Trade Center under construction in 1971

Extensive use of prefabricated parts for the perimeter framing and floor truss systems helped speed up the construction process and reduce costs, while providing greater quality control. Steel components were freighted into a Penn Central yard in Jersey City. From there, they were brought in early morning hours through the Holland Tunnel to the construction site, and lifted into place by a crane. Larger pieces were brought to the construction site by tugboats. A special type of crane, suitable for constructing such tall buildings, that used hydraulics to lift components and provided its own power was used in construction of the World Trade Center. The Favco Standard 2700 Crane, manufactured by Favelle Mort Ltd. of New South Wales, Australia was informally called a "kangaroo crane".

In 1970, tugboat workers went on strike, halting the transport of material to the construction site. The Port Authority attempted other means of transporting material, including via helicopter. When this method was tried, the helicopter lost its load of steel into the Kill Van Kull. Some other mishaps occurred during the construction process, including disruption of telephone service in Lower Manhattan when telephone cables were crushed by pile drivers. On 16 March 1970, an explosion injured six workers when a truck hit a propane tank. In all, 60 workers were killed in construction accidents while the World Trade Center was being built.

The topping out ceremony of 1 WTC (North Tower) took place on 23 December 1970, with 2 WTC's ceremony (South Tower) occurring later on 19 July 1971. The first tenants moved into the North Tower in December 1970, and into the South Tower in January 1972. The buildings were dedicated on 4 April 1973; Tobin, who had resigned the year before, was absent from the ceremonies.

Building the World Trade Center involved excavating 1,200,000 cubic yards (920,000 $m^3$) of material. Rather than transporting this material at great costs out to sea or to landfills in New Jersey, the fill material was used to expand the Manhattan shoreline across West Street. Work to demolish the piers began on 5 January 1967, including Pier 7 to Pier 11 which were all constructed around 1910. The demolition work moved forward, despite conflicts between David Rockefeller, Governor Nelson Rockefeller, and Mayor John Lindsay regarding plans for Battery Park City. Landfill material from the World Trade Center was used to add land, and a cellular cofferdam was constructed to retain the material. The result was a 700-foot (210 m) extension into the Hudson River, running six blocks or 1,484 feet (452 m). This land was a "gift" to New York City, allowing more tax-generating developments in Battery Park City.

The original estimates put forth by the Port Authority had the costs for construction of the World Trade Center at $350 million—an optimistic figure. In December 1966, the Port Authority announced increased cost estimates, bringing the estimated total to $575 million. This announcement brought criticism of the project from private real estate developers, *The New York Times*, and others in New York City. The critics charged that the Port Authority figure was an unrealistically low estimate, and they estimated the project would end up costing $750 million. When the World Trade Center twin towers

were completed, the total costs to the Port Authority had reached $900 million. The project was financed through tax-exempt bonds issued by the Port Authority.

## Other buildings

The World Trade Center complex included four other smaller buildings constructed during the 1970s. 3 World Trade Center was a 22-story building, which was home to the Marriott World Trade Center. It was designed by Skidmore, Owings and Merrill in 1978–79. 4 World Trade Center, 5 World Trade Center, and 6 World Trade Center were all 8–9 story buildings that were designed by the same team as the Twin Towers, including Minoru Yamasaki, Emery Roth & Sons, and Skilling, Helle, Christiansen, Robertson. 7 World Trade Center was built in the mid-1980s, just north of the main World Trade Center site. The 47-story building was designed by Emery, Roth & Sons, and constructed on top of a Con Edison power substation.

## Modifications

Over time, numerous structural modifications were made to suit the needs of tenants in the Twin Towers. Modifications were made in accordance with the Port Authority's *Tenant Alteration Review Manual* and were reviewed by the Port Authority to ensure the changes did not compromise structural integrity of the buildings. In many instances, openings were cut in the floors to accommodate new stairways to connect tenant floors. Some steel beams in the core were reinforced and strengthened to accommodate heavy live loads, such as large amounts of heavy files that tenants had on their floors.

Repairs to structural elements on the lower levels of 1 WTC were made following the 1993 bombing. The greatest damage occurred on levels B1 and B2, with significant structural damage also on level B3. Primary structural columns were not damaged, but secondary steel members experienced some damage. Floors that were blown out needed to be repaired to restore the structural support they provided to columns. The slurry wall was in peril following the bombing and loss of the floor slabs which provided lateral support to counteract pressure from Hudson River water on the other side. The refrigeration plant on sublevel B5, which provided air conditioning to the entire World Trade Center complex, was heavily damaged and replaced with a temporary system for the summer of 1993. The fire alarm system for the entire complex needed to be replaced, after critical wiring and signaling in the original system was destroyed in the 1993 bombing. Installation of the new system took years to complete, and replacement of some components was still underway at the time of the September 11, 2001 attacks.

## Chapter- 7

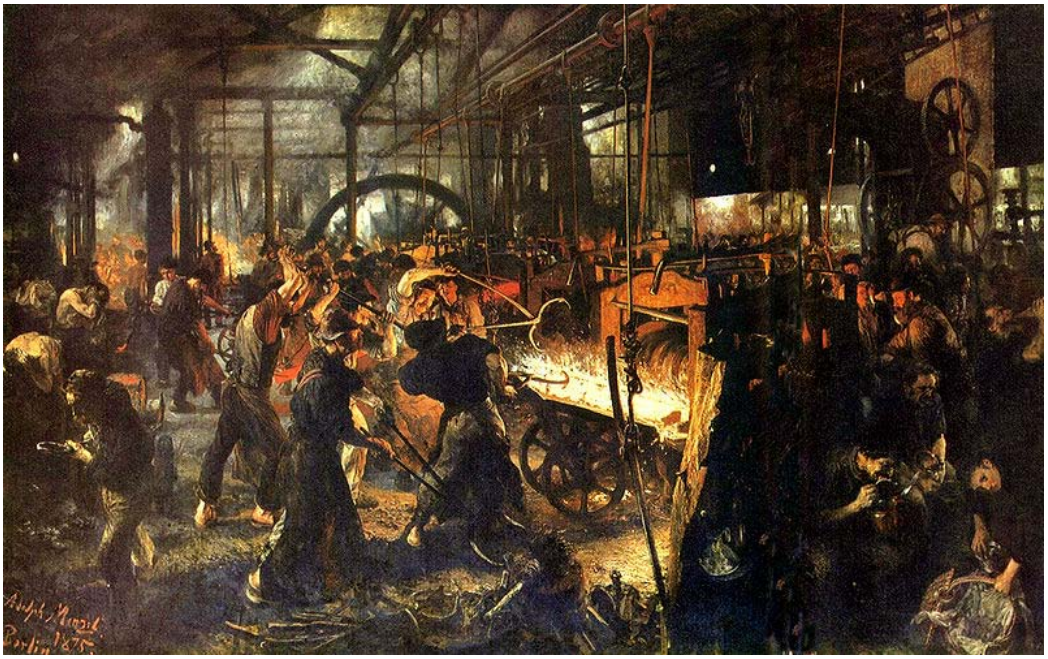
# Factory

Volkswagen factory in Wolfsburg, Germany

A **factory** (previously **manufactory**) or **manufacturing plant** is an industrial building where laborers manufacture goods or supervise machines processing one product into another. Most modern factories have large warehouses or warehouse-like facilities that contain heavy equipment used for assembly line production. Typically, factories gather and concentrate resources: laborers, capital and plant.

# History

Entrance to the Venetian Arsenal by Canaletto, 1732



Adolph von Menzel: *Moderne Cyklopen*

The assembly plant of the Bell Aircraft Corporation at Wheatfield, New York, United States, 1944

A factory worker in 1940s Fort Worth, Texas, United States

Although large mills and workshops were established in ancient China, Rome and the Middle East, the Venice Arsenal provides one of the first examples of a factory in the modern sense of the word. Founded in 1104 in Venice, Republic of Venice, several hundred years before the Industrial Revolution, it mass-produced ships on assembly lines using manufactured parts. The Venice Arsenal apparently produced nearly one ship every day and, at its height, employed 16,000 people.

Many historians regard Matthew Boulton's Soho Manufactory (established in 1761 in Birmingham) as the first modern factory. (Other claims might be made for John Lombe's silk mill in Derby (1721), or Richard Arkwright's Cromford Mill (1771)—purpose built to fit the equipment it held and taking the material through the various manufacturing processes.) One historian, Jack Weatherford, contends that the first factory was in Potosí, for processing silver ingot slugs into coins, because there was so much silver being mined close by.

British colonies in the late 18th century built factories simply as buildings where a large number of laborers gathered to perform hand labor, usually in textile production. This proved more efficient—for administration and for the distribution of raw materials to

individual laborers—than earlier methods of manufacturing such as cottage industries or the putting-out system.

Cotton mills used inventions such as the steam engine and the power loom to pioneer the industrial factory of the 19th century, where precision machine tools and replaceable parts allowed greater efficiency and less waste.

Between 1820 and 1850, the non-mechanized factories supplanted the traditional artisan shops as the predominant form of manufacturing institution. Even though the theory on why and how the non-mechanized factories gradually replaced the small artisan shops is still ambiguous, what is apparent is that the larger-scale factories enjoyed technological gains and advance in efficiency over the small artisan shops. In fact, the larger scale forms of factory establishments were more favorable and advantageous over the small artisan shops in terms of competition for survival.

Henry Ford further revolutionized the factory concept in the early 20th century, with the innovation of mass production. Highly specialized laborers situated alongside a series of rolling ramps would build up a product such as (in Ford's case) an automobile. This concept dramatically decreased production costs for virtually all manufactured goods and brought about the age of consumerism.

In the mid- to late 20th century, industrialized countries introduced next-generation factories with two improvements:

1. Advanced statistical methods of quality control, pioneered by the American mathematician William Edwards Deming, whom his home country initially ignored. Quality control turned Japanese factories into world leaders in cost-effectiveness and production quality.
2. Industrial robots on the factory floor, introduced in the late 1970s. These computer-controlled welding arms and grippers could perform simple tasks such as attaching a car door quickly and flawlessly 24 hours a day. This too cut costs and improved speed.

Some speculation as to the future of the factory includes scenarios with rapid prototyping, nanotechnology, and orbital zero-gravity facilities.

# Siting the factory

Before the advent of mass transportation, factories' needs for ever-greater concentrations of laborers meant that they typically grew up in an urban setting or fostered their own urbanization. Industrial slums developed, and reinforced their own development through the interactions between factories, as when one factory's output or waste-product became the raw materials of another factory (preferably nearby). Canals and railways grew as factories spread, each clustering around sources of cheap energy, available materials and/or mass markets. The exception proved the rule: even greenfield factory sites such as

Bournville, founded in a rural setting, developed its own housing and profited from convenient communications systems.

Regulation curbed some of the worst excesses of industrialization's factory-based society, a series of Factory Acts leading the way in Britain. Trams, automobiles and town planning encouraged the separate development of industrial suburbs and residential suburbs, with laborers commuting between them.

Though factories dominated the Industrial Era, the growth in the service sector eventually began to dethrone them: the focus of labor in general shifted to central-city office towers or to semi-rural campus-style establishments, and many factories stood deserted in local rust belts.

The next blow to the traditional factories came from globalization. Manufacturing processes (or their logical successors, assembly plants) in the late 20th century re-focussed in many instances on Special Economic Zones in developing countries or on maquiladoras just across the national boundaries of industrialized states. Further re-location to the least industrialized nations appears possible as the benefits of out-sourcing and the lessons of flexible location apply in the future.

## New England factories in the 19th century

In New England in the early to mid-19th century, many cotton and textile factories employed large numbers of female adolescent laborers from the New England area. The girls came from families of middling farmers. Factory employment offered an alternative to rural lifestyle, and many women labored, not only to send money back home, but to gain greater social & economic independence. They were able to earn enough at the factory to cover their living expenses and still have spending money and savings for dowries.

In 1834 New England textile factory owners decided to cut the wages of these young women in order to save money. In response, the young factory laborers organized turnouts (strikes) in an attempt to force their employers to raise wages again. These young women viewed themselves as equals to their managers. They saw their wage reductions as attempts to take away their economic independence and force them to become completely dependent upon factory employment for survival—to make them "slaves" to their employers. Because of bad timing and poor organization their 1834 factory turnout was unsuccessful, but it did lay the foundation for successful strikes that helped shape factory life in the future.

## Governing the factory

Much of management theory developed in response to the need to control factory processes. Assumptions on the hierarchies of unskilled, semi-skilled and skilled laborers and their supervisors and managers still linger on; however an example of a more

contemporary approach to handle design applicable to manufacturing facilities can be found in Socio-Technical Systems (STS).

## Shadow factories

A **shadow factory** is a term given to dispersed manufacturing sites in times of war to reduce the risk of disruption due to enemy air-raids and often with the dual purpose of increasing manufacturing capacity.

Production of the Supermarine Spitfire at its parent company's base at Woolston, Southampton was vulnerable to enemy attack as a high profile target and was well within range of *Luftwaffe* bombers. Indeed on 26 September 1940 this facility was completely destroyed by an enemy bombing raid. Supermarine had already established a plant at Castle Bromwich, this action prompted them to further disperse Spitfire production around the country with many premises being requisitioned by the British Government.

Connected to the Spitfire was production of its equally important Rolls-Royce Merlin engine, Rolls-Royce's main aero engine facility was located at Derby, the need for increased output was met by building new factories in Crewe and Glasgow and using a purpose-built factory of Ford of Britain in Trafford Park Manchester.