Teacher Background

Inquiry Description

In many parts of the world today, notably in Asia, societies are rapidly transforming. A major part of this transformation is urbanization, the flocking of people from the countryside to cities. A sign of this transformation is the construction of tall buildings. Since the Lincoln Cathedral surpassed the Pyramids of Egypt in 1300 CE, all of the tallest buildings in the world were in Europe and North America. Then, in 1998, the Petronas Towers opened in Kuala Lumpur, Malaysia. Today the five tallest buildings are in Asia (One World Trade Center in New York City is #6)

These areas are being transformed because of their integration into the world economic system that itself was the result of the Industrial Revolution in the 19th century in Western societies and the subsequent growth and expansion of those western societies. Interestingly, tall buildings, known as skyscrapers, were a sign of urbanization and industrial growth in Europe and North America at that time. This unit explores the connections between industrialization, urbanization, and skyscrapers, and how it was that skyscrapers were able to be built when and how they were. Key areas of attention will be building materials and related technologies that allowed for taller structures.

Teachers are encouraged to use the following notes as they prepare for this unit, and additional secondary resources are listed at the end of this document.

Historical Background

Agriculture and Monumental Architecture
In the long arc of human history, there are two interesting phenomena that might seem separate, but in hindsight are closely related. On the one hand, people have continually intensified their food production, leading to the ability to sustain larger populations on the same amount of land with fewer direct food producers. This change led to specialization of labor (the remaining farmers could support others who could now specialize in different tasks, such as pottery making or warfare) and greater trade, but also to differentiation of wealth and social stratification.

On the other hand, people have shown a desire to erect tall structures, beyond their need for simple shelter. When people were hunter-gatherers wandering across the countryside and setting up temporary camps of materials like wood, this was difficult. But as soon as "the first agricultural revolution" around 10,000 years ago enabled people to settle down, they started to erect not just permanent villages of materials like mudbrick, brick or stone, but large monuments. Around 5,000 years ago, villagers in southern England erected Stonehenge, which included stones 13 feet tall and weighing 25 tons that had been brought great distances.

Stonehenge
(https://commons.wikimedia.org/wiki/File:Stonehenge2007_07_30.jpg)

From Stonehenge onward, archaeology and history suggest that the largest structures were used for ideological purposes, some combination of the expression of religious belief, social cohesion and political power. A few hundred years after the earliest structures at Stonehenge (the monument continued to be added to and rebuilt for over a thousand years), the Egyptians developed an extremely advanced, complex, and centralized society based on the rich irrigation and agriculture afforded by the Nile River. They constructed tombs for their Pharaohs—kings who were also considered gods—in the form of huge stone pyramids. The great Pyramid of Giza, completed around 2560 BCE, was 481 feet tall, and remained the tallest building in the world for almost 4,000 years.

Pyramids at Giza
(https://en.wikipedia.org/wiki/Giza_pyramid_complex#/media/File:Pyramids_of_the_Giza_Necropolis.jpg)

As Europe emerged from the Dark Ages, a series of technological and political achievements enabled the early European states to grow rich, increase their labor specialization and trade, and develop new mechanical tools for production. One sign of this increased wealth was larger architecture, culminating, in the late Middle Ages, in Gothic Cathedrals. Like the pyramids, Gothic cathedrals were constructed of stone. The earliest Cathedral in this form was the Basilica of Saint-Denis, north of Paris, completed in 1144 CE. It featured a new construction technique, the flying buttress, which enabled it to be three stories tall, and rise to a height of 280 feet. A buttress is a structure built against a wall to reinforce it. In a flying buttress, the buttresses are not connected directly to the wall, but by an arch. This enabled the building itself to appear more open and elegant, as the lateral forces were contained not by a massive buttress, but by a pier that could be some distance away from the wall.

Gothic cathedral of St. Denis (https://www.eurotravelogue.com/2012/10/Gothic-Architecture-Emerges.html)

Around the same time, the English began construction on a Gothic cathedral of their own in Lincoln. When it was completed in 1311 CE, it rose to 525 feet tall, the first manmade building to surpass the great Pyramid of Giza in height. It maintained the record for over 200 years, and then in the Early Modern period was overshadowed by a series of taller cathedrals on continental Europe. All of these cathedrals were houses of worship in the Christian religion as well as sites of burial, perhaps also reflecting the glory of the secular rulers and national pride of builders. In use, however, they were hardly different from the Pyramids. Things, however were about to change.

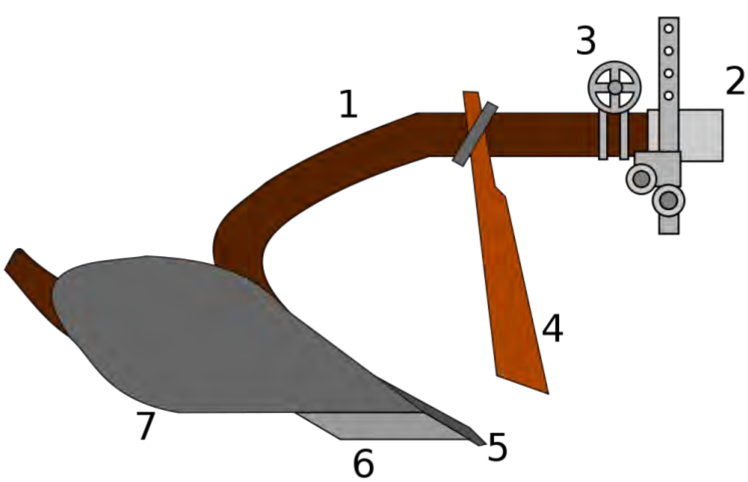
The Second Agricultural Revolution

The technological developments begun in Europe in the late Middle Ages accelerated into the 15th, 16th and 17th centuries, the time of the Renaissance, Reformation, and Enlightenment. The advances in crafts and technology on the one hand, and natural science on the other, began to influence one another. The Printing Press and the spring-driven clock were products of these exciting times. (IEEE REACH has an inquiry unit on the Printing Press. Search for it at reach.ieee.org) These developments would eventually impact manufacturing and construction, but the first and perhaps most important effect was on agriculture.

These developments also led to the expansion of the Europeans at the expense of other cultures around the world, owing to advances in navigation and in firearms, and the beginning of population growth that was soon to be accelerated by the advances in food production.
(IEEE REACH has an inquiry unit on the tools of Early Maritime Navigation. Search for it at reach.ieee.org)

Some form of crop rotation, such as leaving half the fields fallow each year to recover nutrients, had been known since ancient times. But around the 17th century, European farmers perfected a system to rotate four different groups of crops over four fields, such that different nutrients were used and resorted continuously. This technique maximized land use and the growing season, and enabled more fodder to be grown for animals as well as greater varieties of food for people.

To prepare these fields to plant these crops, of course, farmers needed a plow. As with other inventions, such as the compass, the Chinese had invented an improved sort of plow, with a curved mouldboard, but had not carried it out to its logical conclusion. The Europeans, who by then were in contact with the Chinese took the plow and improved it in a number of ways, including a depth adjuster. This new plow could cover land faster with fewer animals, and left a ridged field that was better for drainage.



Mouldboard plow
(https://en.wikipedia.org/wiki/Plowshare#/media/File:Old_plough_schema.svg)

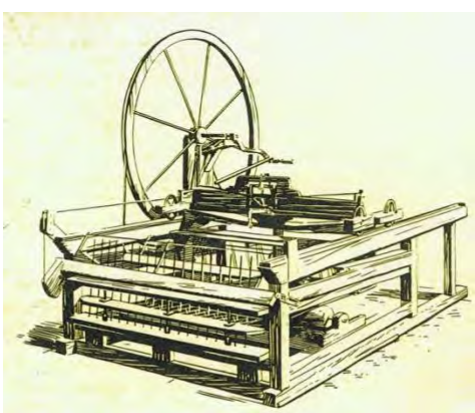
Another important invention was the horse-drawn mechanical seed drill, invented by Jethro Tull in 1700. Tull is a key early figure in how emerging science was consciously put to use to improve technology and engineering.

As a result of these changes and others, productivity more than doubled within a couple lifetimes, leading the Period to be called the Second Agricultural Revolution. Europe then entered one of those periods in history during which a positive feedback loop is set up and technological and social changes reinforce one another and push society in the direction of greater productivity, complexity, and centralization.

The Beginnings of the Industrial Revolution

The increase in the mechanization and productivity of agriculture meant that fewer farmers were needed. This meant that there could be more production specialization in other areas, and that greater infrastructure was needed to produce and transport the increased amounts and varieties of agricultural and nonagricultural goods. Innovators applied the concept of scientific and technological advancement to these new areas. Each invention during the Industrial Revolution is probably worthy of its own inquiry unit, including new devices for mass-producing chemicals, machine tools, and paper. Here it is just worth briefly noting a few key developments to better understand the impact of the Industrial Revolution on monumental architecture. Although there were developments around Europe, the most important events occurred in England, and Great Britain more broadly, so we will focus on those.

Many of the most important commodities were textiles. Intensified agriculture produced greater amounts of cotton and linen than ever before, and new fabrics—notably cotton and silk—were imported by the expanding European empires. The basis of textile production is the spinning of plant fibers into thread or yarn, and the weaving of the yarn into cloth. In 1733, John Kay in England invented the flying shuttle, an innovation that doubled the output of a weaver, and this was followed by a rapid series of inventions of both spinning and weaving machines. Many of these involved replacing human power with animal power, and eventually, water power.



Spinning Jenny (http://www.newlanark.org/uploads/image/The%20spinning%20jenny.jpg)

The main material for constructing tools (and weapons) in Europe had been, for hundreds of years, iron and steel. Iron, a common metal, is relatively soft and needs very high temperatures to melt. It is known as wrought iron in its pure form. Cast iron, an alloy (mixture of iron and carbon) could be melted, but was brittle. The ideal material, steel, was an iron-carbon alloy with less carbon, but had to be produced either by adding carbon to wrought iron or removing carbon from cast iron, techniques that were difficult and required a lot of fuel. Fuel was generally in the form of wood or, more specifically, wood processed into charcoal. Wood is theoretically a renewable resource, but the pace of economic growth meant it was increasingly in scarce supply.

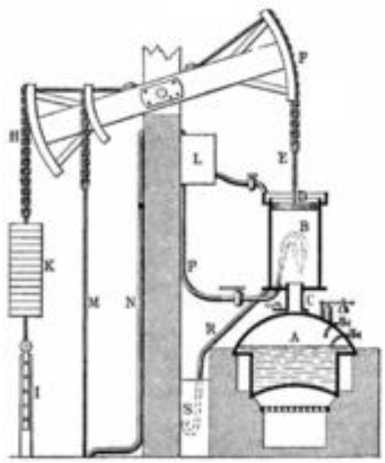
It had been known for some time that a naturally occurring rock—coal—could burn as a fuel. In 17th century England, brewers had experimented with processing coal to make it into a purer form called coke. By the 18th century, ironworkers were using coke to increase the output of cast iron. This led to one of the many important positive feedback loops that drove the Industrial Revolution.

The increased availability of iron led it to be used to construct structures that had previously been of wood or stone, notably bridges. In 1781, the first cast iron bridge opened in Shropshire, England.


Iron bridge (https://misstology.wordpress.com/2011/09/18/interesting-facts-the-first-iron-bridge/)

However, the increased usage led to even further demand. At the same time, as people flocked from the countryside to ever-growing factories, there was need for larger structures to house both machines and humans. The inventive British tried a number of techniques to achieve larger structures with wood, brick, and stone, but faced many difficulties and could not achieve even 10 stories with narrow buildings. Then in 1797, in Shrewsbury, Charles Bage, inspired by the growing number of iron bridges, constructed a flax mill with a similar iron frame. Although "only" five stories, it allowed for a much roomier interior than the almost solid pyramids or the buttressed cathedrals, ideal for a factory. It is also important to note that it was built not for ideological reasons, but purely for commerce.

More on construction soon, but to return to the textile-iron-transportation feedback complex, the increased mining activity for iron ore and coal led to a new specific problem—how could water be removed from mines. The solution turned out to be using the steam produced by boiling water to push a cylinder and create a vacuum, drawing up the water. Such a practical steam engine was produced by Thomas Newcomen in 1712.



Newcomen engine (http://www.eoht.info/page/Newcomen+engine)

Inventors soon realized that such engines could not just pump water but could supply power to replace animal labor and waterpower. After a series of developments, Scotsman James Watt produced a radically improved engine in 1778. These engines were not only used to power factories, but by 1802 they were used to power small trains to transport coal up from the same mines that used steam engines to pump out water. The idea then spread that such steam locomotives could be used to haul the coal and other things—including people—across greater distances, between mines and factories or factories and cities. A challenge was that not only were these locomotives made of iron and steel, they needed tracks of steel, putting even greater stress on that industry. It should be noted that steam power was also being applied to boats by a series of inventors. Although the challenges were initially greater, steamboats were soon important for transportation, both inland over rivers and canals, (another important construction advance of the industrial revolution) and overseas.

As part of this First Industrial Revolution, the first half of the 19th century saw a number of other important scientific and technical advances. The ones that we will mention—because they will become important in the history of tall buildings—are all in the realm of materials.

First, it had been discovered that coal mines sometimes also produced a flammable gas. After a good deal of research, engineers learned how to consciously produce the gas from coal and use it in a number of applications, notably heating and lighting. By 1807, street lighting had been demonstrated in London, and soon after it was finding its way into homes. There remained however, economic and safety issues.

At the same time, it had been known since ancient times that certain minerals when ground up and added to water could then be allowed to set and form a stone-like substance. This is cement. Cement itself is not a good construction substance but when fine sand is added it becomes mortar to bind together stones or bricks, and when gravel is added it becomes concrete, a useful construction material. In 1824, a British builder patented a technique for mass-producing a high-quality cement known as Portland Cement.

Glass is also an ancient substance, and it was also an area of interest for innovators in the early Industrial Revolution. In 1832, the Chance brothers in England found a way to mass-produce sheet glass. In 1851, the British held a Great Exhibition in London to celebrate their empire and technological advances. The centerpiece was The Crystal Palace, a huge structure made of steel and sheet glass, three times larger than St. Paul's Cathedral. The interior height was 128 feet. Glass was not an ideal material for functional walls in most settings, but it worked as an exhibition hall and meant that interior light was not needed. Note that the function of the Crystal Palace was really ideological. It had no function beyond exhibiting technology. This was a tantalizing look into the future, but if buildings were to be made largely of steel—whether with glass or something more practical—much more steel would be needed, and railroads were already putting a huge strain on the supply.

Then, in 1856, came the final triumph of chemical engineering. Charles Bessemer invented a process for directly producing inexpensive steel in large quantities. Thus, in the middle of the 19th century, in Britain and on the continent, and in European colonies and ex-colonies, industrialization was in full swing. Agriculture and manufacturing both continued to be intensified, and people and goods flocked to and from cities increasingly. These trends were perhaps best exemplified by the 1889 World's Fair in Paris, held to celebrate industrialization. The main attraction at the fair was a tower constructed by Gustave Eiffel totally from steel, which immediately became the tallest structure in human history. More on this below.

Eiffel Tower (https://en.wikipedia.org/wiki/Eiffel_Tower#/media/File:Tour_Eiffel_Wikimedia_Commons_(cropped).jpg)

The Rise of America and the Skyscraper

In the meanwhile, in 1776, just as the Industrial Revolution was starting to take off in Europe, the British colonies in North America threw off British rule and set up as an independent United States of America. Although a bit behind Europe in industrialization, the new nation decided that it, too, needed a tall monument to stake its place in the world. Ironically, this tower was designed not to glorify Pharaohs or kings or deities, but to suggest that liberal democracy had replaced these earlier, primitive forms of government and religion—yet its function was still completely ideological. Begun in 1848 and constructed of stone and mortar, when the Washington Monument was completed in 1884 (its construction delayed by the national tensions leading up to and including the Civil War), it was the tallest structure in the world (555 feet). But it was to be replaced by the above-mentioned Eiffel Tower only five years later!

Washington Monument
(https://en.wikipedia.org/wiki/Washington_Monument#/media/File:Washington_October_2016-6_(cropped)_(cropped).jpg)

Prior to the Civil War, the United States had already been rising as an industrial and imperial power, and after the disruption of the War and its aftermath, it began to grow again at an amazing rate, and people flocked from the countryside to large cities. Chicago, recovering from the Great Fire of 1881, became the commercial center of middle America, gathering in agricultural and mining products for processing and shipment to the expanding coastal cities by ship and railroad. (IEEE REACH has an inquiry unit on the Refrigerator Rail Car. Search for it at reach.ieee.org)

One response to the increased population densities was the growth of public transportation, by steam for inter-city rail connections, and with electric streetcars for intra-city mobility. However, the need to continue to build up was clear.

In 1885, the engineer William Le Baron Jenney designed the Home Insurance Building in Chicago a 10-story (138-ft) building that was supported inside and out by a metal frame that combined wrought iron, cast iron, and Bessemer steel. This enabled a much taller open structure—usable for living and business—than was possible before. His innovation probably in part inspired Eiffel in France, but it was Eiffel's above-mentioned demonstration that Bessemer steel alone could build the world's tallest structure. Immediately following the opening of the Eiffel Tower, in the same year 1889, American George A. Fuller—also in Chicago—built the 13-story Tacoma Building completely with Bessemer steel and with no load-bearing walls.

Home Insurance Building
(https://en.wikipedia.org/wiki/Home_Insurance_Building#/media/File:Home_Insurance_Building.JPG)

Ironically, also in that very same year, the Ames Building was built in Boston. It was (and remains!), at 14-stories, one of the tallest buildings in the world built by the old masonry (stone) technique. But it only demonstrated the outer limits of the old technology, while steel-frame technology was just getting going. On the other hand, Boston being a literary town despite being behind on building technique, added an important element to this story. In November 1891, *The Boston Journal* used the term skyscraper (originally the top sail of a sailing ship, and later used to mean anything tall) to describe the Ames Building, and the name has stuck for all tall buildings ever since, especially the ones built of steel and glass. Besides the practical uses of this vertical construction, it is clear from the writings at the time that cities and nations still considered tall structures—though without open ideological or religious connotation—to be monuments to their success. One side note about skyscrapers: depending on what is on top (a decorative statue, an antenna), height can be judged in different ways. The "Age of the New York Skyscraper" (below) is about the race to be the tallest and uses widely accepted criteria, but one can find articles on line about different ways to consider the height of buildings.

Enabling Technologies/The Second Industrial Revolution

Before returning to the race to be tallest, there is something else to consider. Besides the mechanical challenges of building increasingly tall structures, they present some other issues. How are people supposed to go up and down such great vertical distances? How does one heat such a large building; and conversely, since heat rises, how does one make the upper floors bearable, especially in the winter? And how does one light such a building so that life and work can be carried out?

Pulley-based lifting systems had existed since ancient times (and were even used to build the Pyramids!). Naturally, since the beginning of the Industrial revolution inventors worked on improving these. One of the major innovations, as with other areas of industrialization, was the switch from human/animal power to hydraulic power. Initially, these new elevators were used in industrial settings (mines and docks), but were burdened by many safety issues.

Then, in 1852, Elisha Otis invented the "safety elevator," which would not fall even if a cable failed. He then demonstrated in dramatic fashion at the 1854 exhibition at the New York Crystal Palace (modelled on the London Crystal Palace a few years earlier)—he had ax-men cut the cables while he was riding in the device. This led to commercial interest, and, in 1857, he installed one of his elevators in a five-story factory. The steam engine necessary to run the elevator was better suited to the factory floor, where it also powered other industrial equipment, then to a building where people were conducting white-collar work or even living. Although steam could also be used to heat the building in the winter, it was noisy and potentially dangerous, and created great heat during the summer.

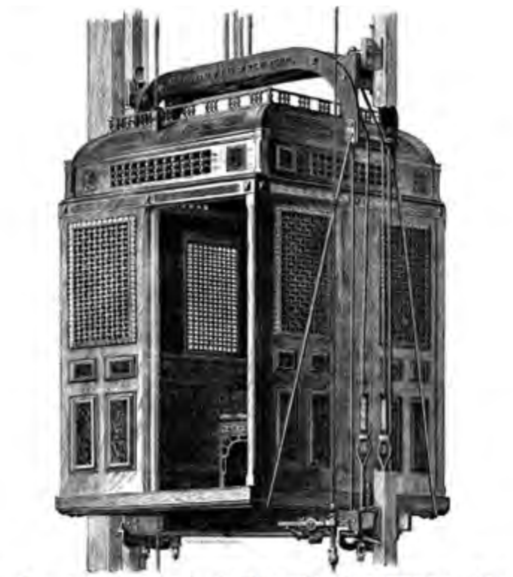


Fig. 1.—THE OTIS ELEVATOR PASSENGER CAR.
Otis elevator (http://www.boweryboyshistory.com/2017/03/going-new-york-got-first-commercial-elevator-160-years-ago.html)

From the 1820s on, gas systems came to be used increasingly in Europe and America for lighting streets and then lighting and heating homes. Gas had many economic and technological challenges, one of safety, which continues, to this day, in places that still use gas for heating and cooking. (In September 2018, a gas explosion in the Merrimack Valley of Massachusetts destroyed 40 homes, killed one person and injured 25 others, and led to the evacuation of 30,000 people for several days.)

Then, from the mid-19th century on, there was a new phenomenon spreading in industrialized nations that led to what many have called the "Second Industrial Revolution"—the use of electricity as a power source. Electricity is generated from steam (though there can be other sources as well), but it does not need to be near the place where the power is used. The electricity can be generated where convenient and then sent over wires, though initially its range was quite limited. From the 1870s on, industrial power became increasingly electric. By 1880, Ernst Werner von Siemens in Germany had developed both an electric streetcar (building out!) and figured out how to electrify the Otis elevator (building up!). The final piece of technology that made the elevator suitable for skyscrapers and not just factories was the invention in 1887, by Alexander Miles, of the modern elevator door that automatically blocks the shaft when the elevator car is on another floor.

Like gas, electricity can generate light as well as heat and power. (IEEE REACH has an inquiry unit on Electric Lighting. Search for it at reach.ieee.org) Even in the 1870s, streets began to be increasingly illuminated with electric arc lights. Arc lights, however, were loud, smelly and potentially a fire hazard, and could not be used indoors. In 1882, the great inventor Thomas Edison unveiled three important innovations: a practical incandescent light bulb; a system for generating and delivering electricity easily in urban areas; and a hydroelectric plant. The Edison Pearl Street Station opened in 1882 to light offices on Wall Street using Edison's incandescent bulbs. Later in 1882, Edison built the Vulcan Street Plant in Appleton, Wisconsin. This demonstrated the viability of hydroelectric power. Electric lights began to replace gas lights in homes and businesses

There was another factor that led to the illumination of skyscrapers. It is mentioned above how the Crystal Palaces of London and New York in the 1850s in part highlighted the industrial advances in glass technology. The fact that steel skyscrapers no longer needed load-bearing walls, meant that windows could be larger and could be designed to open, so more natural light could be let in in addition to the improved artificial light. By 1903, the machine-drawn cylinder sheet glass technique enabled large sheets of glass to be produced at industrial levels, doing for glass what the Bessemer Process had done for steel.

Of course, more glass windows also meant more heat in sunny climates. As was mentioned above, overheating is a challenge in skyscrapers. Based on earlier industrial developments in refrigeration**,** in 1902, William Carrier of Buffalo, NY, invented a practical central air conditioning system for homes and offices. The portable window unit was not invented until 1945.

A final technological challenge that could be mentioned in regards to tall buildings is how one communicates between the floors. Hydraulic tunes, invented in 1836, and the telegraph in 1837, offered some options, although the telegraph would require a skilled operator on each floor. The advent of the elevator meant that messengers could be sent up and down, and indeed these were used in some factories and offices. The invention of the telephone by Alexander Graham Bell in 1876 solved the problem once and for all. Now, intercom systems allowed anyone in the building to speak with anyone else (most commercial office buildings still employed messengers or pneumatic tubes to send letters or small objects).

The Age of the New York Skyscraper

Although the steel construction technique was perfected in Chicago, from the 1880s on, New York was the growing engine of the US economy. Philadelphia, another U.S. economic powerhouse, opened its City Hall in 1894, and for a few years that was the world's tallest building. Then, in 1902, a Chicago company built the then world's tallest skyscraper, the 22-story Flatiron Building, in New York. Ten years later, the Flatiron Building was not even close to being the tallest in the City…the 57-story Woolworth building opened in 1913 as the tallest in the world (792 ft). From 1912 – 1973, various New York skyscrapers kept surpassing each other. Within a one-year period, from 1930 – 1931, three different buildings in New York held the world title: 40 Wall Street—71 stories, 836 feet; The Chrysler Building, 77 stories, 927 ft; and The Empire State Building, 102 stories, 1250 ft. An interesting side story is that Native Americans from the Mohawk Tribe in upstate New York became a major component of the construction teams of New York City skyscrapers. The work was dangerous and involved walking on narrow beams high over the city.

Empire State Building
(https://en.wikipedia.org/wiki/Empire_State_Building#/media/File:Empire_State_Building_(aerial_view).jpg)

If the focus during the pre-World War II period was on showcasing industrial might among capitalist nations, after World War II it shifted to the competition between global capitalism and global communism. In 1953, the Soviet Union opened the Main Building of the Moscow State University at 36 floors and 790 feet. It was the tallest building in Europe (though only seventh in the world thanks to U.S. dominance), and the tallest educational building. So, although one can argue that it was functional, it clearly seems to have been meant to make an ideological statement about priorities and the future when compared with the U.S. skyscrapers, which were all based around the financial industry. In 1961, the Canadians followed and built the financial industry's CIBC Tower in Montreal (45 stories, 820 ft.), the tallest building in all the British Commonwealth.

But still none of these other nations was able to outdo the United States, the birthplace of the skyscraper. In 1971 the original World Trade Center (94 stories, 1368 ft.), later destroyed in a terrorist attack (which also says something about the ideological nature of skyscrapers) had replaced the Empire State Building as the world's tallest building, and then, ironically, the Sears Tower (108 stories, 1450 ft) briefly returned the crown to Chicago. But the global economic tide was shifting.

Growth of Asian Economies in the late 20th century, the role of the Skyscraper and its future in the 21st Century

In terms of the global economy, with the exception of Japan, Asia had been a backwater until World War II. Following World War II, a devastated Japan quickly recovered, and eventually was joined in the 1970s by Hong Kong, Singapore, Taiwan and South Korea (the Four Asian "Tigers" or "Dragons" as engines of global economic growth. At the same time, the global oil shocks led to great wealth in

Middle Eastern oil-producing countries (though without concomitant industrialization). With the end of the Cold War in the 1980s, incentives for showing off in Europe and North America receded.

In 1996, the Petronas towers opened in Kuala Lampur, Malaysia at 88 floors and 1483 feet, the world's tallest skyscraper. Now it was Asia where the contest rapidly went back and forth. Taipei 101 opened in 2004 at 101 floors, 1671 ft., and Burj Khalifa opened in Dubai in 2010 at 160 floors, 2717 ft. There are currently taller structures planned in several Asian countries, notably one for Shanghai, China, but, interestingly, none elsewhere. In Asia, now, the skyscraper has become the symbol of a nation having arrived as developed and taking its place on the global stage.

But is the skyscraper model sustainable in what some consider now the Third Industrial Revolution (or Post-Industrial Revolution)—the Information Age. Tall buildings have been the rule since people first settled down in the First Agricultural Revolution. People did not concern themselves with sustainability in the First or Second Industrial Revolutions, but the technology of skyscrapers discussed throughout this essay gives them a major carbon footprint. Now, however, shortage of resources and Global Climate Change are major issues. The fact that Taipei 101 has the highest rating from LEED (Leadership in Energy and Environmental Design, the most widely used green building rating system in the world) is an interesting and hopeful sign for the future.

Security is also a new issue. And there is also the possibility that the invention of the Internet and World-Wide Web will enable telecommuting and reduce the need for people to gather together, and at the same time advances in ground transportation, such as high-speed and Maglev trains, will make building out more attractive.

These are important issues to explore critically with the students.

Glossary

Electric generator: A device that converts motive mechanical energy into electrical power. The mechanical energy is usually circular motion in a unit of the generator called a turbine and can be produced in several ways, notably by steam produced by burning coal.

First Agricultural Revolution: Also known as the Neolithic revolution, the time about 10,000 years ago when people first abandoned the hunter-gatherer lifestyle and settled down in villages supported by domesticating plants and animals.

First Industrial Revolution: The period in the late 18th and early- and mid-19th century when new manufacturing processes powered by water and steam transformed technology and society in Europe and its colonies and former colonies, notably those in North America.

Hydroelectric power: Electrical power where the mechanical energy for the generator is produced by natural falling water turning the turbine of an electric generator.

Second Agricultural Revolution: A period in the 18th and early 19th century in Europe and its colonies that saw a drastic increase in agricultural productivity through mechanical innovation and better land-use techniques. This increased productivity was one of the main factors leading to the First Industrial Revolution

Second Industrial Revolution: The period in the West in the late 19th and early 20th centuries, centered around the United States, where the use of electricity revolutionized manufacture, as well lifestyle (through electric lighting and electric appliances), transportation (through electric traction), and communication (through the telegraph, telephone, and radio).

Skyscrapers: A continuously habitable high-rise building. The modern definition is often 40 or more floors, but as described in this essay the earliest skyscrapers of the 19th century had 10 – 20 floors. They are generally characterized by steel-frame construction.

Steel: A combination of iron and carbon that represents one of the best metal alloys for construction and other uses. The challenge is getting the right amount of carbon into the iron. Too much and one has cast iron, which can be cast in molds but which is brittle. Too little carbon and one has wrought iron, which is decorative but too soft for many applications.

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Hopkinson, Deborah and James E. Ransome, *Sky Boys: How They Built the Empire State Building*, Schwartz & Wade, 2006 (actually a picture book, but good for elementary and middle school, with great photographs)

Paumgarten, Nick, "Up and Then Down: The Lives of Elevators," *The New Yorker*, 21 April 2008.

Museum Sites

National Building Museum, Washington, DC: https://www.nbm.org/

The Skyscraper Museum, New York, NY: https://www.skyscraper.org/