Skyscrapers

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B.S. Architectural Engineering (U. Texas)
M.Eng. Engineering Science (Penn State)
Ph.D. Electrical & Computer Engineering (U. Delaware)

Plus 2 years of Urban Design (U. California, San Diego)

AGENDA

• Engineering innovations leading to skyscrapers
• Selected skyscrapers
Engineering innovations that led to skyscrapers
CONCRETE
A mix of **AGGREGATE** (rocks) and a cementations binding material (**CEMENT**) - Romans used it extensively from 300BC to 475AD

Image From: http://thumbs.media.smithsonianmag.com/filer/Roman-cement.png

Image From: http://upload.wikimedia.org/wikipedia/commons/5/51/Rome-Pantheon-Interieur1.jpg
History

Prior to 1800’s, most buildings not very tall, and mostly made of unreinforced masonry or wood

**Early 1800’s:**
First cast-iron frames and building fronts
(often painted to look like stone or other materials)

**1865+**
Industrial revolution – mass production
Tall buildings were a result of rising urban real estate values, and the desire of businesses to remain in the center of activity.
REINFORCED Concrete
A COMPOSITE MATERIAL of:

1. **Concrete**
   (High Compression strength)

2. **Steel Reinforcing-Bars ("Re-Bar")**
   (High tensile strength)

A Wunderlich family project included reinforced concrete ......
REINFORCED concrete allows taller structures than unreinforced concrete or masonry.
REINFORCED concrete
REINFORCED Concrete

“SLIP FORMS” allows taller buildings

But steel frames needed for really tall buildings .................................
Cast IRON

“a alloy of iron, carbon, and silicon that is cast in a mold and is hard, brittle, nonmalleable”

Wrought IRON

“a form of iron that is tough, malleable, and relatively soft, contains less than 0.3 percent and usually less than 0.1 percent carbon, and carries 1 or 2 percent of slag mechanically mixed with it”

STEEL

“commercial iron that contains carbon as an essential alloying constituent, and is distinguished from cast iron by its malleability and lower carbon content” – and therefore less brittle (more ”ductile”)

## Comparison between Cast Iron, Wrought Iron & Steel

<table>
<thead>
<tr>
<th></th>
<th>Cast Iron</th>
<th>Wrought iron</th>
<th>Steel</th>
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<tbody>
<tr>
<td>Rusting</td>
<td>Does not rust easily</td>
<td>Rusts more than Cast Iron</td>
<td>Rusts easily</td>
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<tr>
<td>Malleability &amp; Ductility</td>
<td>Brittle &amp; cannot be welded or rolled into sheets</td>
<td>Tough, malleable, ductile &amp; moderately elastic</td>
<td>Tough, malleable &amp; Ductile</td>
</tr>
<tr>
<td>Reaction to sudden shock</td>
<td>Does not absorb shocks</td>
<td>Cannot stand heavy shocks</td>
<td>Absorbs shocks</td>
</tr>
<tr>
<td>Forging &amp; Welding</td>
<td>Brittle and cannot be welded or rolled into sheets</td>
<td>Easily forged or welded</td>
<td>Rapidly forged or welded</td>
</tr>
</tbody>
</table>
“Wide-Flange” steel beam or column (sometimes called an “I beam”) helped allow taller buildings

Great:

- Flexural Strength
- Compression Strength
- Shear Strength
- Tensile Strength
STEEL FRAME STRUCTURES

- can melt, so fire safety coatings developed (*in Chicago after great fire of 1874*)
- handle large LATERAL LOADS
  - wind
  - seismic (earthquake) forces

• in one of two ways:

"**BRACED-FRAME**" Diagonal braces OR "**MOMENT CONNECTION**"

**BRACED-FRAME**

- Cheaper

**MOMENT CONNECTION**

(“MOMENT” = “TORQUE”)

- Un-obstructed views out windows
- Simpler interiors

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**Image From:** [http://www.stlsi.com/images/DSC01209.JPG](http://www.stlsi.com/images/DSC01209.JPG)

**Image From:** [https://d2t1xqejof9utc.cloudfront.net/screenshots/pics/a97c97f0e72c8856c002117a53f2b8b1b/medium.jpg](https://d2t1xqejof9utc.cloudfront.net/screenshots/pics/a97c97f0e72c8856c002117a53f2b8b1b/medium.jpg)


**Image From:** [http://programas.cype.es/imagen/nuevoMetal3D/union_I_soldada_49.gif](http://programas.cype.es/imagen/nuevoMetal3D/union_I_soldada_49.gif)

**Image From:** [http://buildipedia.com/images/masterformat/Channels/On_Site/Technical_Lessons_Learned/Steel_Connection.jpg](http://buildipedia.com/images/masterformat/Channels/On_Site/Technical_Lessons_Learned/Steel_Connection.jpg)
BRACED-FRAME

MOMENT CONNECTION

Image From: http://jiano.typepad.com/photos/uncategorized/brb_02.jpg

Image From: http://www.featurepics.com/FL/Thumb300/20070505/Highrise-Construction-306455.jpg
Glass CURTAIN WALL common in modern commercial buildings

Image From: http://img.archiexpo.com/images_ae/photo-g/stainless-steel-fixing-systems-suspended-curtain-wall-55078-1714337.jpg
Glass CURTAIN WALL

Image From: http://www.extal.com/userfiles/products/msg/Msg_02.jpg
Structural Load carried by core and columns.

Glass CURTAIN WALL doesn’t carry load.

This allows a SHELL to be built, followed by TENANT IMPROVEMENTS in interior.

Tenants given a fixed $ per square foot, and they use a different architect (a “SPACE PLANNER”)

Image From: http://www.expressstowers.in/images/floor_plan1_1.jpg
JT Wunderlich 1984,85
Project Manager / Designer
West Lake Oaks Office Park
(13 buildings)
Doerring Development Company
Austin TX

• Wrote architectural and engineering specifications under registered Architect
• Managed all construction (Doerring acted as General Contractor)
66,000sf hi-tech office and light manufacturing

44,000sf office building

- On Architectural Design Team
- Project nominated for annual San Diego “Orchid Award”
Hydraulic **elevators** for short buildings

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High-speed **elevators** for skyscrapers
-- use cables and electric motors

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Image From: [http://www.fema.gov/sites/default/files/orig/plan/prevent/earthquake/fema74/images/chapter6_4_10/fig1_1.jpg](http://www.fema.gov/sites/default/files/orig/plan/prevent/earthquake/fema74/images/chapter6_4_10/fig1_1.jpg)

Elevator SAFETY-SYSTEMS allowed taller buildings

**Braking** system stops elevator from free-fall if cable snaps or melts

Also, **hydraulic buffers** are at bottoms of shafts to dampen a falling elevator


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INTERIOR STRUCTURES and corresponding building heights

EXTERIOR STRUCTURES and corresponding building heights

Selected Skyscrapers
William Le Baron Jenny

**Home Insurance Building**

**Chicago 1883**

Demolished 1931

First “Steel Skeleton”

– but also much cast iron, and the first floor had masonry load-bearing walls


Burnham and Root

Rand McNally Building

Chicago 1889

Demolished 1911

First to use Structural Steel for entire frame
Frank Lloyd Wright
(a protégée of Louis Sullivan)
called this building:

"the very first human expression of a tall steel office-building as Architecture"

Building has a base, a middle section, and a top -- like a classical column
One of the last exterior load-bearing-masonry skyscrapers.
Walls very thick to carry load.

Building also has an internal iron frame for lateral bracing of exterior walls.

Daniel H. Burnham & John Welborn Root

*Monadnock Building*

*Chicago 1891*
External skin of terracotta and glass clipped onto internal steel skeleton

Precursor to glass curtain walls of 1960’s and 70’s
Balance of vertical and horizontal elements

Has “Chicago Windows” with large fixed panes between operable windows
Daniel Burnham and Frederick Dinkelberg

Flatiron Building
New York 1902

One of the first very tall buildings

Cass Gilbert
Woolworth Building
New York 1913

Neo-Gothic
Architectural Style

VIDEO
https://www.youtube.com/watch?v=YdGymhueLxM

Image From http://www.cassgilbertsociety.org/images/works/f/nyc-woolworth-bldg2.jpg
William Van Alan

Chrysler Building
New York 1930

Art Deco
Architectural Style

Image From:
William F. Lamb, Gregory Johnson

Empire State Building
New York 1931

Art Deco
Architectural Style

The Word’s tallest building for 40 years

1933 Movie clip:
https://www.youtube.com/watch?v=CuRQH_hLcTw

BAHAUS SCHOOL
Germany 1919 to 1933
Founder: Architect Walter Gropius

The Bauhaus combined art, architecture, graphic design, interior design, industrial design, and typography. This school had influence on the Modern Architecture movement to come – in Chicago

Modern
Architectural Style

• Simplicity
• Minimalistic
• No ornament
• Harmony between function and Design

“Modern” Architecture

Closed due to pressure from Nazi’s claiming it was a center of communist intellectualism
Le Corbusier

*Unité d'Habitation*

*Marseille, France 1945*

“Modern” Architecture

Le Corbusier

*Villa Savoye*

*Poissy, France 1931*
Le Corbusier - a planned city concept:

Modern
Ludwig Mies van der Rohe (a Bauhaus Architect from Germany)

**Seagram Building**
New York 1958

**Modern**

Ludwig Mies van der Rohe

**S.R. Crown Hall**
Chicago 1956

Ludwig Mies van der Rohe

**Farnsworth House**
Plano, IL 1951
The Word’s tallest building for 25 years after it surpassed the Empire State Building.

POSTMODERN Architectural style
- references elements prior to the Modernist movement -- in contrast to the simplicity of Modern movement

Phillip Johnson was first a Modern Architect

Phillip Johnson
Glass House
Canaan, CT 1949
At its top, a pediment. **Postmodern** reminiscent of a grandfather clock, or a tall 18th century chest-of-drawers.
At its base, **Postmodern** reminiscent of Italian renaissance architecture

**St. Peters Basilica in Rome**

*(photo by Wunderlich)*
Phillip Johnson

**Sony Tower**
New York 1984

*Postmodern* reminiscent of Italian renaissance architecture

Vatican Museum in Rome
*(photo by Wunderlich)*

Image From http://upload.wikimedia.org/wikipedia/commons/1/1f/Sony_Building_by_Matthew_Bisanz.jpg
César Pelli

Petronas Towers
Kuala Lumpur, Malaysia 1996

Postmodern
C.Y. Lee & Partners

Taipei 101
Taipei, Taiwan 2004
Neo-Futuristic Architectural Style

Norman Foster

The Gherkin
London, 2004
CCTV Headquarters
Beijing, China 2008

Deconstructive Architectural Style

Rem Koolhaas, Ole Scheeren

Image From
Frank Gehry

Spruce St. Tower
New York 2011

Deconstructive
World's Tallest Building
Burj Khalifa

### Burj Khalifa

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<th>Floors</th>
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<td>160 and above</td>
<td>Mechanical</td>
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<td>Communication and broadcast</td>
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<td>Corporate suites</td>
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<td>125–135</td>
<td>Corporate suites</td>
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<td>123</td>
<td>Sky lobby</td>
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<td>122</td>
<td>At.mosphere restaurant</td>
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<td>76</td>
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<td>73–75</td>
<td>Mechanical</td>
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<td>44–72</td>
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<td>43</td>
<td>Sky lobby</td>
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<td>40–42</td>
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<tr>
<td>38–39</td>
<td>Armani Hotel suites</td>
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<tr>
<td>19–37</td>
<td>Residential</td>
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<td>17–18</td>
<td>Mechanical</td>
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<tr>
<td>9–16</td>
<td>Armani Residences</td>
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<td>1–8</td>
<td>Armani Hotel</td>
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<tr>
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<td>Armani Hotel</td>
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<td>B1–B2</td>
<td>Parking, mechanical</td>
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Dimetric projection with floors colour-coded by function[^84]
Video:

http://www.skymetweather.com/content/earth-and-nature/must-watch-natures-lightning-show-over-burj-khalifa/
Artist’s rendition
Shanghai Tower
Shanghai Tower

CONCEPTUAL DESIGN

Shanghai Tower

CONCEPTUAL DESIGN

Diagram showing architectural design elements with annotations and calculations.
Huge glass *curtain walls* hung from upper decks

Image From:http://www.anotherpartofme.com/wp-content/uploads/2013/05/shanghai_tower03.jpg
Huge glass curtain walls hung from upper decks
Double outer walls allows for internal open spaces
Shanghai Tower

Video:

https://www.youtube.com/watch?v=G9S7Ix_0bBg
1. Glass façade reduces wind loads by 24%. Therefore 25% less structural steel saves US$58 million

2. Construction practices optimized

3. Vertical-axis wind turbines at top generate 350,000 kWh of electricity per year

4. Double-layered insulating glass façade reduces need for air conditioning

5. Heating &cooling use geothermal energy

6. Rain water collection

Shanghai Tower

Has a concrete core, and structural steel.

Not tallest building, but doesn’t aspire to be – it’s something completely new

A

VERTICAL CITY
However,

We shouldn’t always need to create artificial interior worlds

Especially if we are wrecking the natural world
Wright persuaded Harold Price to build headquarters on 19 floors instead of 3 by showing how power, climate control, plumbing, and communications are simpler & more efficient via a central stack.
Frank Lloyd Wright
known more for “Horizontal” Architecture,
designing on a Human Scale,
and with a great respect for Nature
Frank Lloyd Wright

2015 Architecture Minor Students & Faculty
At Falling Water & Kentuck Knob in PA
Kentuck Knob

2015 Architecture Students & Faculty

Professor Ricci
2015 Architecture Students & Faculty

Professor Ricci
Professor Friedly
2015 Architecture Students & Faculty

Professor Wunderlich
### Architectural Studies Minor

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<tr>
<th>Course Code</th>
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<td>ART 105</td>
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<td>ART 280</td>
<td>History of World Architecture</td>
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<td>ART 120</td>
<td>Sculpture</td>
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<td>EGR 343</td>
<td>Green Architectural Engineering</td>
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Select one of the following elective options - 4 credits

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<tr>
<td>EGR 276</td>
<td>Sustainable Resource Engineering &amp; Design</td>
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**OR** one of the following options with an emphasis in Architecture**

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**Contact Advisors:** Joseph Wunderlich Phd, or Patricia Ricci PhD