Skyscrapers

JT Wunderlich PhD

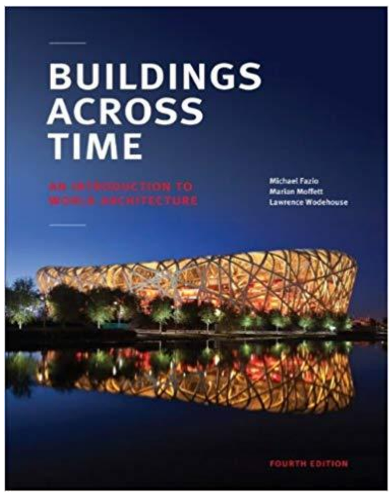
Primary Sources

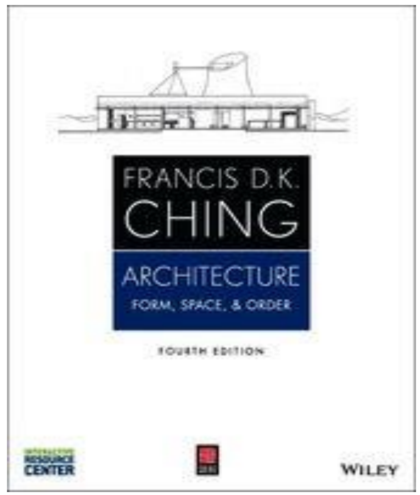
[1] Fazio, Michael and Moffett, Marian. ***Buildings Across Time.*** Lawrence Wodehouse, 4th Edition, McGraw Hill, 2013.

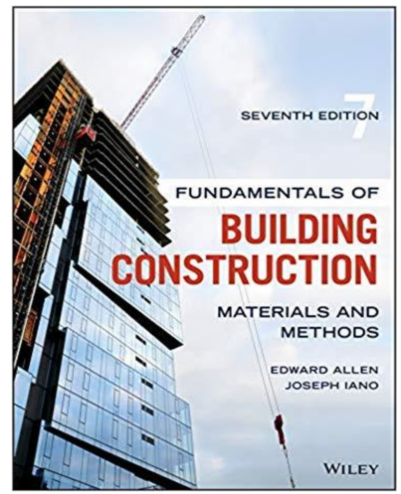
[2] Ching, Francis D.K. ***Architecture: Form, Space, and Order.*** 4 ed. Wiley, 2014.

[3] Allan, Edward and Iana, Joseph, *Fundamentals of Building Construction: Materials and Methods*. Wiley; 7thedition (October 15, 2019).

[4] AISC, Steel Construction Manual, 15th Edition, 2017.







- Personal Architecture projects in Texas, California, and Pennsylvania
  - BS Architectural Engineering (U.Texas 84)
  - 1-1/2 years of Urban Design (UCSD 1986-87)
  - Education and experience for past 40 years applicable towards licensing as both a Professional Engineer and a Registered Architect
- Frequent international travel pictures of Architecture and Urban Design

A skyscraper is a Tower

During Feudal times (e.g. Europe or Japan), towers protected cities and castles, and demonstrated status of feudal Lords and Kings

WALL PLANE

Kasteel Beersel, Belgium

WALL PLANE

Belgium 2014

Kasteel Beersel, Belgium


Belgium 2014
Kasteel Beersel, Belgium

Selecting a castle to visit on 2014 Belgium/Italy/England trip


GASBEEK 10am to 6pm (last visit starts at 5pm), Tuesday to Sunday, April to October. 4 €.The big park surrounding the castle is open 8am to 8pm and admission is free. Daily => (except a few Tuesdays and the first Saturday of the month) from 1st April to 30th September, from 10:00 am to 5:30 pm. Admission is 5 €f

No

From 10am to 12noon and 2pm to 6pm, Tuesday to Sunday from 1 March to 15 November

The castle is open from 1:00 pm to 6:00 pm everyday from 15 May to 30 September, and on weekends and holidays from 1 April to 14 May, or everyday from April to 15 October on demand for groups

The castle is open everyday, except Mondays which are not public holidays, from 10:00 am to 6:00 pm (last admission 5:30 pm). Entry to the castle is 4.96 € for adults, 3.72 € for senior (over 60), youth (12 to 18)

Rixensart Castle is only open on weekends and holidays from 2:00 pm to 6:00 pm, between 15 April to 31 October.

Entry cost 3.80 € for adults, 2.5 € for students and people between 13 and 18 and over 60 years old, 1.3 € for children between 6 and 13 years old and free under 6 and for disabled people. Guided tours take place every Sunday from April to October from 3:00 pm (6 €).

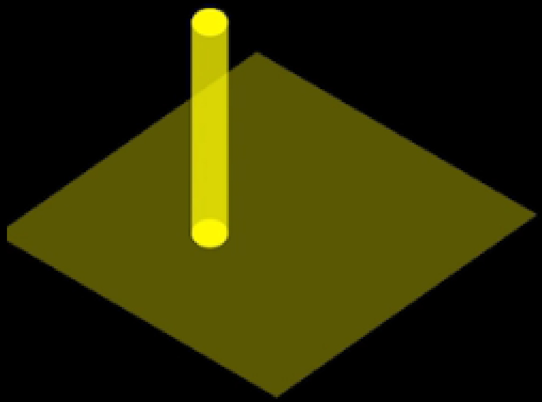
The castle is only open from 1st May to 28th September on Sundays and public holidays from 10:00 am to 6:00 pm (also Saturdays in July and August). Entry is 7 € for adults, and 2 € for children between 6 and 10 years old.

Kasteel Beersel, Belgium

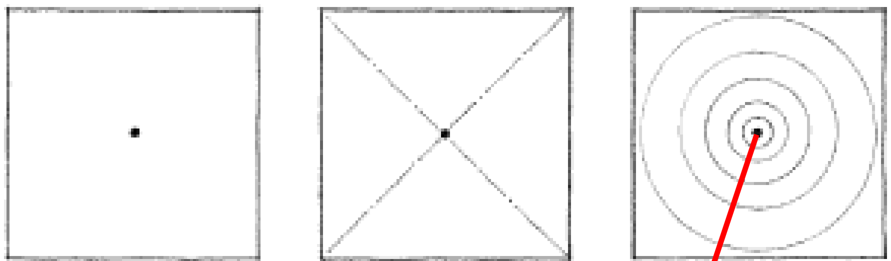
DEFINING SPACE

"A obelisk or tower establishes a point on the ground and makes it visible in space

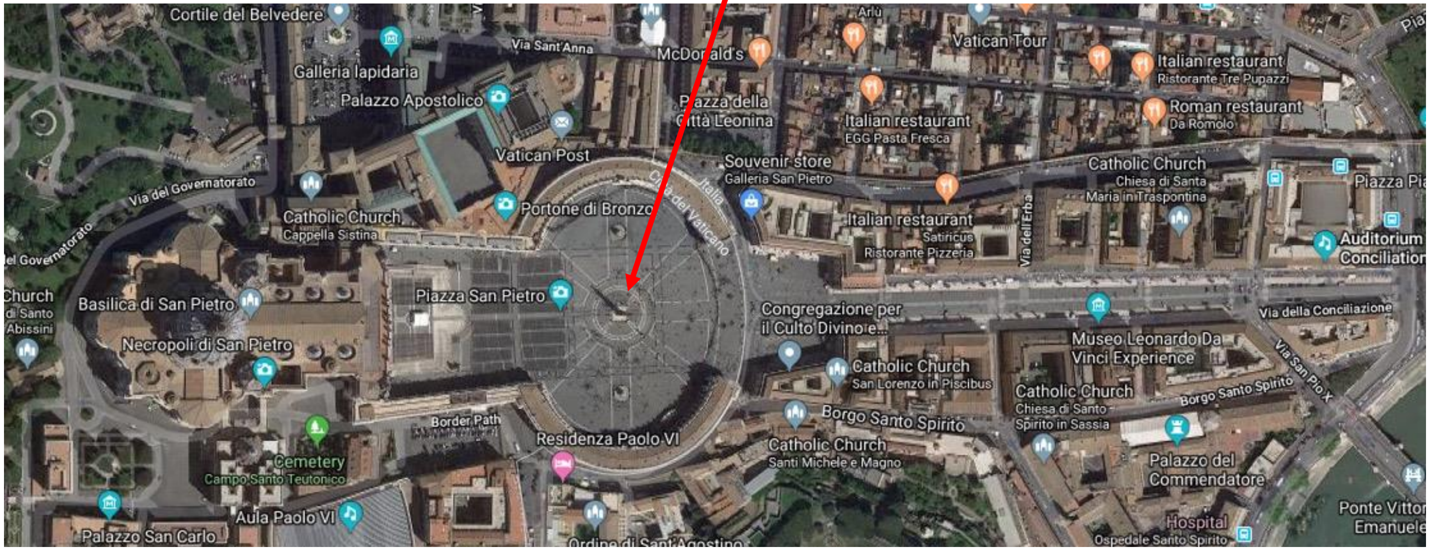
… a column generates a field about itself and interacts with the space" [2]



"At the center of its environment, a point is stable and at rest, organizing surrounding elements about itself and dominating its field" [2]



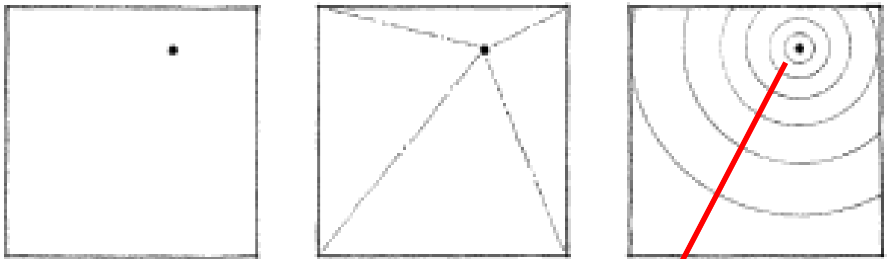
Rome, 2011



Piazza San Pietro, Vatican City, Rome

Rome 2011

*'When moved **off center**, it's field becomes more aggressive and begins to compete for visual supremacy. **Visual tension is created between the point and it's field"*** [2]



Campanile di San Marco in Piazza San Marco, Venice

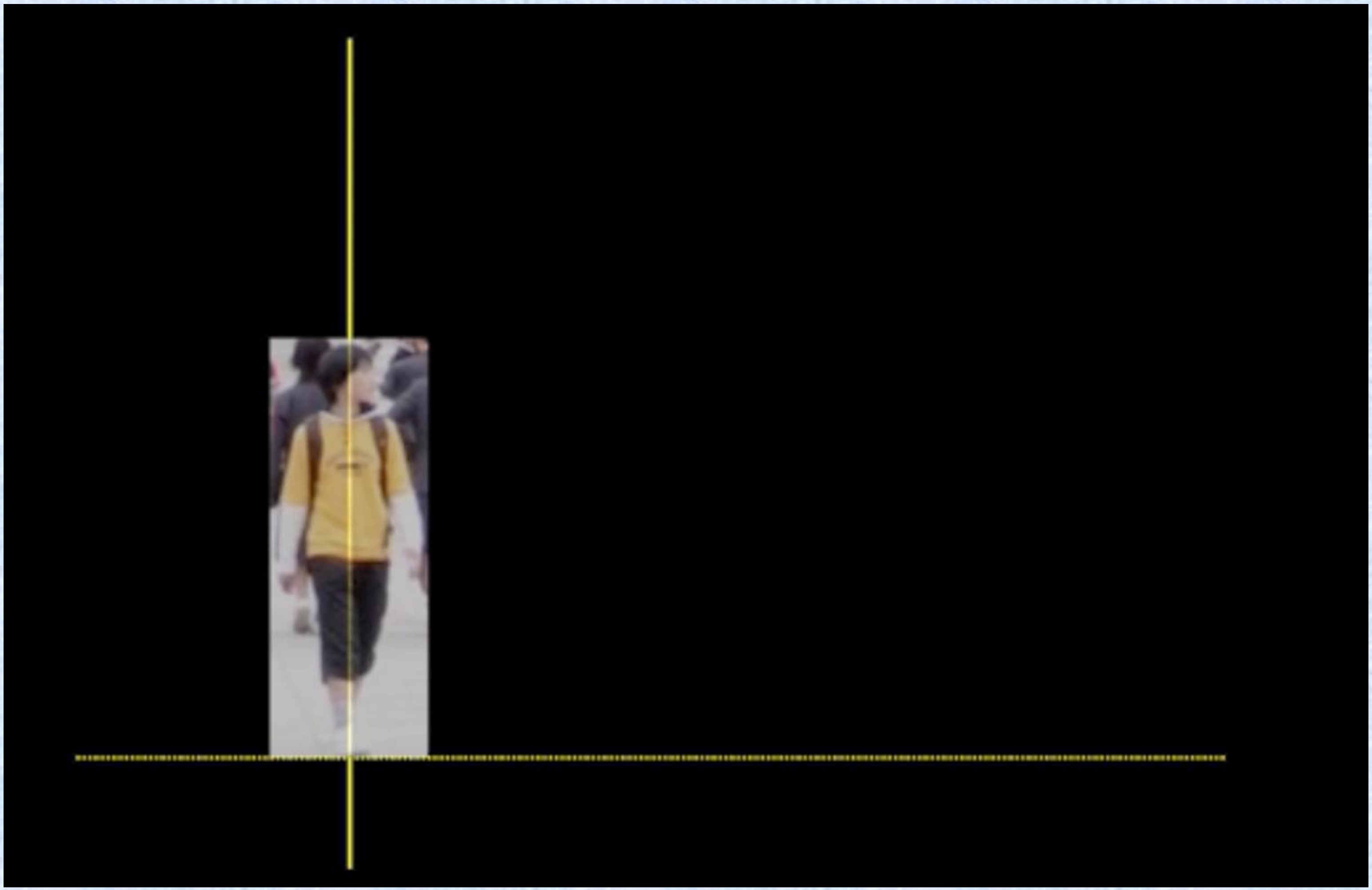
Venice 2008,2011,2014,2017

POINT off-center -- >Visual Tension

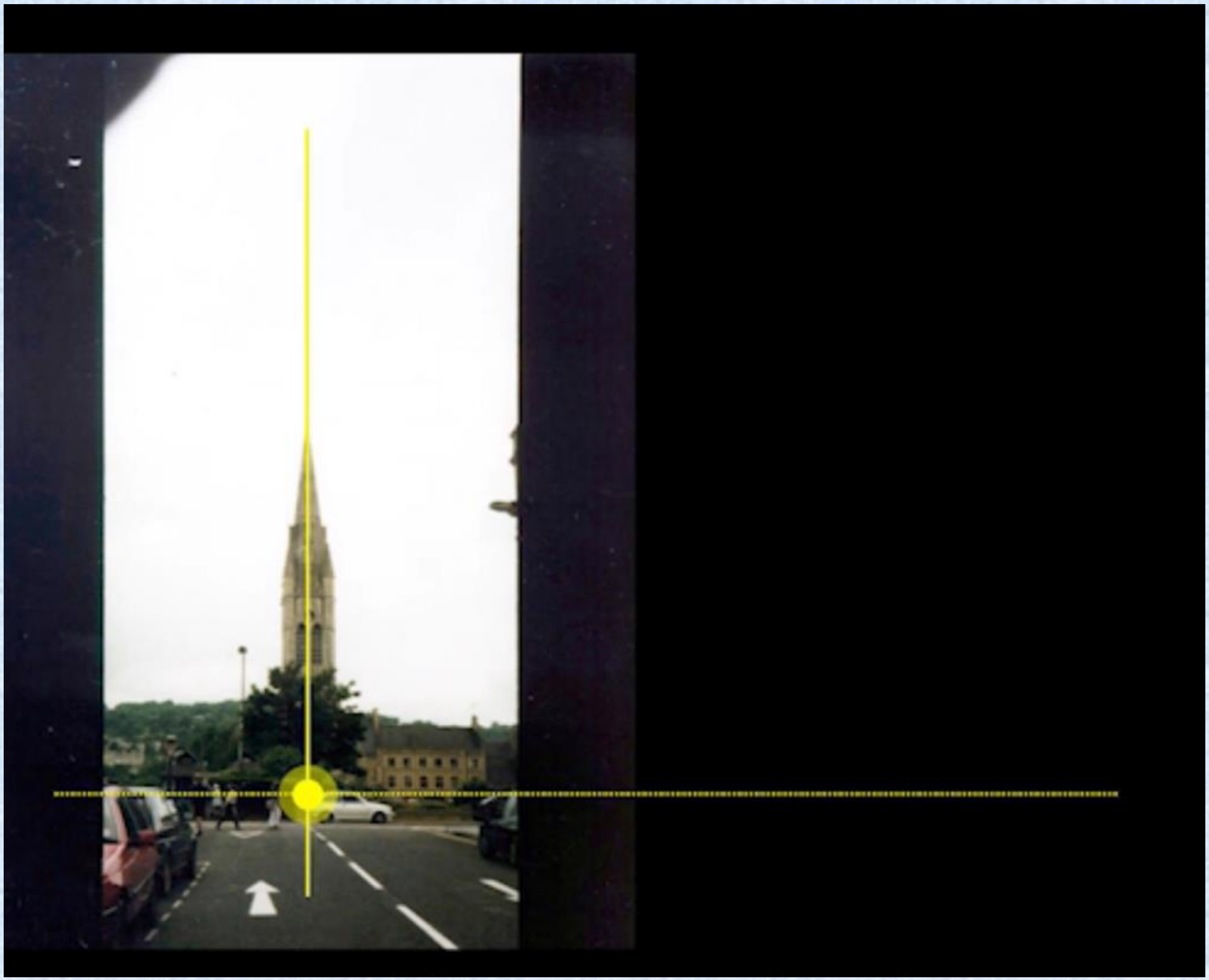
Venice 2008,2011,2014,2017

Venice 2008,2011,2014,2017

"A vertical line can express a state of equilibrium with gravity, and symbolize the human condition" [2]



“vertical equilibrium …the human condition” [2]



Venice 2008,2011,2014,2017

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

UNREINFORCED CONCRETE

Concrete is a “concretion” of a mix of **AGGREGATE** (rocks) and a cementations binding material (**CEMENT**)

- Romans used it extensively from 300BC to 475AD

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

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

Early 1800's in the U.S.

First cast-iron frames and building fronts

(often painted to look like stone or other materials)

1865+ in the U.S.

Industrial revolution – mass production

Tall buildings a result of rising urban real estate values, and desire of businesses to remain in center of activity

Cast IRON

Alloy of iron, carbon, and silicon cast in a mold; and is **Hard, Brittle**, **Nonmalleable**"

Wrought IRON

A form of iron; **Tough, Malleable**, relatively soft, contains usually less than 0.1 percent **carbon**, and 1 or 2 percent **slag** (stony waste matter separated from metals during the smelting or refining of ore)

STEEL

Commercial iron with **varying degrees of carbon content yields different strengths for structural** steel building skeletons. Also more **malleability** than cast iron… i.e., **less brittle (more "Ductile")**. Structural engineers want to specify for both strength and ductility.

SOURCE: http://www.merriam-webster.com/dictionary/

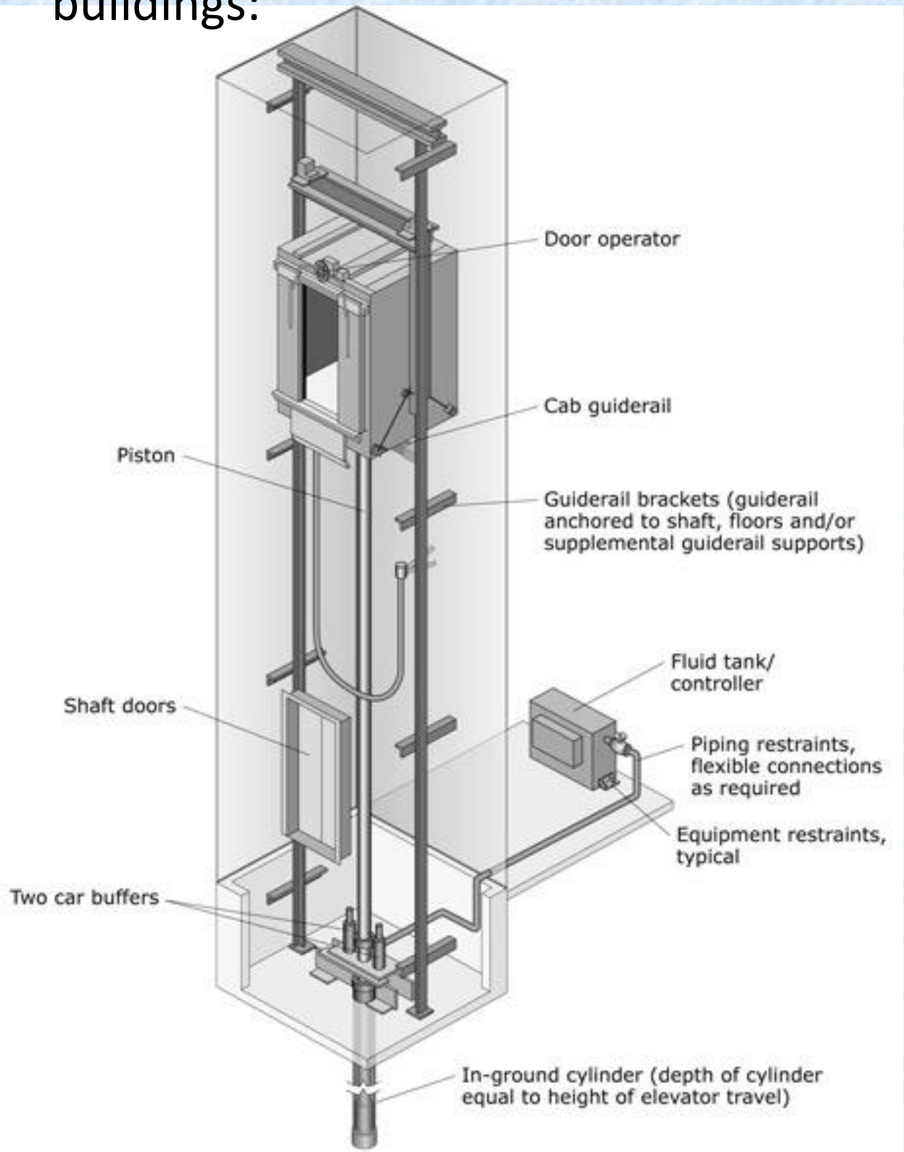
From http://image.slidesharecdn.com/structural-steel-8768/95/structural-steel-6-728.jpg?cb=1173466999

Comparison between Cast Iron, Wrought Iron & Steel

	Cast Iron	Wrought iron	Steel
Rusting	Does not rust easily	Rusts more than Cast Iron	Rusts easily
Malleability&Ductility	Brittle & cannot be welded or rolled into sheets	Tough, malleable, ductile & moderately elastic	Tough, malleable & Ductile
Reaction to sudden shock	Does not absorb shocks	Cannot stand heavy shocks	Absorbs shocks
Forging & Welding	Brittle and cannot be welded or rolled into sheets	Easily forged or welded	Rapidly forged or welded

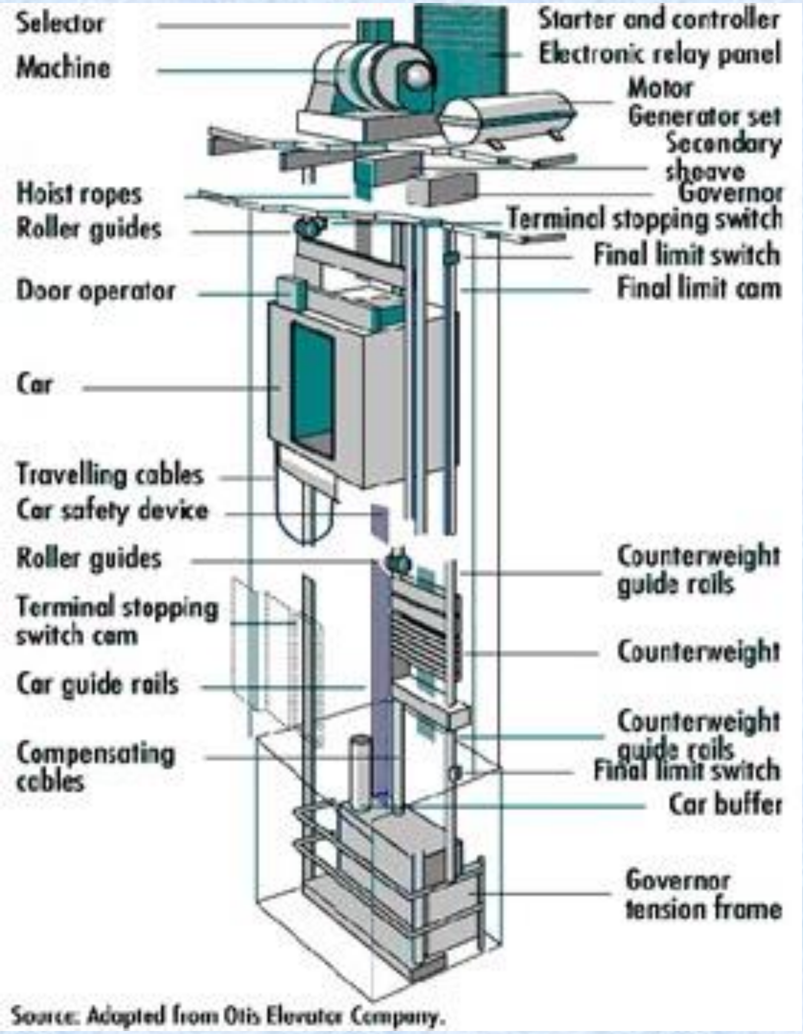
The ELEVATOR helped facilitate taller buildings

Modern **Hydraulic elevators** for shorter buildings:



http://www.fema.gov/sites/default/files/orig/plan/prevent/earthquake/fema74/images/chapter6_4_10/fig1_1.jpg

Modern High-speed **electric motors elevators for tall buildings**

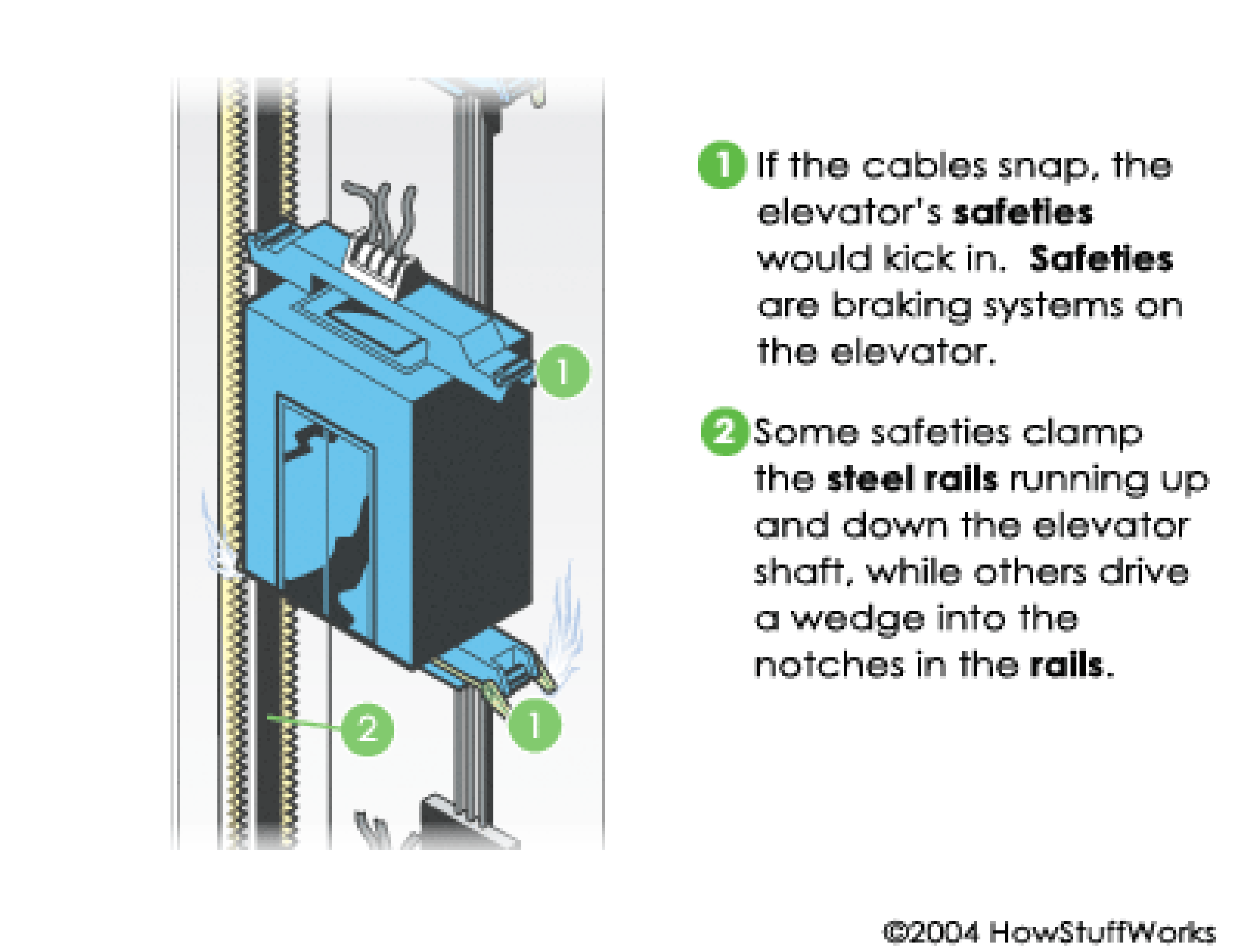


http://www.featurepics.com/FI/Thumb300/20070505/Highrise-Construction-306455.jpg

Elevator **SAFETY-SYSTEMS** allowed even taller buildings

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

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



http://static.ddmcdn.com/gif/runaway-elevator-2.gif

William Le Baron Jenny

Home Insurance Building

Chicago 1883

Demolished 1931

1883 STEEL

and an elevator

First *"Steel Skeleton"*

– but also much cast iron, and the first floor had masonry load-bearing walls [1]

Also one of the first skyscrapers to use an elevator (hydraulic)

https://en.wikipedia.org/wiki/Home_Insurance_Building#/media/File:Home_Insurance_Building.JPG

Burnham and Root

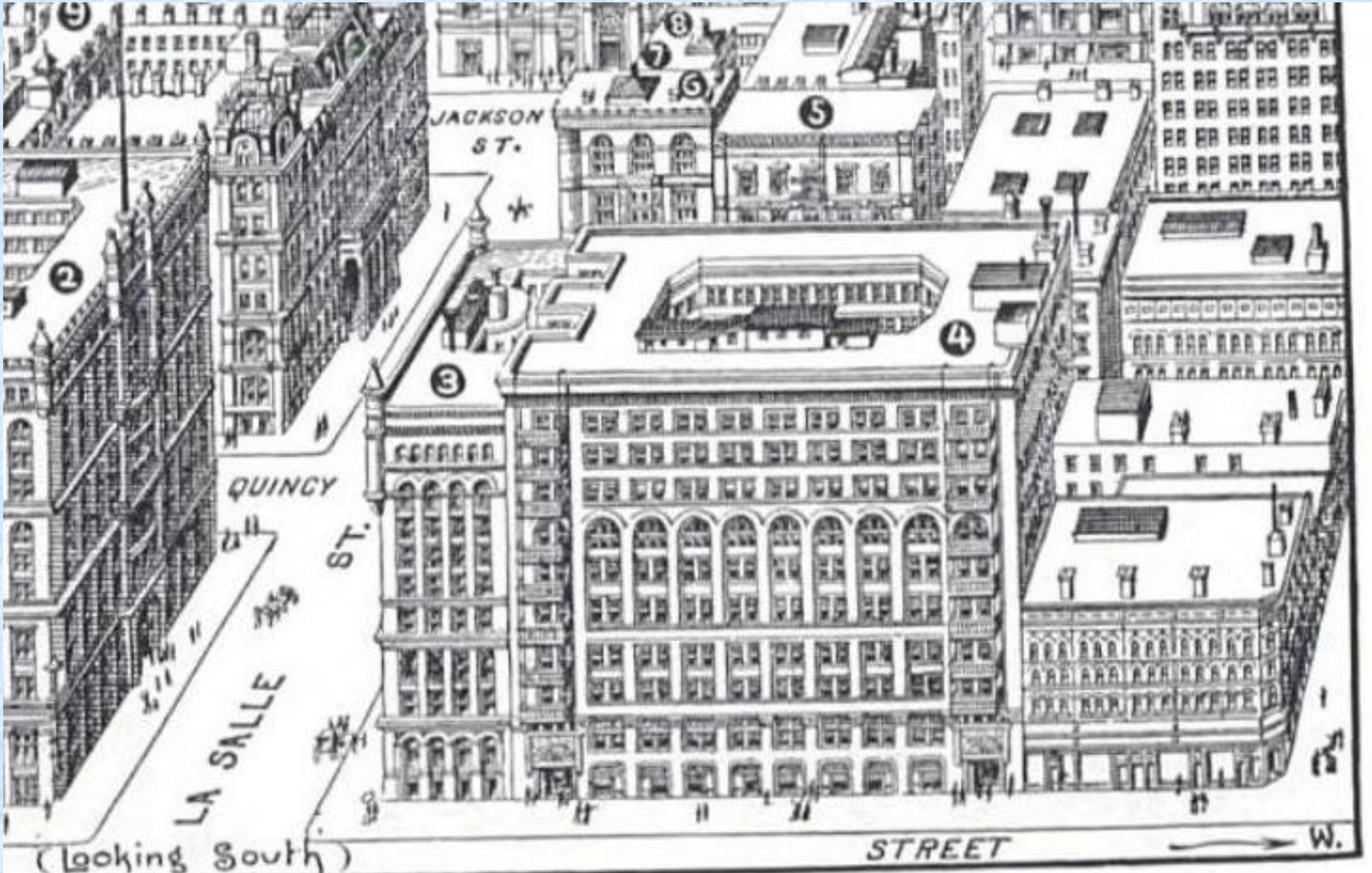
Rand McNally Building

Chicago 1889

Demolished 1911

STEEL

First to use Structural Steel for entire frame [1]



http://www.appstate.edu/~riedme/burnham&root/gallery.html

Louis Sullivan, The Father of Skyscrapers

Architect Louis Sullivan

1856-1924

At age 21, **Frank Lloyd Wright** approached the most famous architect in Chicago, **Louis Sullivan**

*"I was accepted by Mr. Sullivan and went to work for **Adler and Sullivan**, then the only moderns in architecture, and with whom, for that reason, I wanted to work."*

Frank Lloyd Wright

Architect Louis Sullivan

Auditorium Building
Chicago, 1889, Adler and Sullivan

Architect Louis Sullivan

Dankmar Adler and **Louis Sullivan**
Wainwright Building
St. Louis 1890

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 [1]

Architect Louis Sullivan

http://en.wikipedia.org/wiki/Wainwright_Building

Daniel H. Burnham & John Welborn Root

Monadnock Building

Chicago 1891

One of the last exterior load-bearing-masonry skyscrapers

- Walls very thick, to carry load

Also an internal iron frame for lateral bracing of exterior walls [1]

http://www.american-architecture.info/USA/CHICAGO/CHIC-LS/018-reliance1a.gif

- **Neither Architect liked Neoclassicism** (Greek or Roman)
  - Both annoyed by “White City” built for 1893 Worlds Fair in Chicago
  - Frank Lloyd Wright quoted French poet Victor Hugo:

“The setting Sun all mistook for Dawn”’

- **Both Architects in search of an entirely new American Architecture**

Frank Lloyd Wright

“White City” built for 1893 Worlds Fair in Chicago

Architect Louis Sullivan

https://mohistory.org/collections/item/resource:140756

Union Trust Company Building,
St Louis, 1893, Adler and Sullivan

Architect Louis Sullivan

The Guaranty Building (now the Prudential Building)
Buffalo, New York, 1895, Adler and Sullivan

Architect Louis Sullivan

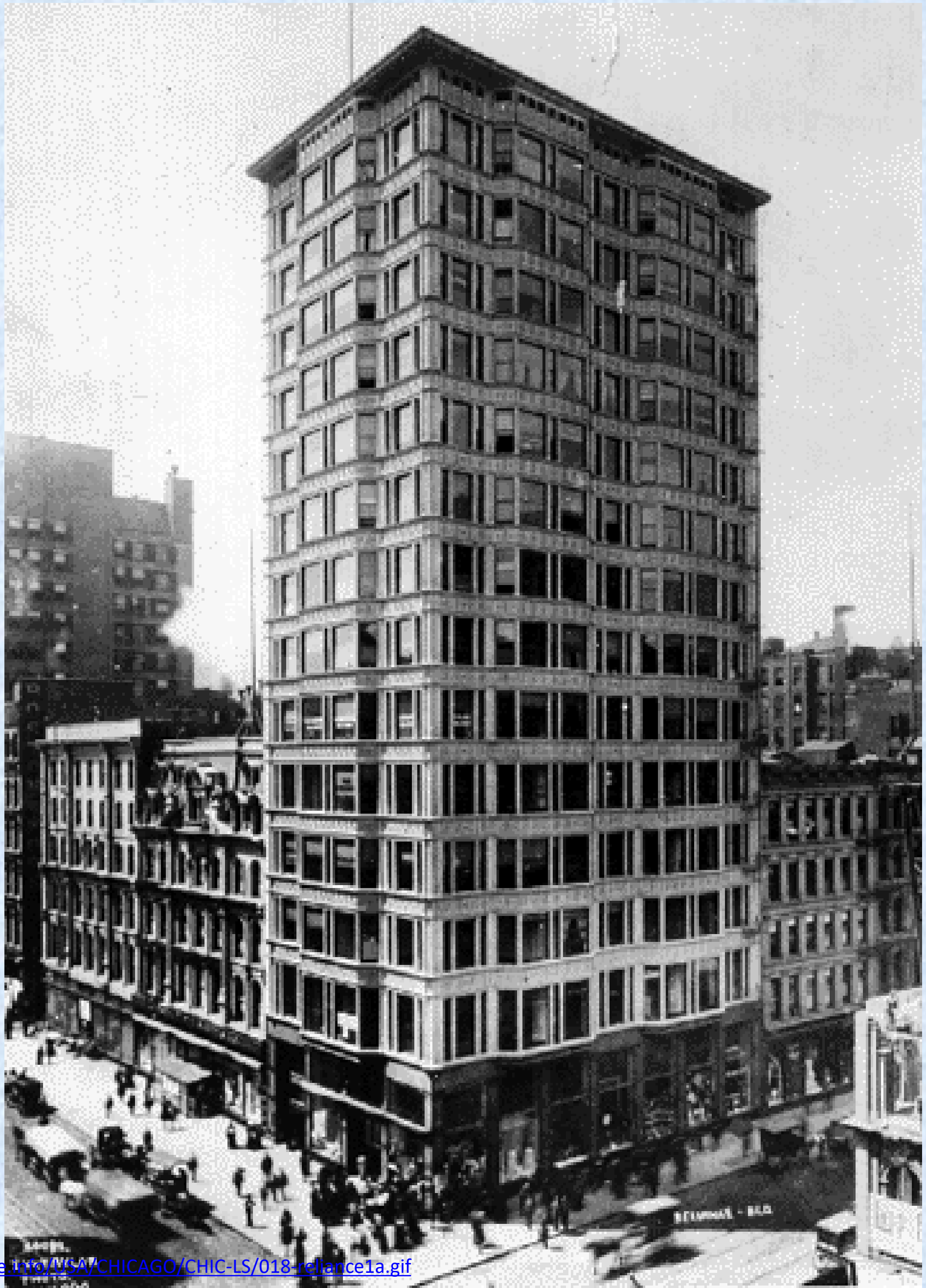
John Root and Charles Atwood

Reliance Building

Chicago 1895

External skin of terracotta and glass clipped onto internal steel skeleton [1]

Precursor to glass curtain walls



http://www.american-architecture.info/USA/CHICAGO/CHIC-LS/018-reliance1a.gif

Louis Sullivan

Pirie Scott Department Store Chicago 1899

Balance of vertical and horizontal elements

Has "**Chicago Windows**" with large fixed panes between operable windows [1]

http://blogs.artinfo.com/objectlessons/2012/07/27/louis-sullivans-carson-pirie-scott-co-building-reopens-as-a-target-and-why-chicagoans-should-be-smiling/

Architect Louis Sullivan

Daniel Burnham and Frederick Dinkelberg

Flatiron Building

New York 1902

One of the first very tall buildings

http://www.nyc-architecture.com/GRP/GRP24A.jpg

Elzner & Anderson
Ingalls Building
Cincinnati 1903

REINFORCED CONCRETE

A COMPOSITE MATERIAL of:

1. **Concrete**
   (High Compression strength)
2. **Steel Reinforcing-Bars (“Re-Bar”)**
   (High tensile strength)

First Reinforced Concrete Skyscraper

https://www.loopnet.com/listing/6-e-4th-st-cincinnati-oh/12158560/

Today's REINFORCED CONCRETE

REINFORCED Concrete in more recent times

"**SLIP FORMS**" allows taller buildings

http://www.wlport-land.com/images/xSlip1.jpg

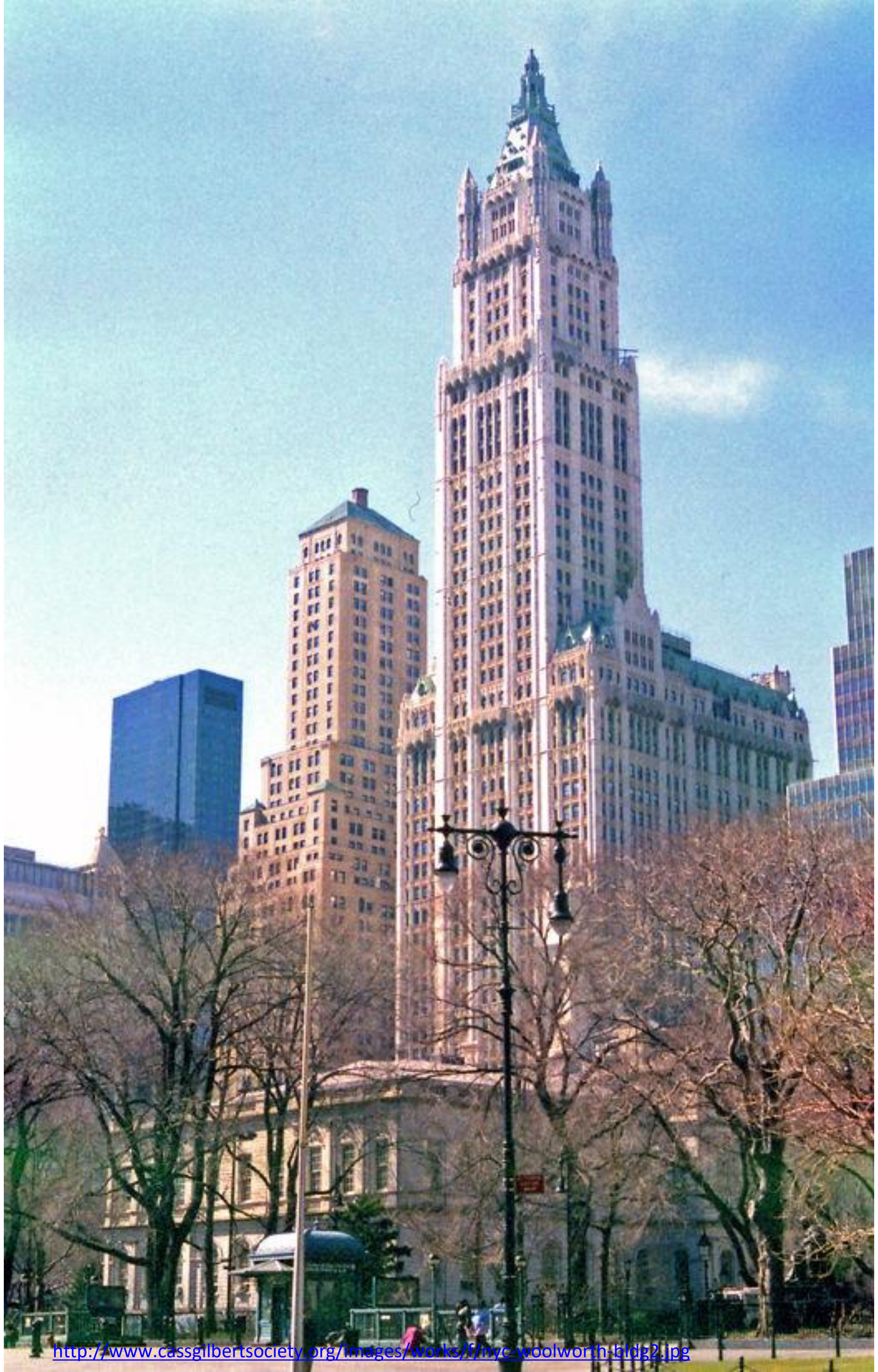
http://www.structuremag.org/images/0407-f1-1.jpg

Wunderlich family project included reinforced concrete to strengthens foundation

Today's REINFORCED CONCRETE

Cass Gilbert
Woolworth Building
New York 1913

Art Deco
Architectural Style



http://www.cassgilbertsociety.org/images/works/f/nyc-woolworth-bldg2.jpg

William Van Alan

Chrysler Building

New York 1930

Art Deco

Architectural Style

http://www.central-nyc.com/wp-content/uploads/2013/04/chrysler-building-296507.jpeg

William F. Lamb, Gregory Johnson

Empire State Building
New York ***1931***

Art Deco

Architectural Style

The Word's tallest building for 40 years [1]

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

BAHAUS SCHOOL

Germany 1919 to 1933

Founder: Architect Walter Gropius

"Modern" Architecture

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**

Closed due to pressure from Nazi's claiming it was a center of communist intellectualism

https://en.wikipedia.org/wiki/Bauhaus

Modern
Architectural Style

Le Corbusier

Unité d'Habitation

Marseille, France ***1945***

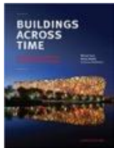
http://thepositive.com/sounds-and-lights-animate-the-machine-for-living/

Le Corbusier

Villa Savoye

Poissy, France ***1931***

http://www.fondationlecorbusier.fr/CorbuCache/410x480_2049_791.jpg



Le Corbusier - *a planned city concept:*

Modern
Architectural Style

http://http://www.archdaily.com/411878/ad-classics-ville-radieuse-le-corbusier

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

Seagram Building

New York 1958

Modern

Architectural Style

http://www.curbed.com/maps/mies-van-der-rohe-important-works

http://conservapedia.com/images/a/a6/Seagram_Building.jpg

http://conservapedia.com/images/a/a6/Seagram_Building.jpg

Ludwig Mies van der Rohe

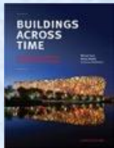
S.R. Crown Hall

Chicago 1956

Ludwig Mies van der Rohe

Farnsworth House

Plano, IL 1951



Frank Lloyd Wright

Price Tower
Bartlesville, Oklahoma 1952

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 [1]

http://0.tqn.com/d/architecture/1/0/9/v/PriceTower.jpg

Modern
Architectural Style

Phillip Johnson
IDS Center
Minneapolis 1968

Phillip Johnson was first a **Modern** Architect

Phillip Johnson
Glass House
Canaan, CT 1949

http://assets.bizjournals.com/twincities/print-edition/IDS-center*304.jpg?v=1

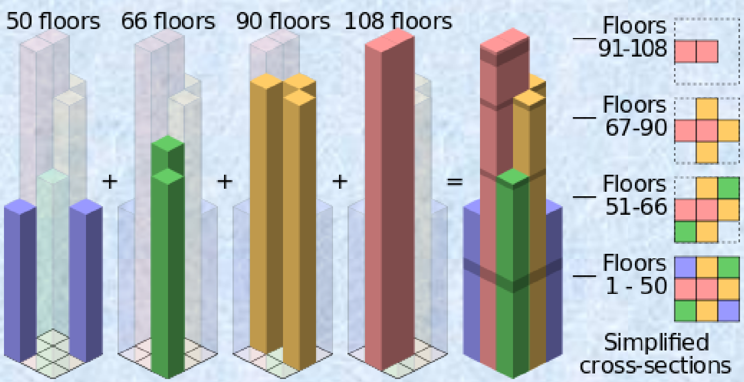
Modern
Architectural Style

Fazlur Rahman Khan, Bruce Graham

Sears Tower ("Willis Tower")

Chicago 1973

The Word's tallest building for 25 years after it surpassed the Empire State Building [1]



Source: http://en.wikipedia.org/wiki/Willis_Tower

Phillip Johnson

AT&T Building, now Sony Tower

New York 1984

POSTMODERN Architectural style - references elements prior to the Modernist movement -- in contrast to the simplicity of Modern movement [1]

At it's top, a pediment. **Postmodern** reminiscent of a grandfather clock, or a tall 18th century chest-of drawers

http://www.achievement.org/achievers/joh0/large/joh0-050.jpg

Phillip Johnson

AT&T Building, now Sony Tower

New York 1984

Postmodern

Architectural Style

At it's base, **Postmodern** reminiscent of Italian renaissance architecture

http://www.constructionphotography.com/ImageThumbs/A08
00022_Sony_Plaza_tower_Manhattan_New_York_City.jpg

St. Peters Basilica in Rome 2011

Phillip Johnson

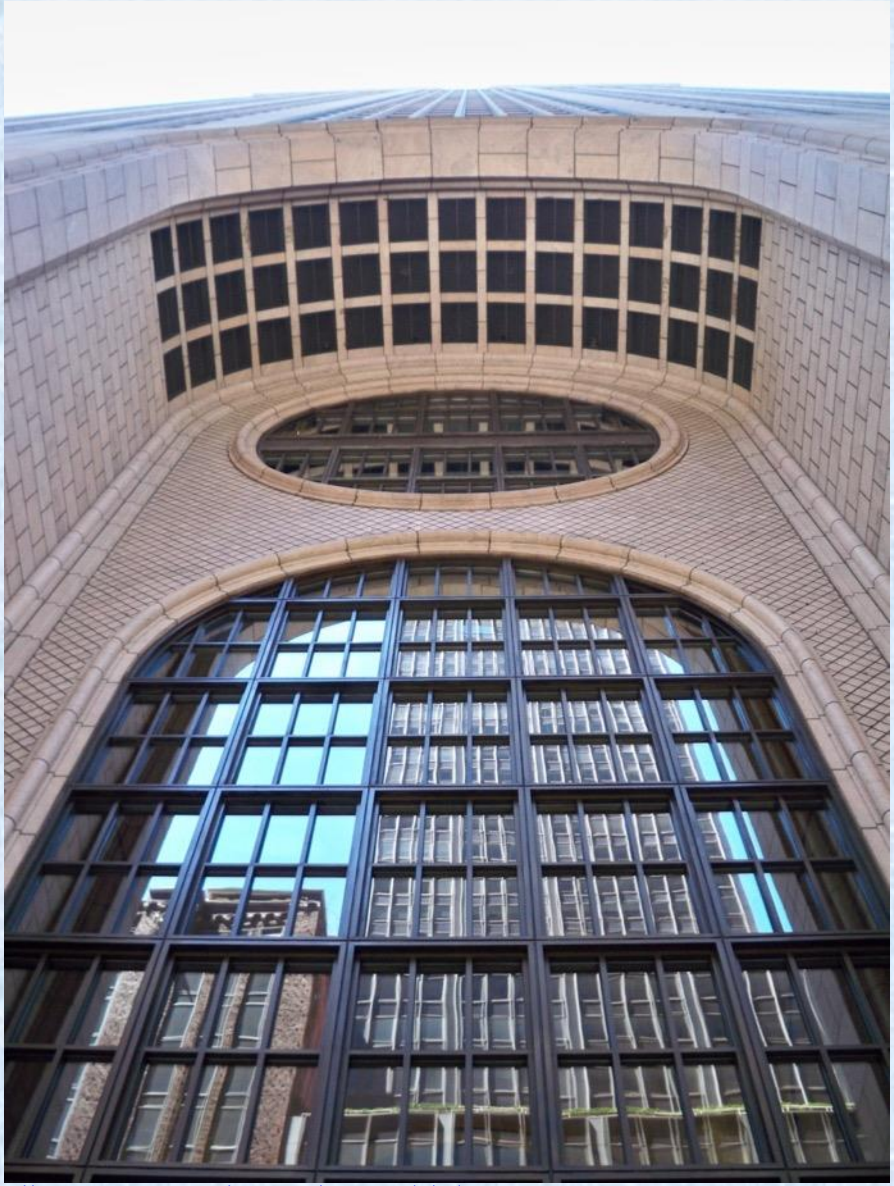
Sony Tower

New York 1984

Postmodern reminiscent of Italian renaissance architecture

Postmodern

Architectural Style



Vatican Museum in Rome 2011

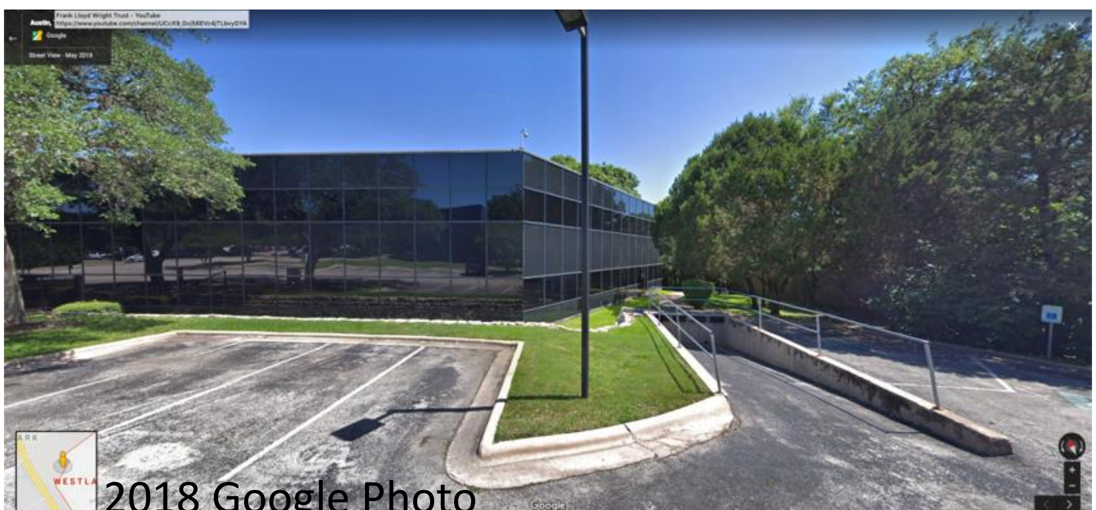
http://upload.wikimedia.org/wikipedia/commons/1/1f/Sony_Building_by_Matthew_Bisanz.jpg

JT Wunderlich 1984,85 Project Manager / Designer

"West Lake Oaks" (13 buildings),

DDC Development, Austin TX

- Architecture , Engineering, and management of 60 contracts and several employees



Two IBM360

Computer Centers

Glass CURTAIN WALL common in modern commercial buildings

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

Recent **CURTAIN WALL**

http://www.extal.com/userfiles/products/msg/Msg_02.jpg

Typical Modern Commercial Construction

Recent **CURTAIN WALL**

Structural Load carried by **core** and **columns**

Glass **CURTAIN WALL** doesn't carry load

http://www.expresstowers.in/images/floor_plan1_1.jpg

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**")

JT Wunderlich 1984,85

Austin TX

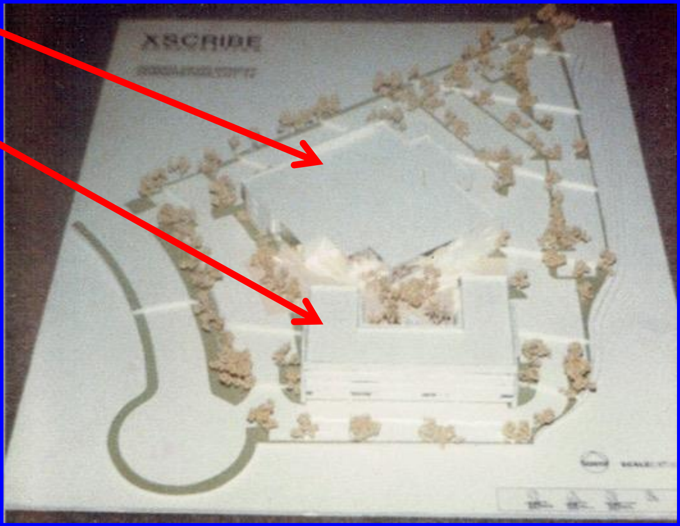
Recent **CURTAIN WALL**
STEEL SKELETON

- 2018 Photo

JT Wunderlich 1985,86
Director of Projects / Designer
JDC Development, La Jolla, CA

66,000sf hi-tech office
and light manufacturing
44,00sf office building

Recent CURTAIN WALL
Steel and Reinforced Concrete



JT Wunderlich 1985,86

La Jolla, CA

Recent CURTAIN WALL

Steel and Reinforced Concrete

- Led Design Team, Modified forms, Selected materials & landscaping
- Project nominated for Award

César Pelli

Petronas Towers

Kuala Lumpur, Malaysia 1996

Postmodern

Architectural Style

http://www.orangesmile.com/extreme/en/highest-buildings/petronas-towers.htm

C.Y. Lee & Partners

Taipei 101

Taipei, Taiwan 2004

Postmodern

Architectural Style

http://www.lonelyplanet.com/taiwan/taipei/sights/architecture/taipei-101

Norman Foster

The Gherkin

London, 2004

Neo-Futuristic

Architectural Style

http://www.luxuryestate.com/blog/wp-content/uploads/2014/09/copertina3-720x408.jpg

Rem Koolhaas, Ole Scheeren

CCTV Headquarters

Beijing, China 2008

Deconstructive

Architectural Style

http://www.skyscrapercity.com/showthread.php?t=179084

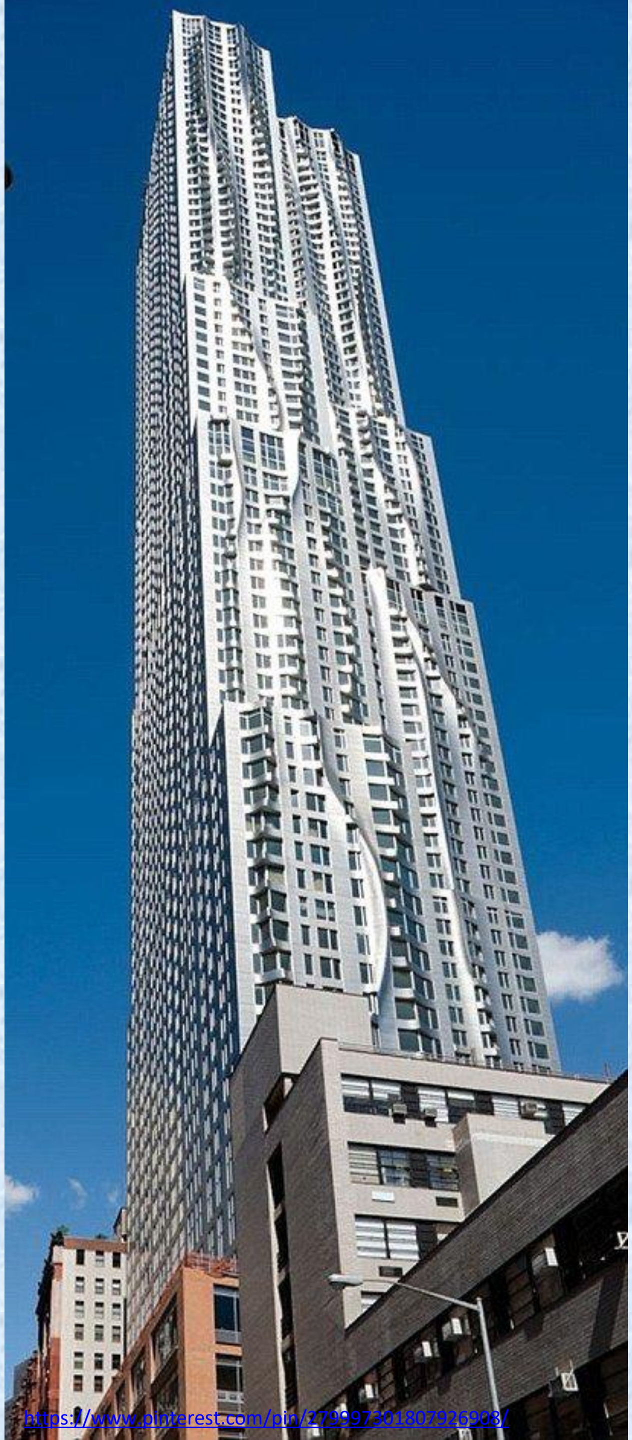
Frank Gehry

Spruce St. Tower

New York 2011

Deconstructive

Architectural Style



https://www.pinterest.com/pin/279997301807926938/

https://www.flickr.com/photos/bostoncitywalk/6657472251

Adrian Smith, Marshall Strabala,
George J. Efstathiou, William F. Baker

Burj Khalifa
Dubai, United Arab Emirates 2014

Neo-Futuristic

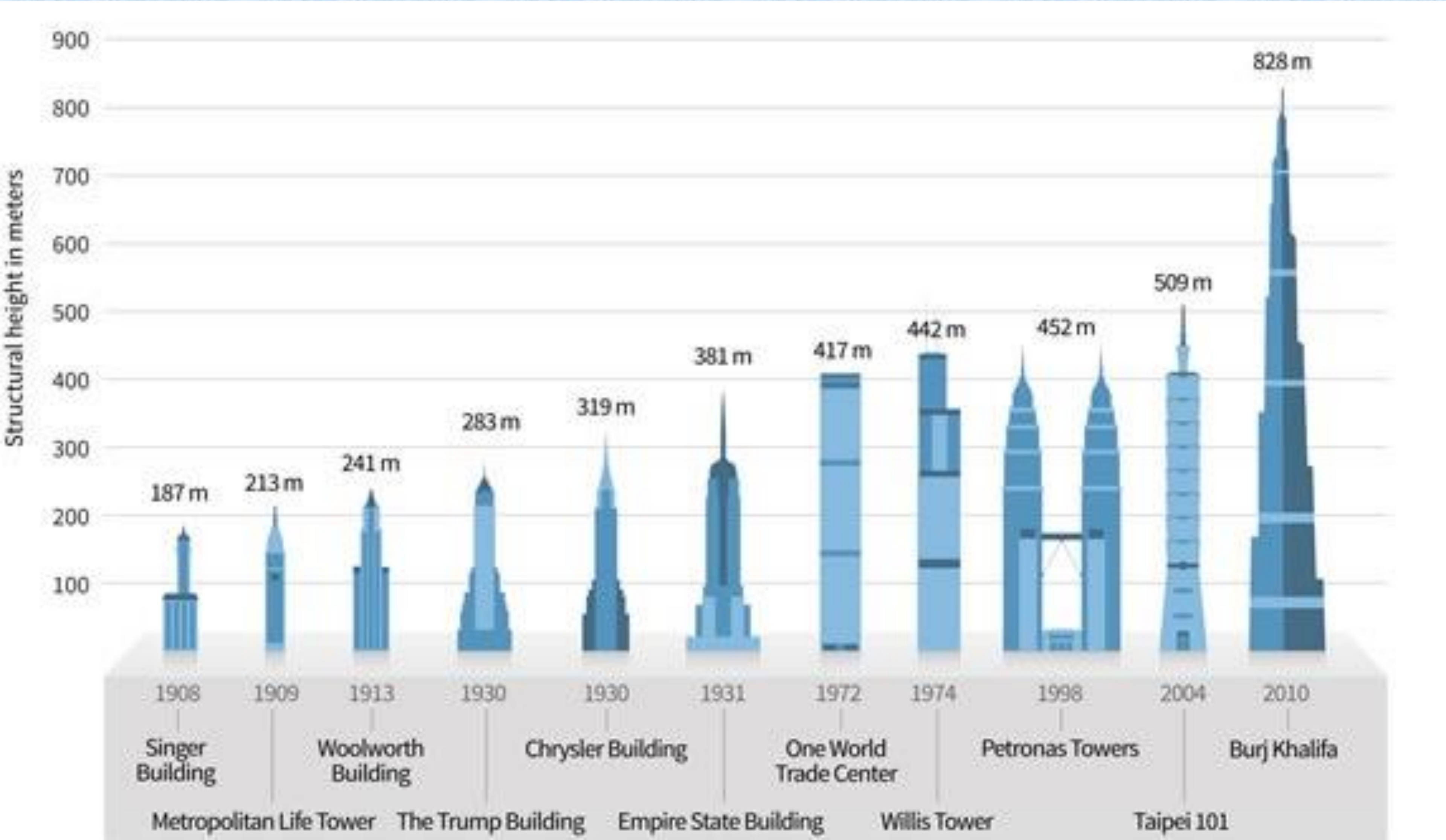
Architectural Style

World’s
Tallest Building

http://en.wikipedia.org/wiki/File:Burj_dubai_aerial_closeup.jpg

Burj Khalifa 2014

Neo-Futuristic
Architectural Style

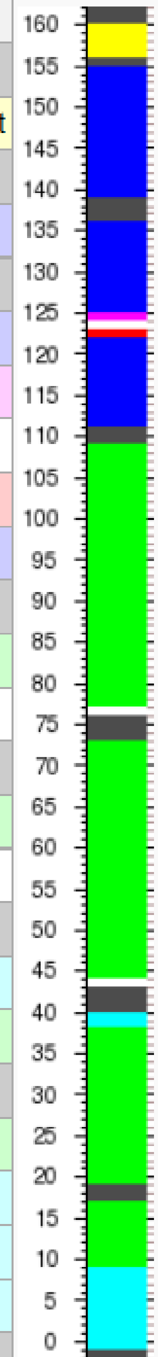


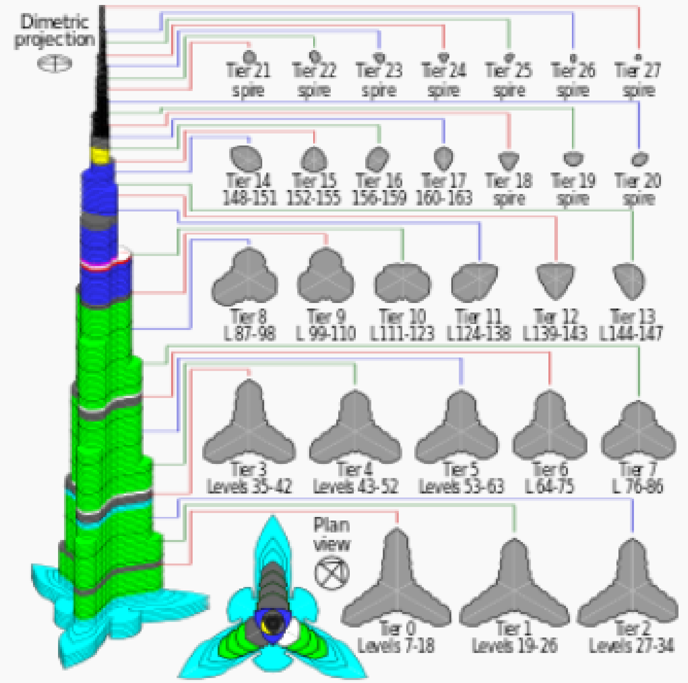
http://highrisefacilities.com/wp-content/uploads/2013/12/Skyscraper-History-Chart.jpg

Burj Khalifa 2014

Neo-Futuristic
Architectural Style

Floors	Use
160 and above	Mechanical
156–159	Communication and broadcast
155	Mechanical
139–154	Corporate suites
136–138	Mechanical
125–135	Corporate suites
124	*At the Top* observatory
123	Sky lobby
122	*At.mosphere* restaurant
111–121	Corporate suites
109–110	Mechanical
77–108	Residential
76	Sky lobby
73–75	Mechanical
44–72	Residential
43	Sky lobby
40–42	Mechanical
38–39	Armani Hotel suites
19–37	Residential
17–18	Mechanical
9–16	Armani Residences
1–8	Armani Hotel
Ground	Armani Hotel
Concourse	Armani Hotel
B1–B2	Parking, mechanical





Dimetric projection with floors colour-coded by function[84]

http://upload.wikimedia.org/wikipedia/commons/thumb/0/06/Burj_Khalifa_floors.svg/512px-Burj_Khalifa_floors.svg.png

Video:

http://www.skymetweather.com/content/earth-and-nature/must-watch-natures-lightning-show-over-burj-khalifa/

Marshall Strabala, Jun Xia

Shanghai Tower

Shanghai, China 2015

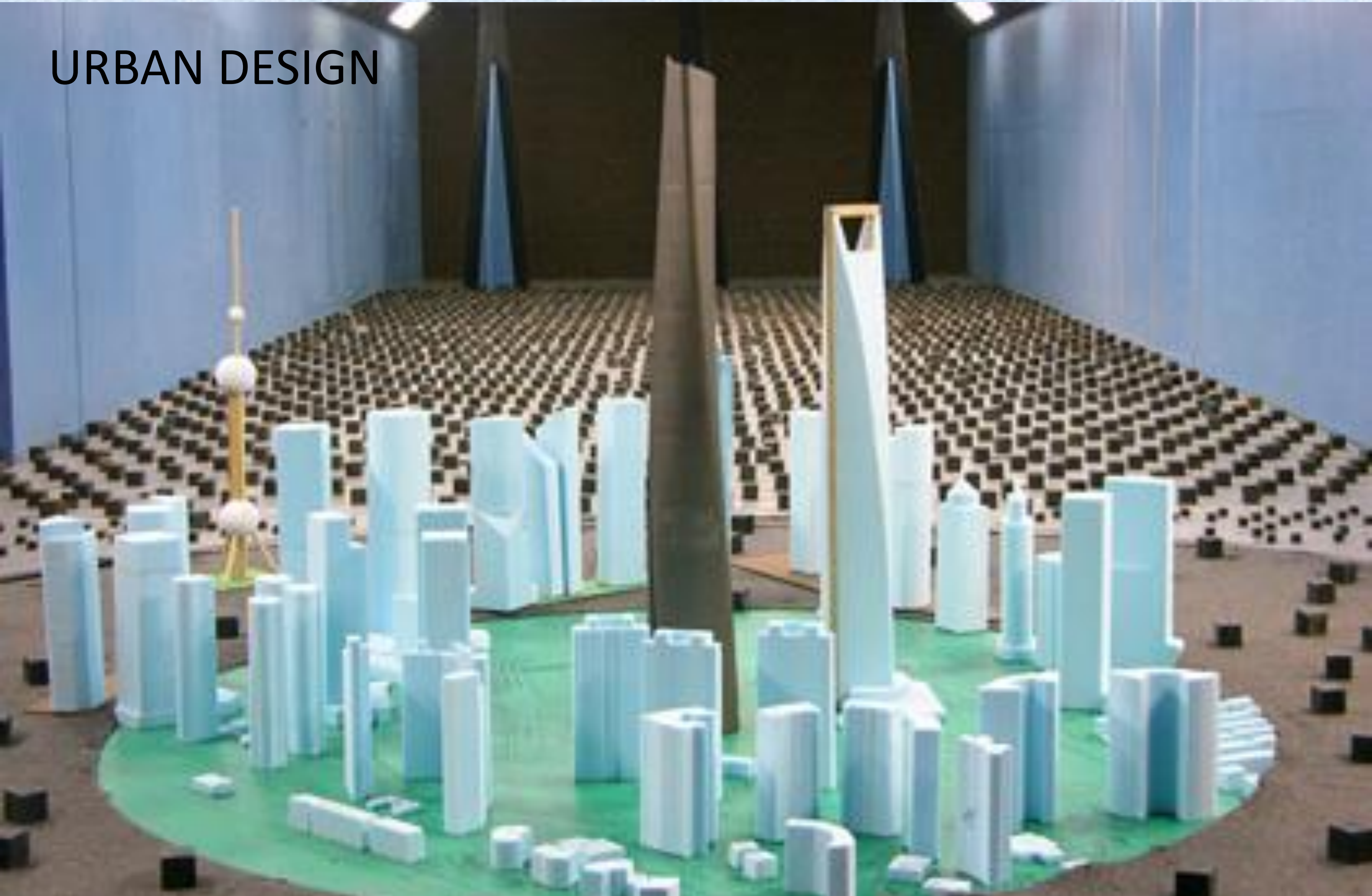
Artist's rendition

http://www.evolo.us/wp-content/uploads/2010/07/twisting-tower-shanghai.jpg

Sustainable Design

https://en.wikipedia.org/wiki/Shanghai_Tower

URBAN DESIGN



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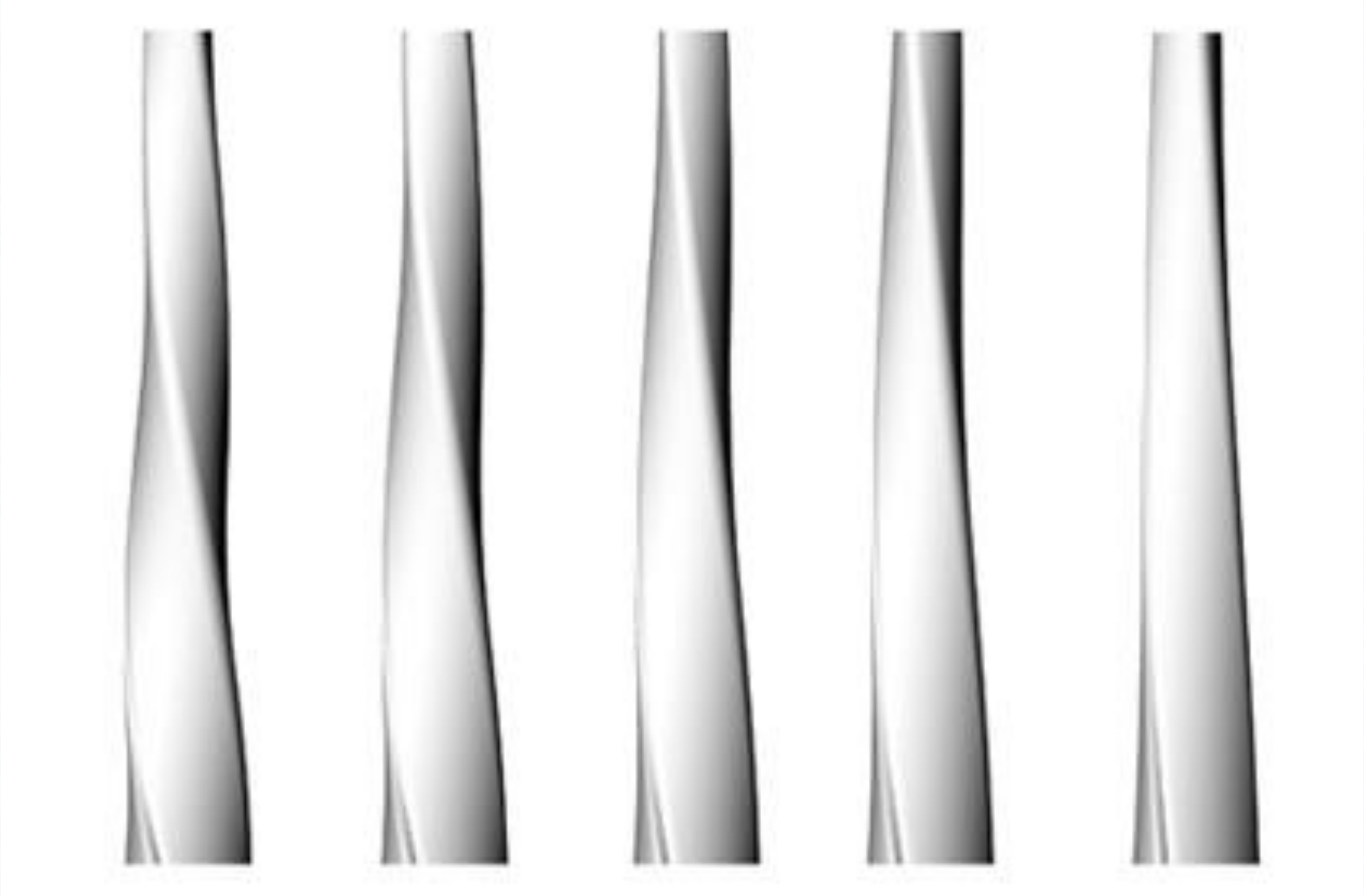
CONCEPTUAL DESIGN



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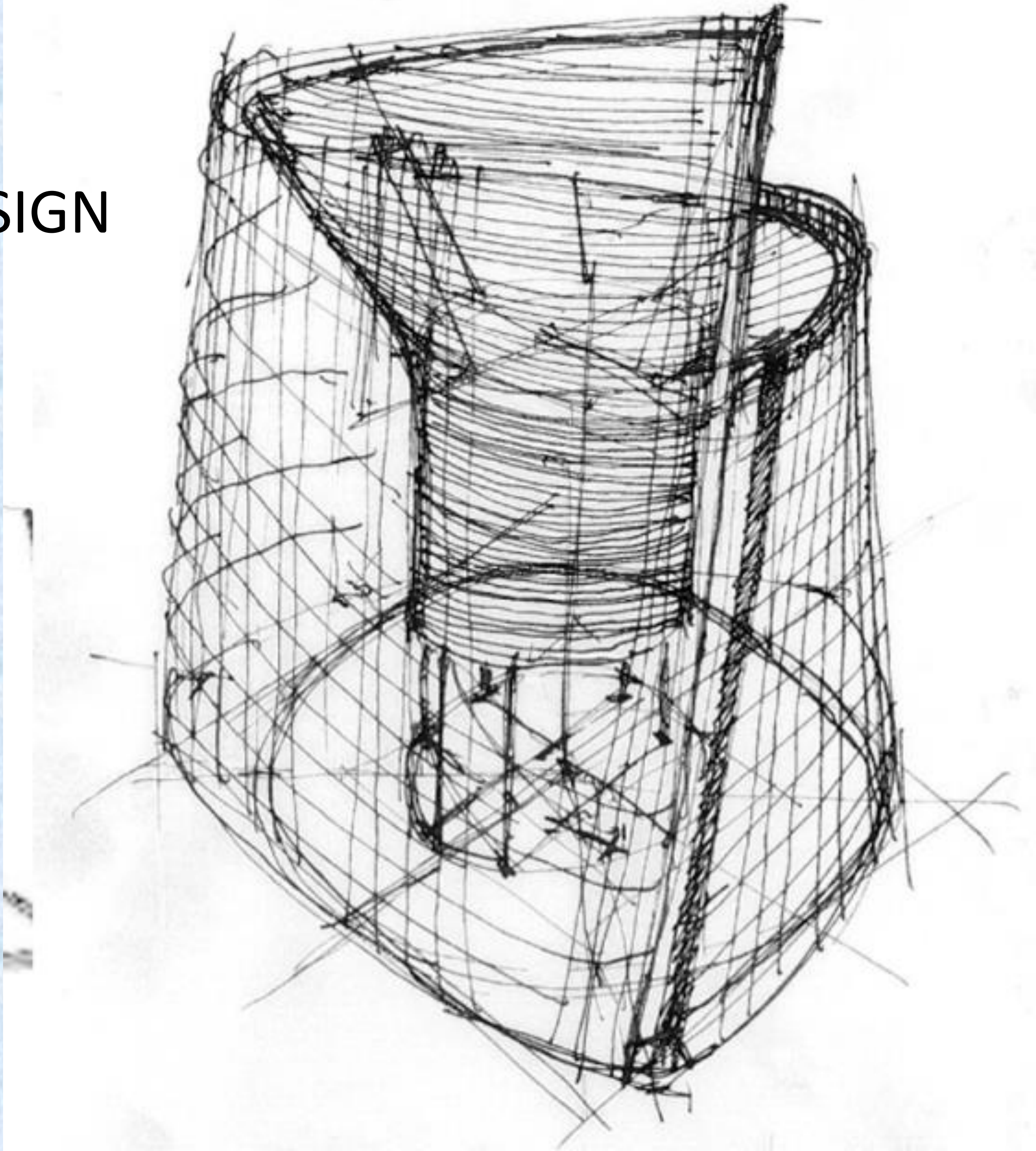
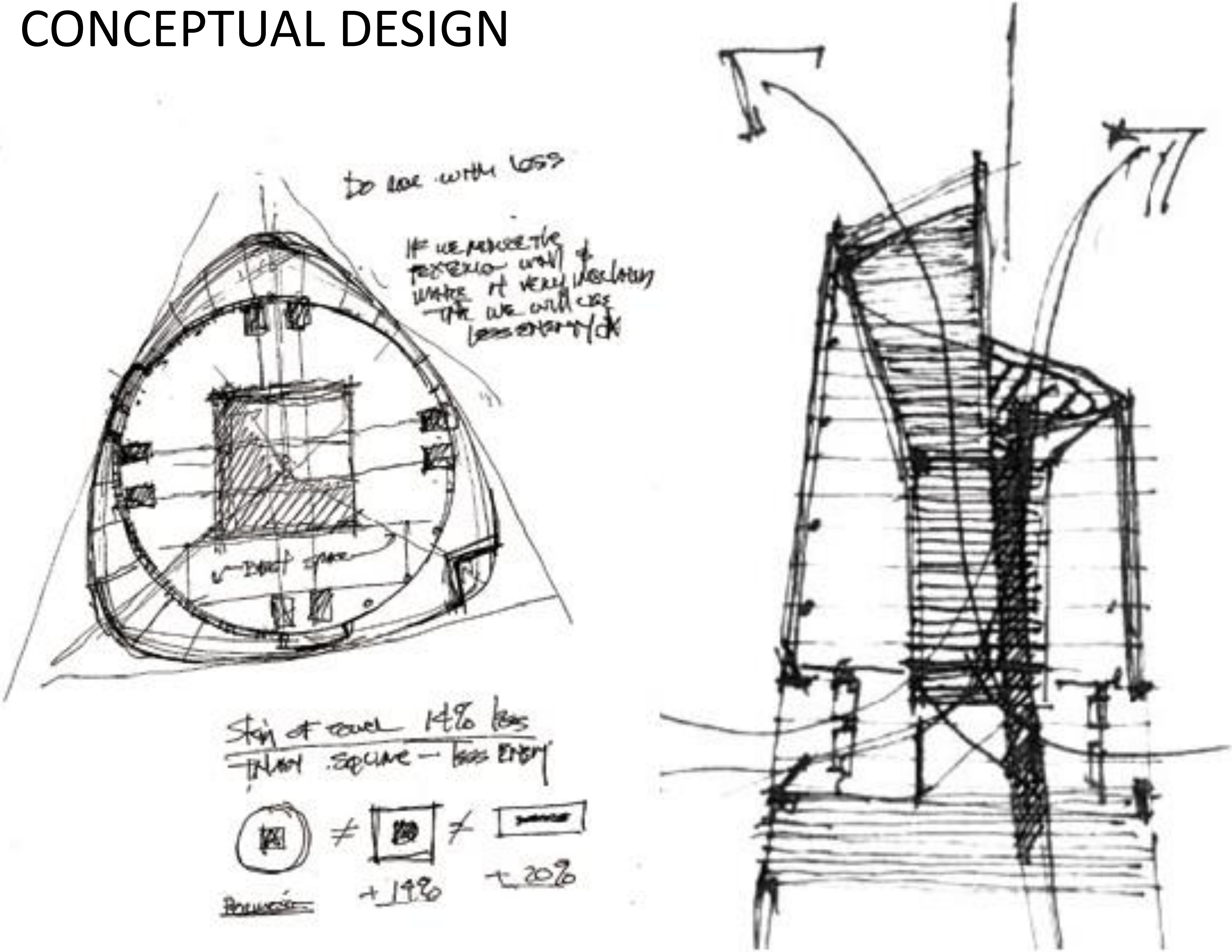
CONCEPTUAL DESIGN



http://www.gensleron.com/storage/post-images/WineyPost1Image1.jpg

CONCEPTUAL DESIGN



Sustainable Design

Huge glass **curtain walls** hung from upper decks

Image From:http://www.anotherpartofme.com/wp-content/uploads/2013/05/shanghai_tower03.jpg

Shanghai Tower *2015*

Sustainable Design

http://sites.psu.edu/khalqubbaj/wp-content/uploads/sites/4598/2013/09/ShanghaiTower_8_v2.jp g

Shanghai Tower *2015*

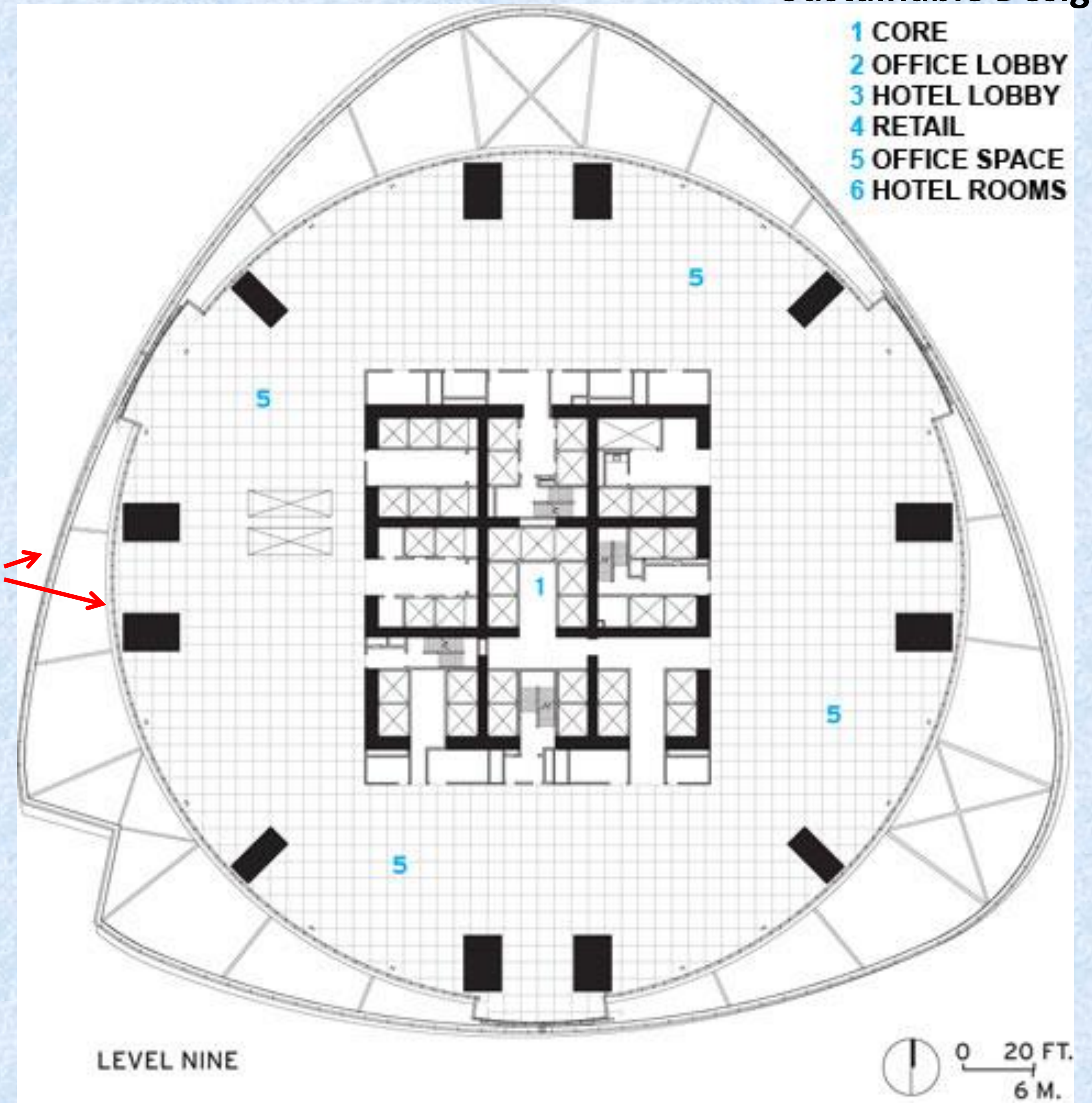
Sustainable Design

Huge glass **curtain walls** hung from upper decks

http://assets.inhabitat.com/wp-content/blogs.dir/1/files/2011/12/Shanghai-tower-6.jpg

Shanghai Tower *2015*

Sustainable Design



Double outer walls allows for internal open spaces

http://www.china-sbs.com/userfiles/26.jpg

Shanghai Tower *2015*

Sustainable Design

1. Glass façade reduces wind loads by 24%. Therefore 25% less structural steel saves US$58 million

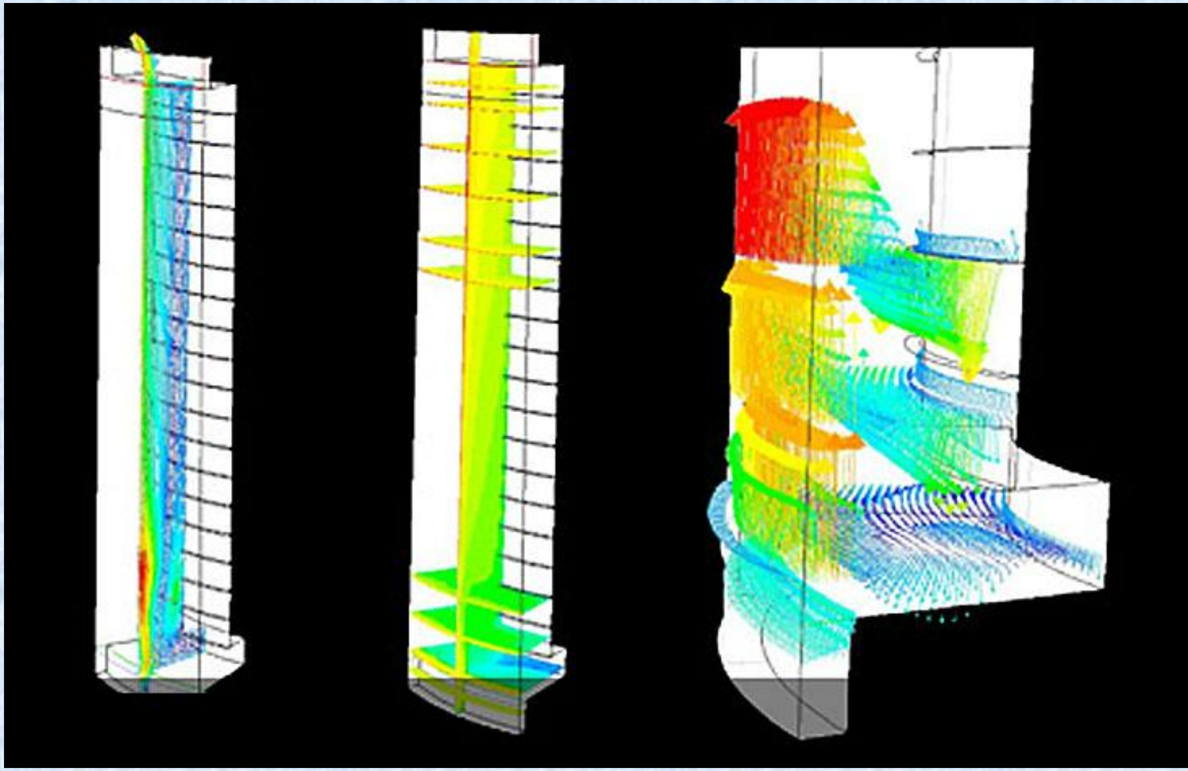
2. Construction practices optimized

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



Source: http://assets.inhabitat.com/wp-content/blogs.dir/1/files/2011/12/shanghai-tower-bim.jpg

Shanghai Tower **2015**

Sustainable Design

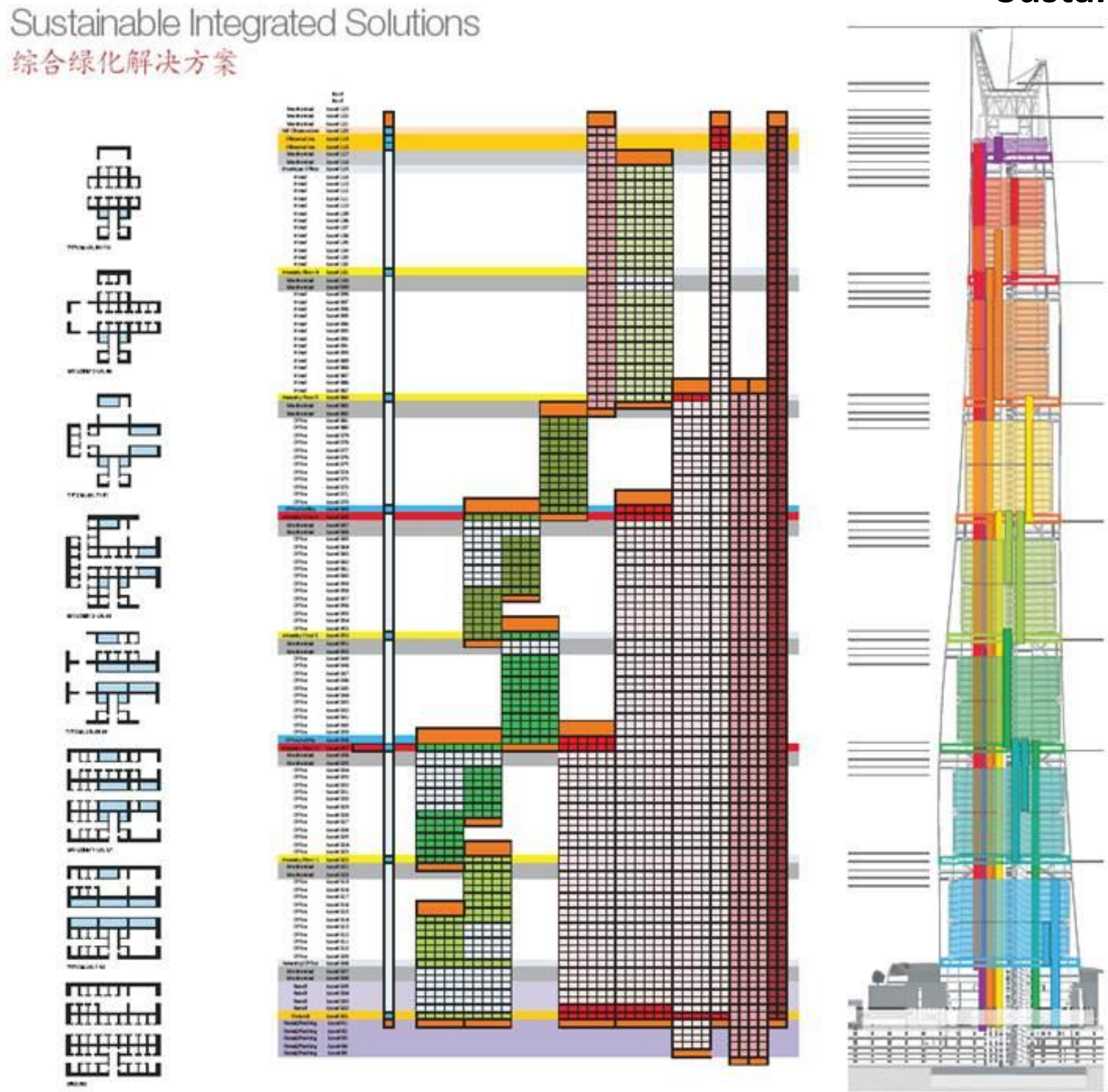


Image From:http://4.bp.blogspot.com/-UGNergNxHYA/UCPj3Bp2gDI/AAAAAAAAHQk/KaEbJhj_qH8/s1600/Shanghai_Tower_worlds_tallest_skyscrapers_Blueprints_Structural_Models_and_floor_plans_by_Gensler_world_of_architecture_worldofarchi_08.j

Has a concrete core,
and structural steel.

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

A
VERTICAL GREEN CITY

http://www.e-architect.co.uk/images/jpgs/shanghai/shanghai-tower-g070813-3.jpg

However,

We hopefully won’t rely entirely on artificial interior worlds – no matter how well we can make them “Sustainable”

http://www.e-architect.co.uk/images/jpgs/shanghai/shanghai-tower-g070813-3.jpg

https://en.wikipedia.org/wiki/Shanghai_Tower

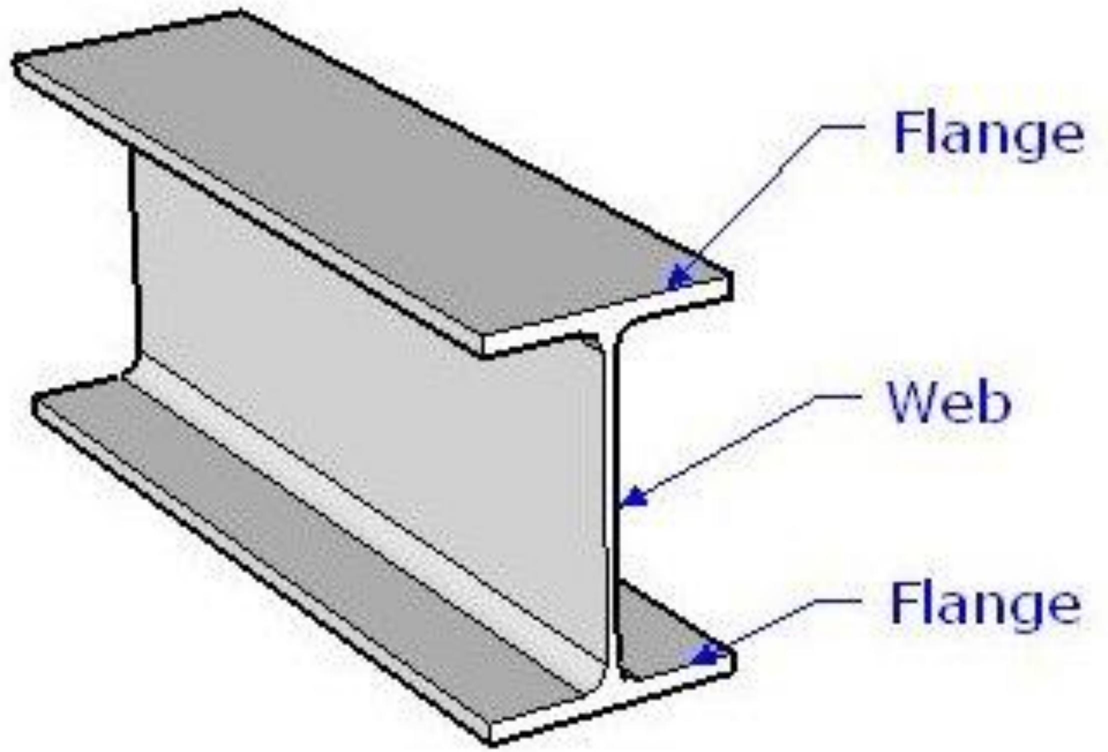
"Wide-Flange" steel beam or column

(sometimes called an "I beam", but not by Engineers or most Architects)

helped allow taller buildings

Great:

- Flexural Strength
- Compression Strength
- Shear Strength
- Tensile Strength



http://www.architectionary.com/uploads/WideFlangeSection/wshape.jpg

STRUCTURAL STEEL FABRICATION

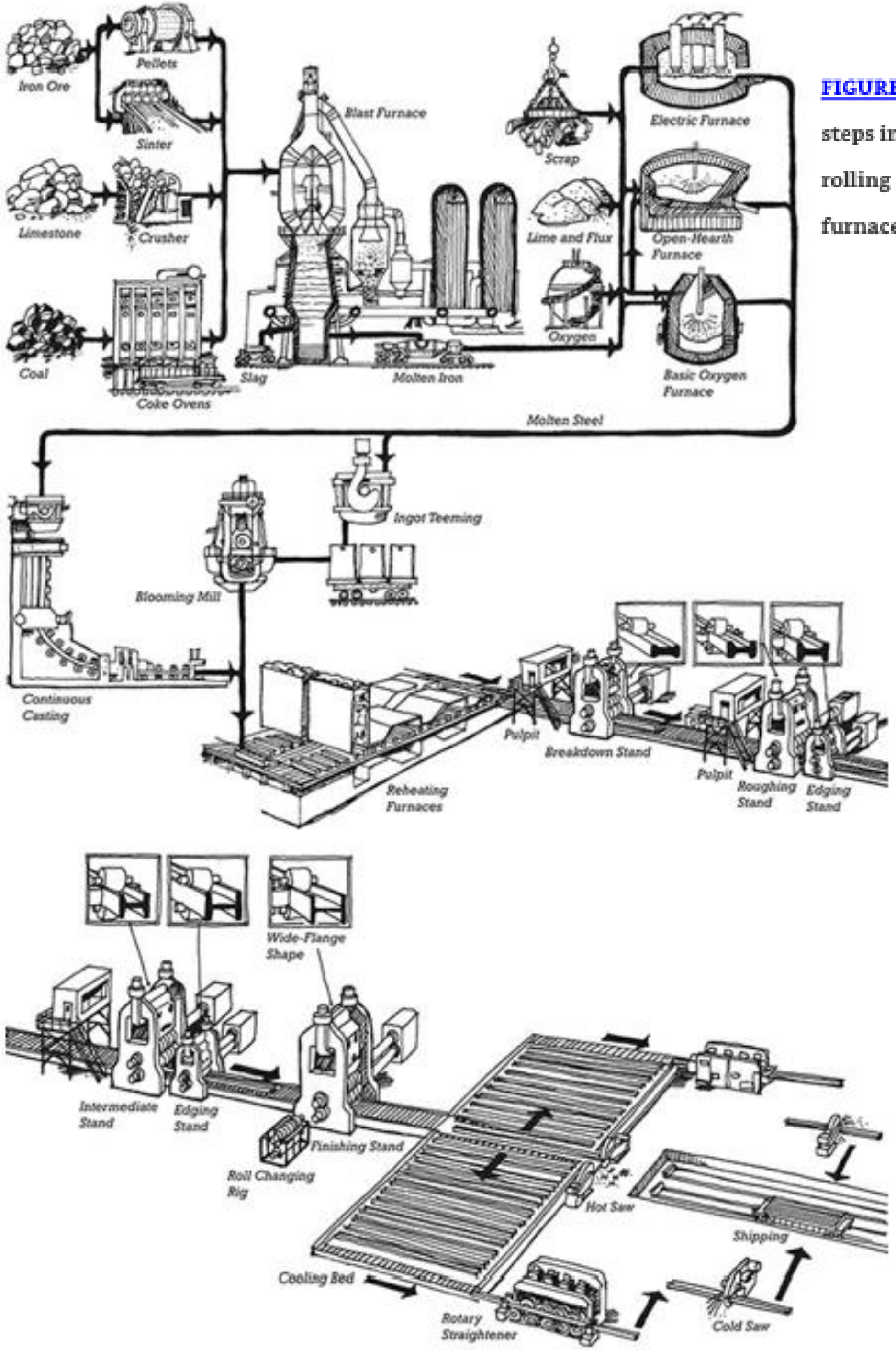
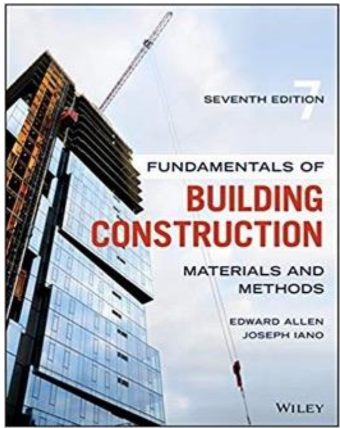


FIGURE 11.5 The steelmaking process, from iron ore to structural shapes. Notice particularly the steps in the evolution of a wide-flange shape as it progresses through the various stands in the rolling mill. Today, most structural steel in the United States is made from steel scrap in electric furnaces.



STRUCTURAL STEEL FABRICATION

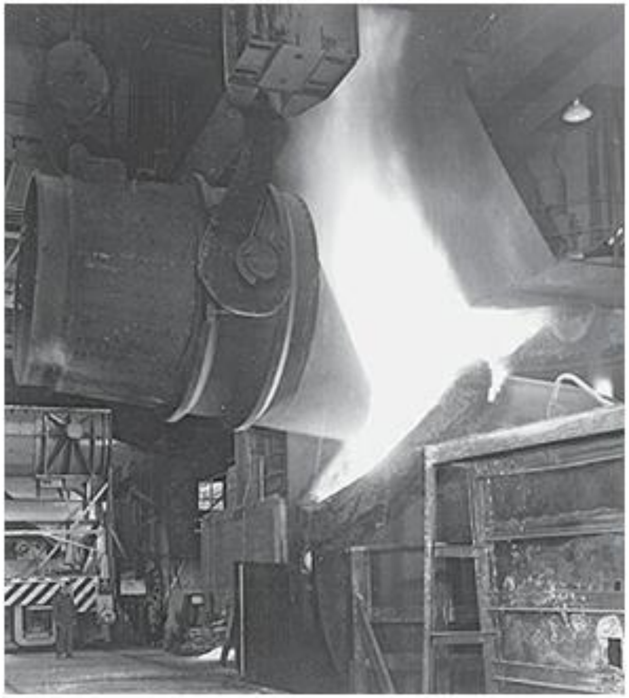


FIGURE 11.6 Molten iron is poured into a crucible to begin its conversion to steel in the basic oxygen process.

MOLTEN IRON

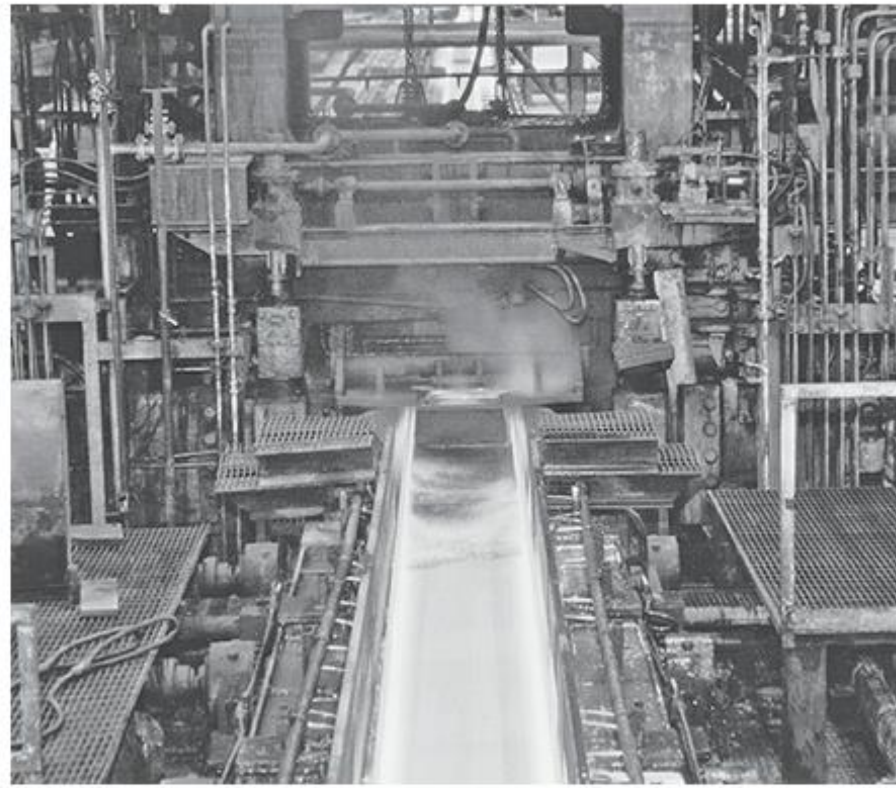
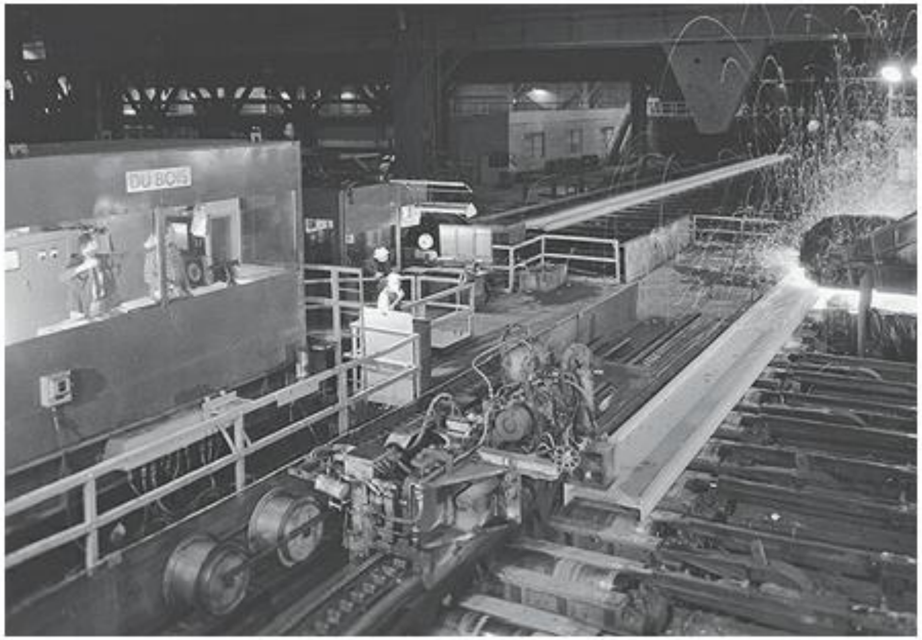


FIGURE 11.7 A glowing steel wide-flange shape emerges from the rolls of the finishing stand of the rolling mill.

ROLLING MILL (forming a Wide-Flange)

STRUCTURAL STEEL FABRICATION

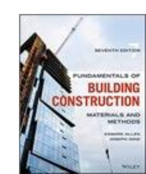


[FIGURE 11.8](#) A hot saw cuts pieces of wide-flange stock from a continuous length that has just emerged from the finishing stand in the background. Workers in the booth control the process.

ROLLING MILL (cutting a Wide-Flange)

[FIGURE 11.9](#) Wide-flange shapes are inspected for quality on the cooling bed.

INSPECTING Wide-Flange Beams/Columns



STRUCTURAL STEEL SHAPES

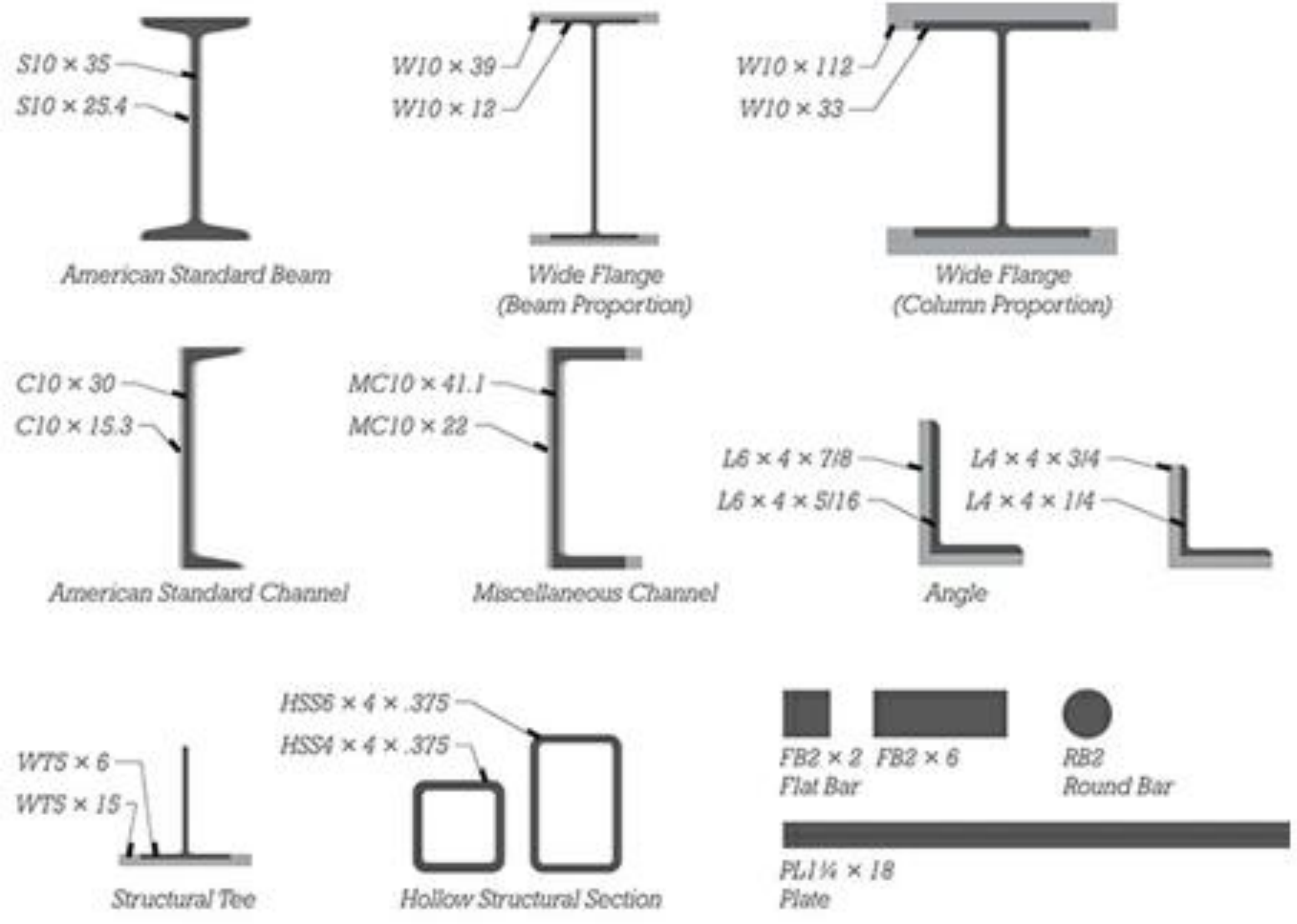
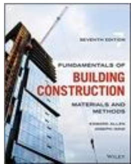


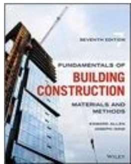
FIGURE 11.10 Standard structural steel shapes. Where two shapes are superimposed, they illustrate different weights of the same section, produced by varying the spacing of the rollers in the structural mill. Structural steel shapes and their basic properties are defined in ASTM A6. Bars are round, rectangular, and hexagonal solid shapes generally not greater than 8 inches (203 mm) in any cross-sectional dimension. Wider solid shapes are called plate or sheet, depending on their thickness in relation to their width. Plate is thicker than sheet.



STRUCTURAL STEEL SHAPES

Shape	Example of Designation	Explanation	Range of Available Sizes
Wide flange	W21 × 83	Nominal depth × weight	4"–44" *102 mm–1118 mm* in 4" increments
American Standard beam	S18 × 70	Nominal depth × weight	3"–24" *76 mm–610 mm*
Channel	MC10 × 36	Nominal depth × weight	6"–18" *152 mm–457 mm*
American Standard channel	C6 × 13	Nominal depth × weight	3"–15" *76 mm–381 mm*
Structural tee	WT13.5 × 47	Nominal depth × weight	WTs are split from wide-flange shapes. See the W beam sizes listed above and divide by 2 for available WT depths.
Angle	L4 × 3 × ⅜	Length of each leg followed by thickness	Legs: 2"–8" (*51–203 mm*) Thickness: ⅛" to 1⅛" (*3–29 mm*)
HSS Square, Rectangular, or Elliptical	HSS10 × 8 × ½	Nominal depth and width followed by wall thickness	Depth and width: 1"–48" (*25–1219 mm*) Wall thickness: ⅛"–⅝" (*3–16 mm*)
HSS Round	HSS8 × ½	Nominal diameter followed by wall thickness	Diameter: 1.66"–20" (*42–508 mm*) Wall thickness: 0.109"–0.625" (*2.8–16 mm*)

FIGURE 11.11 Commonly used steel shapes and sizes.



STEEL STRUCTURAL ENGINEERING

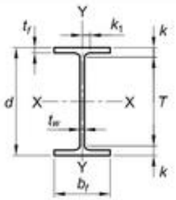


Table 1-1
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W44×335[c]	98.5	44.0	44	1.03	1	1/2	15.9	16	1.77	1 3/4	2.56	3	1 3/4	38	5 1/2
×290[c]	85.4	43.6	43 5/8	0.865	7/8	7/16	15.8	15 7/8	1.58	1 9/16	2.36	2 13/16	1 5/8		
×262[c]	77.2	43.3	43 1/4	0.785	13/16	7/16	15.8	15 3/4	1.42	1 7/16	2.20	2 5/8	1 5/8		
×230[c,v]	67.8	42.9	42 7/8	0.710	11/16	3/8	15.8	15 3/4	1.22	1 1/4	2.01	2 7/16	1 9/16		
W40×655[h]	193	43.6	43 5/8	1.97	2	1	16.9	16 7/8	3.54	3 9/16	4.72	4 13/16	2 3/16	34	7 1/2
×593[h]	174	43.0	43	1.79	1 13/16	15/16	16.7	16 3/4	3.23	3 1/4	4.41	4 1/2	2 1/8		
×503[h]	148	42.1	42	1.54	1 9/16	13/16	16.4	16 3/8	2.76	2 3/4	3.94	4	2		
×431[h]	127	41.3	41 1/4	1.34	1 5/16	11/16	16.2	16 1/4	2.36	2 3/8	3.54	3 5/8	1 7/8		
×397[h]	117	41.0	41	1.22	1 1/4	5/8	16.1	16 1/8	2.20	2 3/16	3.38	3 1/2	1 13/16		
×372[h]	110	40.6	40 5/8	1.16	1 3/16	5/8	16.1	16 1/8	2.05	2 1/16	3.23	3 5/16	1 13/16		
×362[h]	106	40.6	40 1/2	1.12	1 1/8	9/16	16.0	16	2.01	2	3.19	3 1/4	1 3/4		
×324	95.3	40.2	40 1/8	1.00	1	1/2	15.9	15 7/8	1.81	1 13/16	2.99	3 1/16	1 11/16		
×297[c]	87.3	39.8	39 7/8	0.930	15/16	1/2	15.8	15 7/8	1.65	1 5/8	2.83	2 15/16	1 11/16		
×277[c]	81.5	39.7	39 3/4	0.830	13/16	7/16	15.8	15 7/8	1.58	1 9/16	2.76	2 7/8	1 5/8		
×249[c]	73.5	39.4	39 3/8	0.750	3/4	3/8	15.8	15 3/4	1.42	1 7/16	2.60	2 11/16	1 9/16		
×215[c]	63.5	39.0	39	0.650	5/8	5/16	15.8	15 3/4	1.22	1 1/4	2.40	2 1/2	1 9/16		
×199[c]	58.8	38.7	38 5/8	0.650	5/8	5/16	15.8	15 3/4	1.07	1 1/16	2.25	2 5/16	1 9/16		
W40×392[h]	116	41.6	41 5/8	1.42	1 7/16	3/4	12.4	12 3/8	2.52	2 1/2	3.70	3 13/16	1 15/16	34	7 1/2
×331[h]	97.7	40.8	40 3/4	1.22	1 1/4	5/8	12.2	12 1/8	2.13	2 1/8	3.31	3 3/8	1 13/16		
×327[h]	95.9	40.8	40 3/4	1.18	1 3/16	5/8	12.1	12 1/8	2.13	2 1/8	3.31	3 3/8	1 13/16		
×294	86.2	40.4	40 3/8	1.06	1 1/16	9/16	12.0	12	1.93	1 15/16	3.11	3 3/16	1 3/4		
×278	82.3	40.2	40 1/8	1.03	1	1/2	12.0	12	1.81	1 13/16	2.99	3 1/16	1 3/4		
×264	77.4	40.0	40	0.960	15/16	1/2	11.9	11 7/8	1.73	1 3/4	2.91	3	1 11/16		
×235[c]	69.1	39.7	39 3/4	0.830	13/16	7/16	11.9	11 7/8	1.58	1 9/16	2.76	2 7/8	1 5/8		
×211[c]	62.1	39.4	39 3/8	0.750	3/4	3/8	11.8	11 3/4	1.42	1 7/16	2.60	2 11/16	1 9/16		
×183[c]	53.3	39.0	39	0.650	5/8	5/16	11.8	11 3/4	1.20	1 3/16	2.38	2 1/2	1 9/16		
×167[c]	49.3	38.6	38 5/8	0.650	5/8	5/16	11.8	11 3/4	1.03	1	2.21	2 5/16	1 9/16		
×149[c,v]	43.8	38.2	38 1/4	0.630	5/8	5/16	11.8	11 3/4	0.830	13/16	2.01	2 1/8	1 1/2		

[c] Shape is slender for compression with $F_y = 50$ ksi.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.
[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with $F_y = 50$ ksi.

Table 1-1 (continued)
W-Shapes
Properties

W44–W40

Nominal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
335	4.50	38.0	31100	1410	17.8	1620	1200	150	3.49	236	4.24	42.2	74.7	535000
290	5.02	45.0	27000	1240	17.8	1410	1040	132	3.49	205	4.20	42.0	50.9	461000
262	5.57	49.6	24100	1110	17.7	1270	923	117	3.47	182	4.17	41.9	37.3	405000
230	6.45	54.8	20800	971	17.5	1100	796	101	3.43	157	4.13	41.7	24.9	346000
655	2.39	17.3	56500	2590	17.1	3080	2870	340	3.86	542	4.71	40.1	589	1150000
593	2.58	19.1	50400	2340	17.0	2760	2520	302	3.80	481	4.63	39.8	445	997000
503	2.98	22.3	41600	1980	16.8	2320	2040	249	3.72	394	4.50	39.3	277	789000
431	3.44	25.5	34800	1690	16.6	1960	1690	208	3.65	328	4.41	38.9	177	638000
397	3.66	28.0	32000	1560	16.6	1800	1540	191	3.64	300	4.38	38.8	142	579000
372	3.93	29.5	29600	1460	16.5	1680	1420	177	3.60	277	4.33	38.6	116	528000
362	3.99	30.5	28900	1420	16.5	1640	1380	173	3.60	270	4.33	38.6	109	513000
324	4.40	34.2	25600	1280	16.4	1460	1220	153	3.58	239	4.27	38.4	79.4	448000
297	4.80	36.8	23200	1170	16.3	1330	1090	138	3.54	215	4.22	38.2	61.2	399000
277	5.03	41.2	21900	1100	16.4	1250	1040	132	3.58	204	4.25	38.1	51.5	379000
249	5.55	45.6	19600	993	16.3	1120	926	118	3.55	182	4.21	38.0	38.1	334000
215	6.45	52.6	16700	859	16.2	964	803	101	3.54	156	4.19	37.8	24.8	284000
199	7.39	52.6	14900	770	16.0	869	695	88.2	3.45	137	4.12	37.6	18.3	246000
392	2.45	24.1	29900	1440	16.1	1710	803	130	2.64	212	3.30	39.1	172	306000
331	2.86	28.0	24700	1210	15.9	1430	644	106	2.57	172	3.21	38.7	105	241000
327	2.85	29.0	24500	1200	16.0	1410	640	105	2.58	170	3.21	38.7	103	239000
294	3.11	32.2	21900	1080	15.9	1270	562	93.5	2.55	150	3.16	38.5	76.6	208000
278	3.31	33.3	20500	1020	15.8	1190	521	87.1	2.52	140	3.13	38.4	65.0	192000
264	3.45	35.6	19400	971	15.8	1130	493	82.6	2.52	132	3.12	38.3	56.1	181000
235	3.77	41.2	17400	875	15.9	1010	444	74.6	2.54	118	3.11	38.1	41.3	161000
211	4.17	45.6	15500	786	15.8	906	390	66.1	2.51	105	3.07	38.0	30.4	141000
183	4.92	52.6	13200	675	15.7	774	331	56.0	2.49	88.3	3.04	37.8	19.3	118000
167	5.76	52.6	11600	600	15.3	693	283	47.9	2.40	76.0	2.98	37.6	14.0	99700
149	7.11	54.3	9800	513	15.0	598	229	38.8	2.29	62.2	2.89	37.4	9.36	80000

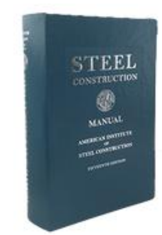
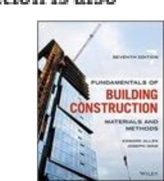


FIGURE 11.12 A portion of the table of dimensions and properties of wide-flange shapes from the *Steel Construction Manual* of the American Institute of Steel Construction. This is information is also available in tabulated spreadsheet and database formats. One inch equals 25.4 mm.



AMERICAN INSTITUTE OF STEEL CONSTRUCTION

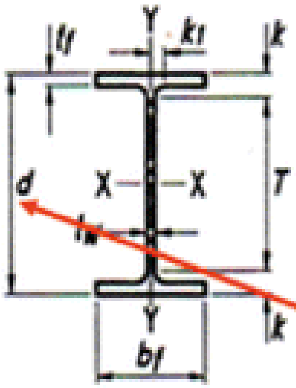


Table 1-1
W Shapes
Dimensions

Actual depth

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	Distance k_1	Distance T	Distance Work-able Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W44×335[c]	98.5	44.0	44	1.03	1	½	15.9	16	1.77	1¾	2.56	2⅝	1^5/$_{16}$	38¾	5½
×290[c]	85.4	43.6	43⅝	0.865	⅞	^{7}/$_{16}$	15.8	15⅞	1.58	1^9/$_{16}$	2.36	2^7/$_{16}$	1¼	↓	↓
×262[c]	76.9	43.3	43¼	0.785	^{13}/$_{16}$	^{7}/$_{16}$	15.8	15¾	1.42	1^7/$_{16}$	2.20	2¼	1^3/$_{16}$		
×230[c,v]	67.7	42.9	42⅞	0.710	^{11}/$_{16}$	⅜	15.8	15¾	1.22	1¼	2.01	2^1/$_{16}$	1^3/$_{16}$		

Cross-sectional area

Steel Construction Manual, 15th Ed. (Print)

MEMBER: **$200.00**

NON-MEMBER: **$400.00**

STEEL STRUCTURAL ENGINEERING

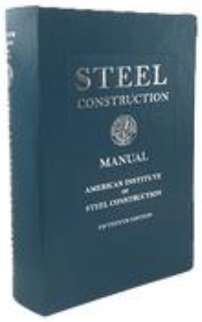
Table 1-1 (continued)
W-Shapes
Properties

W44–W40

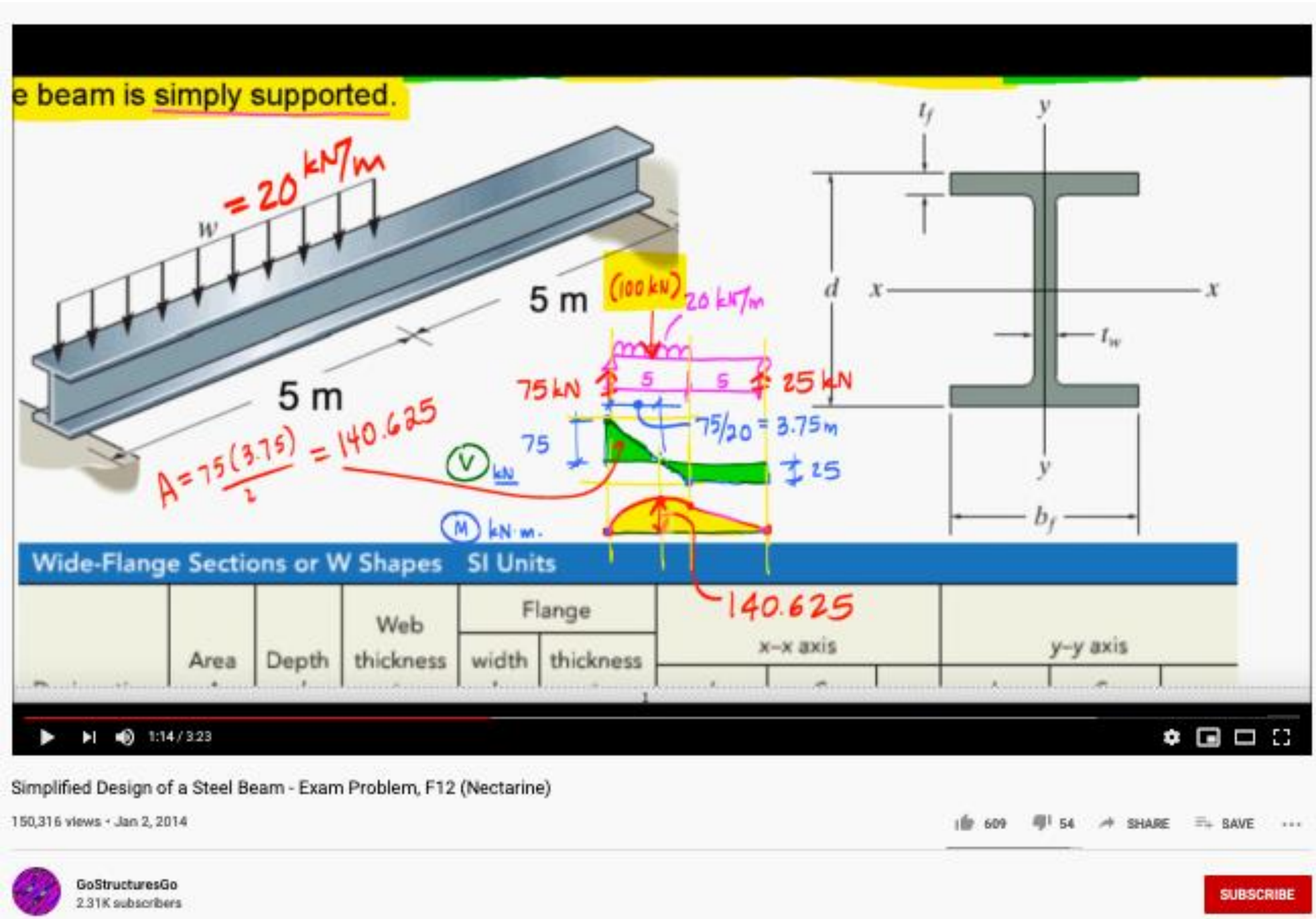
Nom-inal Wt.	Compact Section Criteria		Axis X-X				Axis Y-Y				r_{ts}	h_o	Torsional Properties	
	$\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	I	S	r	Z	I	S	r	Z			J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
335	4.50	38.0	31100	1410	17.8	1620	1200	150	3.49	236	4.24	42.2	74.7	535000
290	5.02	45.0	27000	1240	17.8	1410	1040	132	3.49	205	4.20	42.0	50.9	461000
262	5.57	49.6	24100	1110	17.7	1270	923	117	3.47	182	4.17	41.9	37.3	405000
230	6.45	54.8	20800	971	17.5	1100	796	101	3.43	157	4.13	41.7	24.9	346000

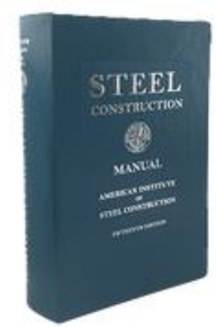
SKIM THROUGH STEEL DESIGN MANUAL *(WHAT STRUCTURAL ENGINEERS USE)*:
https://www.aisc.org/publications/steel-construction-manual-resources/

DESIGN EXAMPLES:
https://www.aisc.org/globalassets/aisc/manual/v15.1-companion/v15.1_vol-1_design-examples.pdf



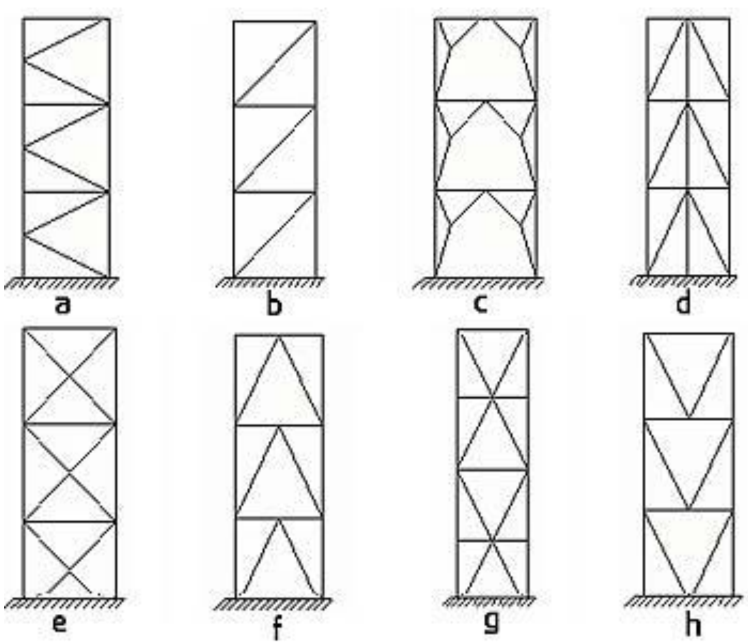
Watch structural Steel Beam design video:
https://youtu.be/AUwxAFCnAZw

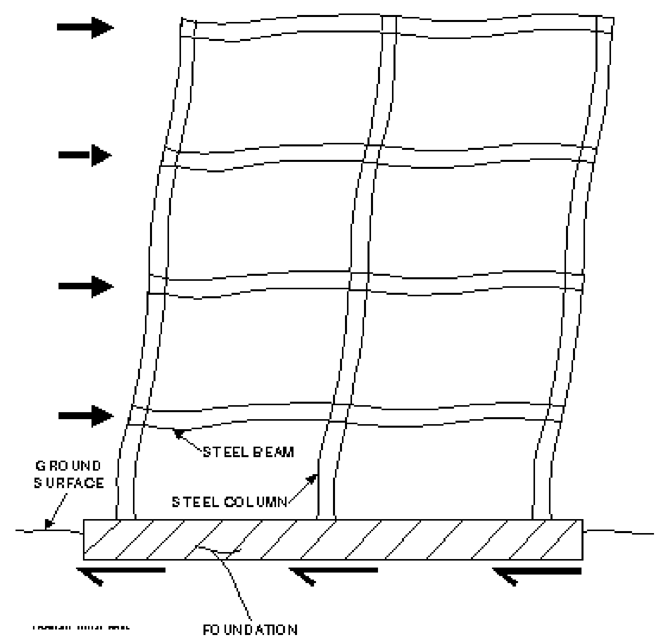




- Can melt, so fire safety coatings developed *(in Chicago after great fire of 1874)*
- Can handle large LATERAL LOADS
    - wind
    - seismic (earthquake) forces
        - in one of two ways:

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



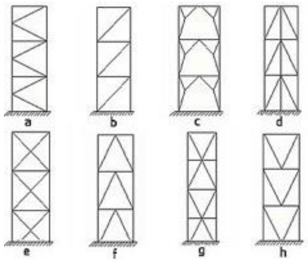


http://www.graitec.com/en/images/products/ad_bracings_01.jpg

http://www.graitec.com/en/images/products/ad_bracings_01.jpg

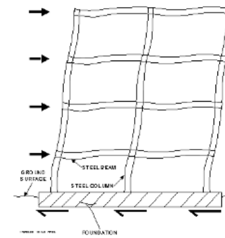
BRACED-FRAME

- Cheaper

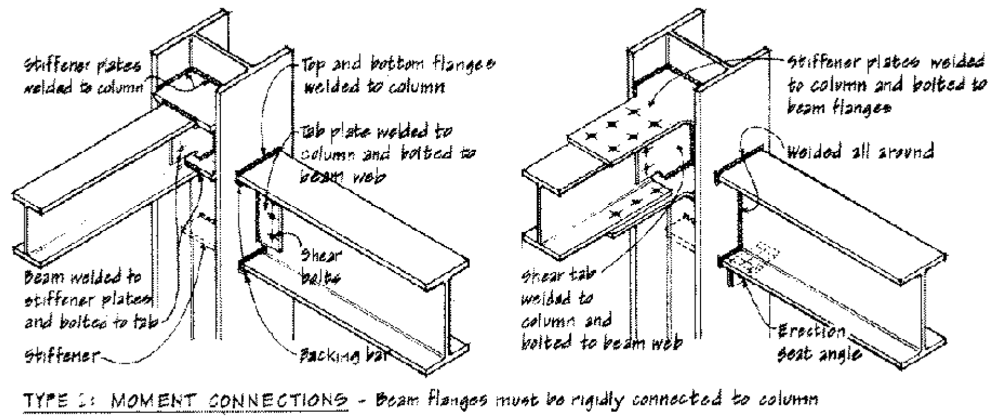


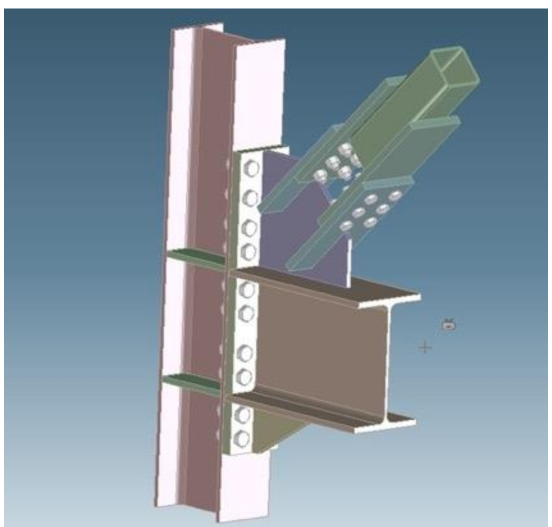
MOMENT CONNECTION

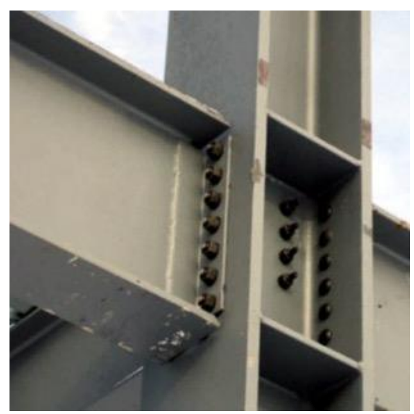
("MOMENT" = "TORQUE")

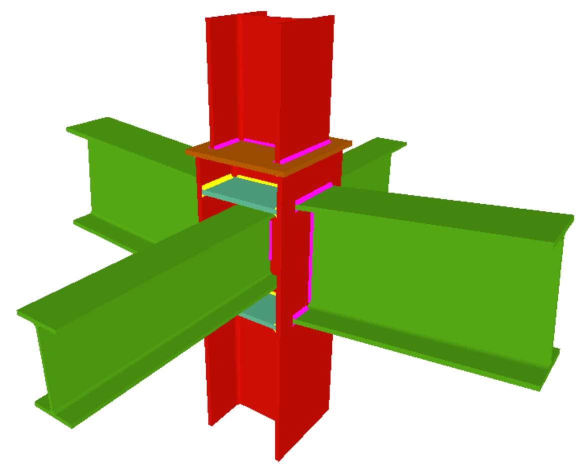


- Unobstructed views
- Simpler interiors









http://www.ashleyvance.com/projects/commercial/soma-renovation-and-seismic-upgrade
http://www.stlsi.com/images/DSC01209.JPG
https://d2t1xqejof9utc.cloudfront.net/screenshots/pics/a97c97f0e72c8856c002117a53f2bb1b/medium.jpg
http://www.graitec.com/en/images/products/ad_bracings_01.jpg
http://programas.cype.es/imagen/nuevoMetal3D/union_I_soldada_49.gif
http://buildipedia.com/images/masterformat/Channels/On_Site/Technical_Lessons_Learned/

BRACED-FRAME

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

MOMENT CONNECTION

http://www.featurepics.com/FI/Thumb300/20070505/Highrise-Construction-306455.jpg

CONNECTIONS
(RIVET)

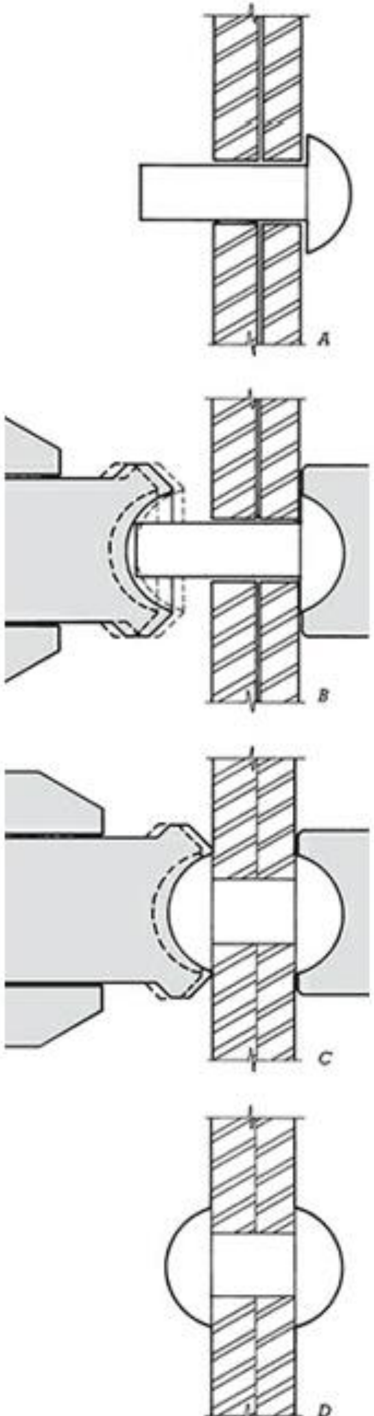


FIGURE 11.15 How riveted connections are made. (*A*) A hot steel rivet is inserted through holes in the two members to be joined. (*B, C*) Its head is placed in the cup-shaped depression of a heavy, hand-held hammer. A pneumatic hammer drives a rivet set repeatedly against the body of the rivet to form the second head. (*D*) The rivet shrinks as it cools, drawing the members tightly together.

CONNECTIONS
(BOLT)

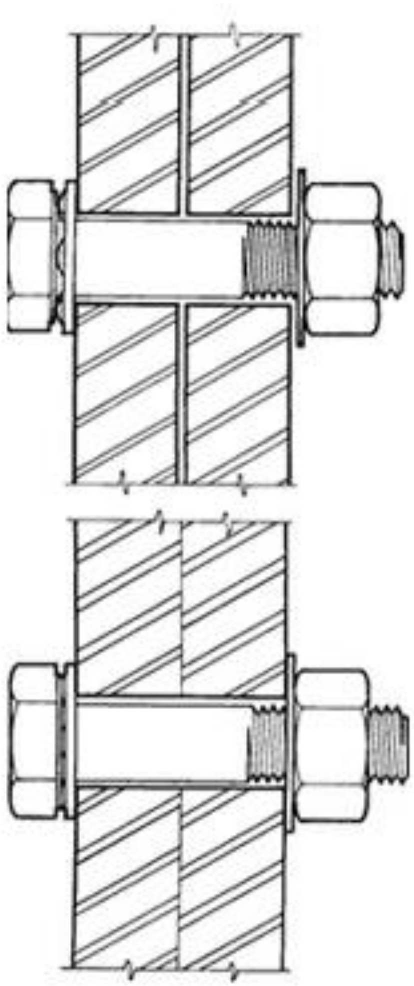
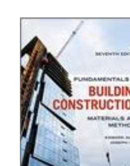


FIGURE 11.16 An ironworker tightens high-strength bolts with a pneumatic impact wrench.

FIGURE 11.17 *Top*: An untightened high-strength bolt with a load indicator washer under the head. *Bottom*: The bolt and washer after tightening; notice that the protrusions on the load indicator washer have flattened.



STEEL STRUCTURAL ENGINEERING

CONNECTIONS
(WELD)

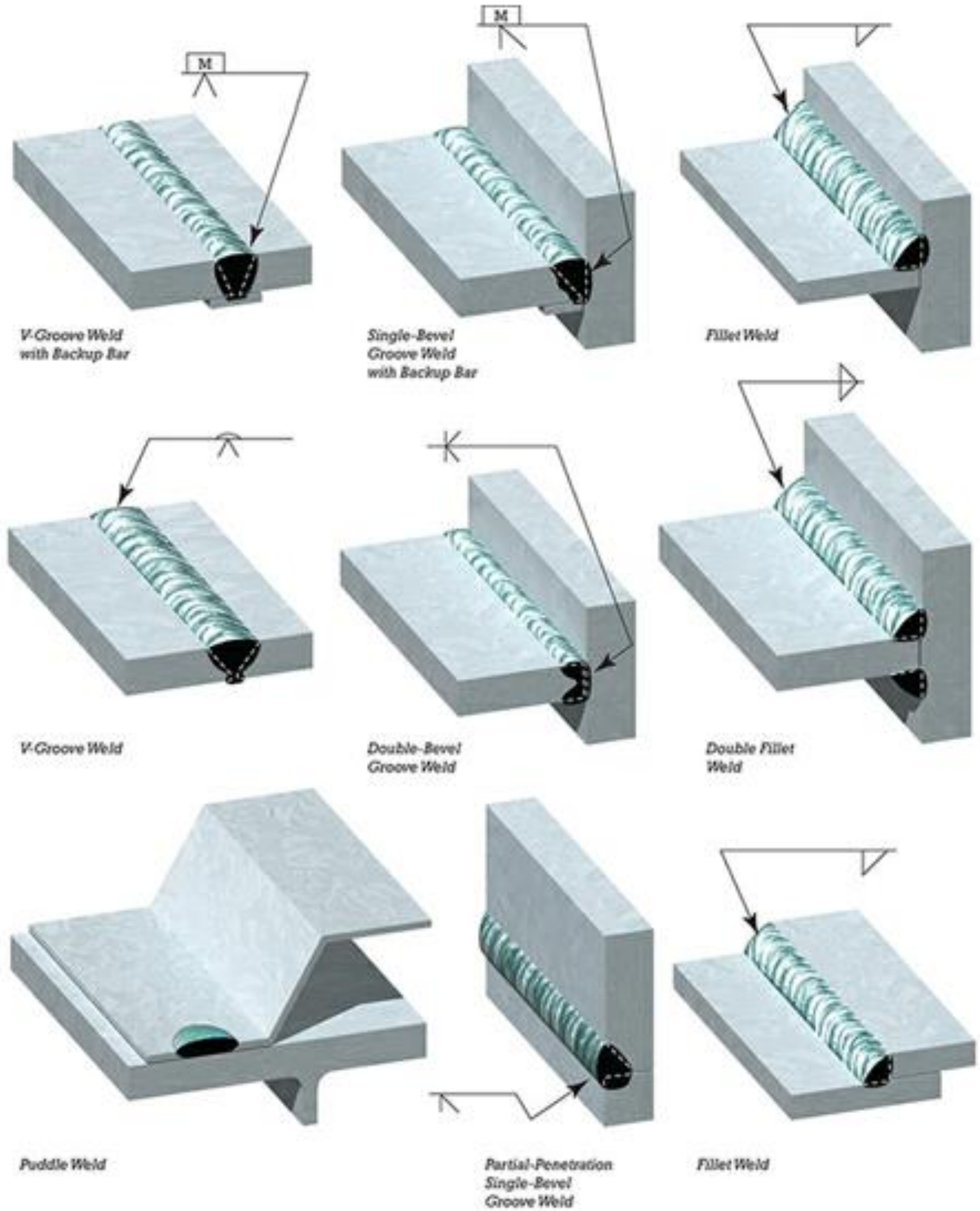


FIGURE 11.22 Typical welds used in steel frame construction. Fillet welds are the most economical because they require no advance preparation of the joint, but full-penetration groove welds are stronger. The standard symbols used here are explained in Figure 11.21.

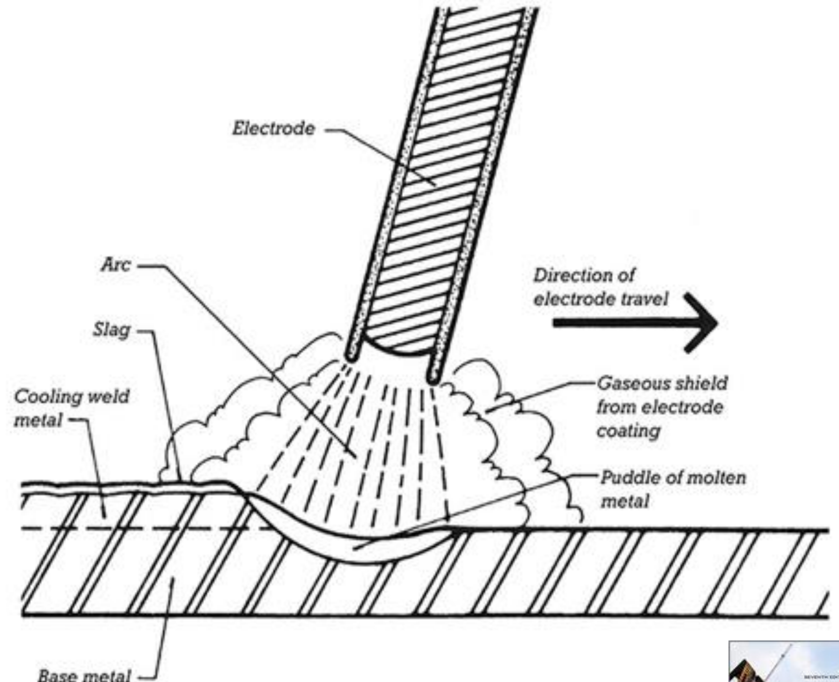
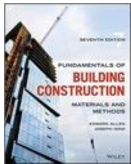


FIGURE 11.20 Close-up diagram of the electric arc welding process.



STEEL STRUCTURAL ENGINEERING

CONNECTIONS

(BOLT, WELD)

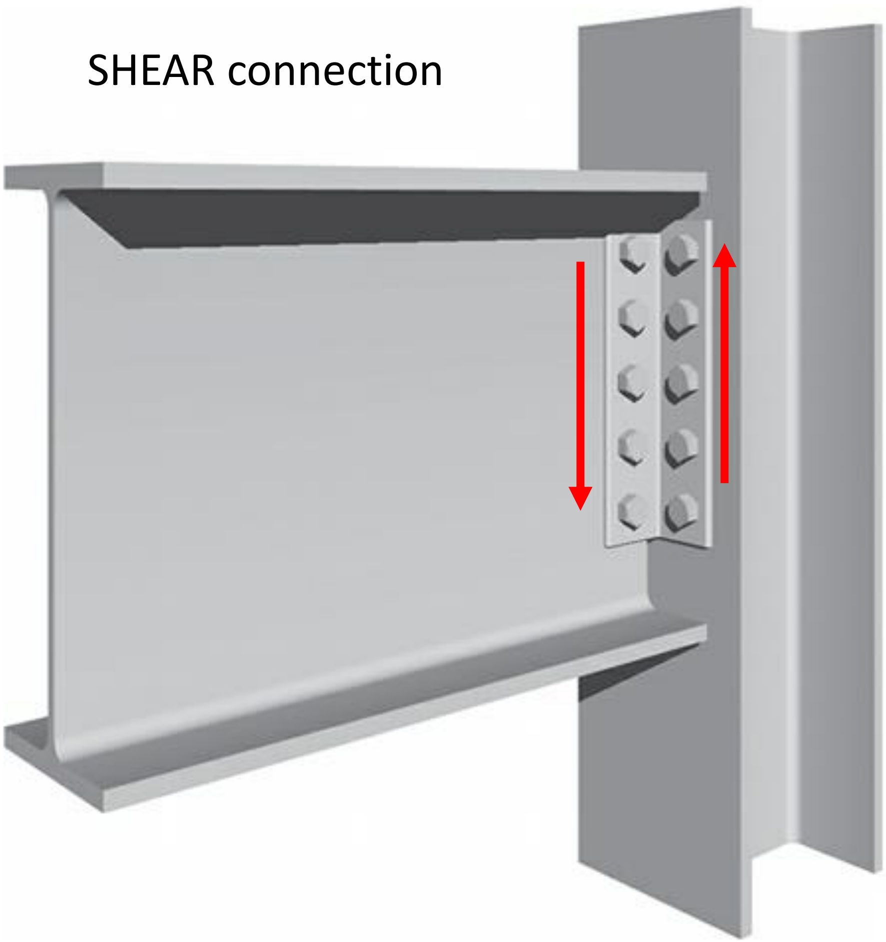


FIGURE 11.26 A pictorial view of a framed, bolted beam-to-column-flange shear connection.

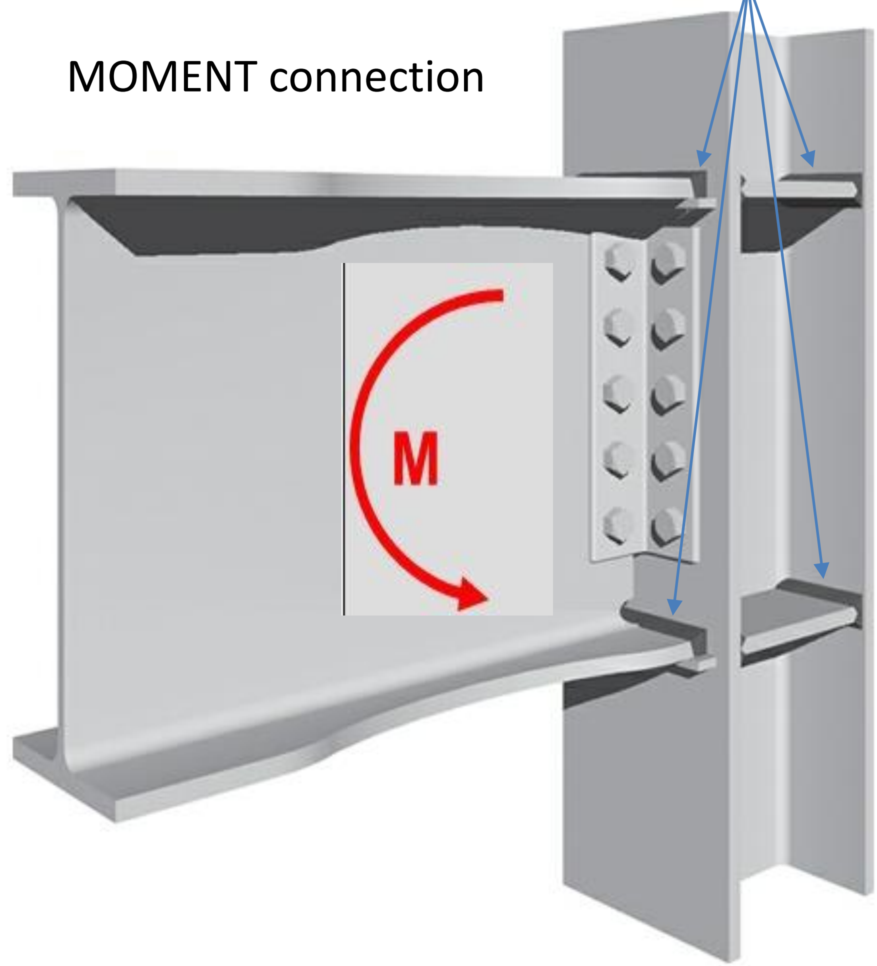
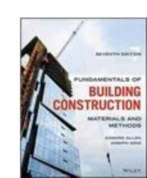


FIGURE 11.27 A welded moment connection (AISC fully restrained) for joining a beam to a column

A MOMENT connection can handle a Moment (torque) at connection



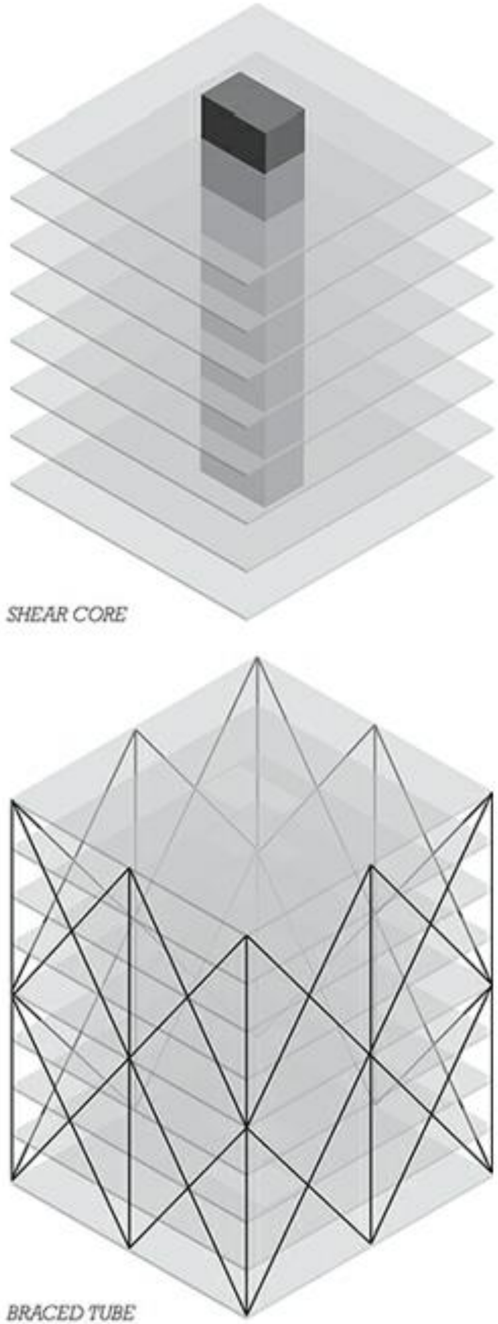
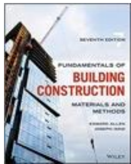


FIGURE 11.30 Core structures (*top*) concentrate the lateral force resisting system at the center of the structure, leaving the remainder of the structure unencumbered by lateral force resisting elements.



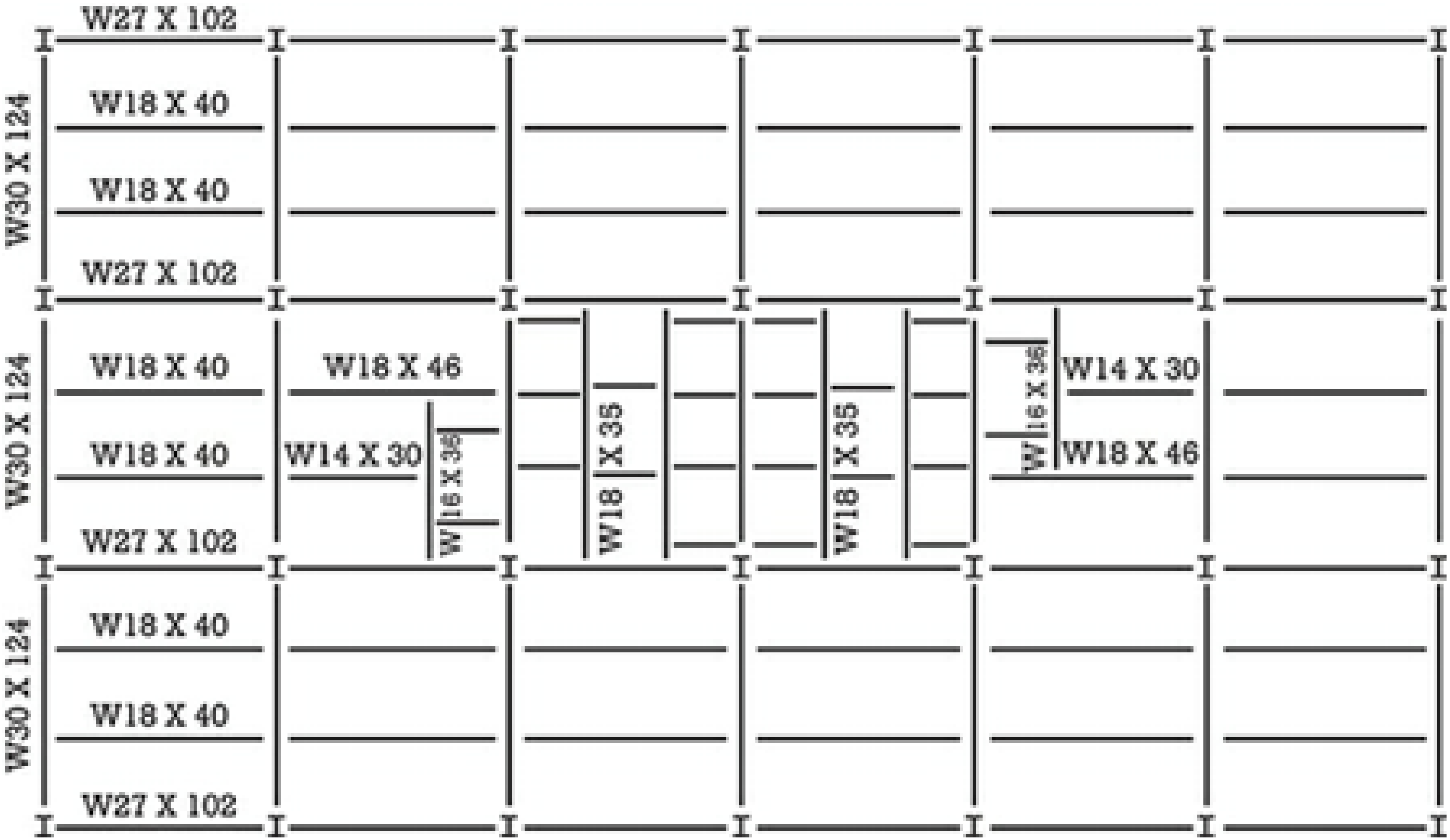
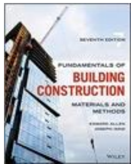
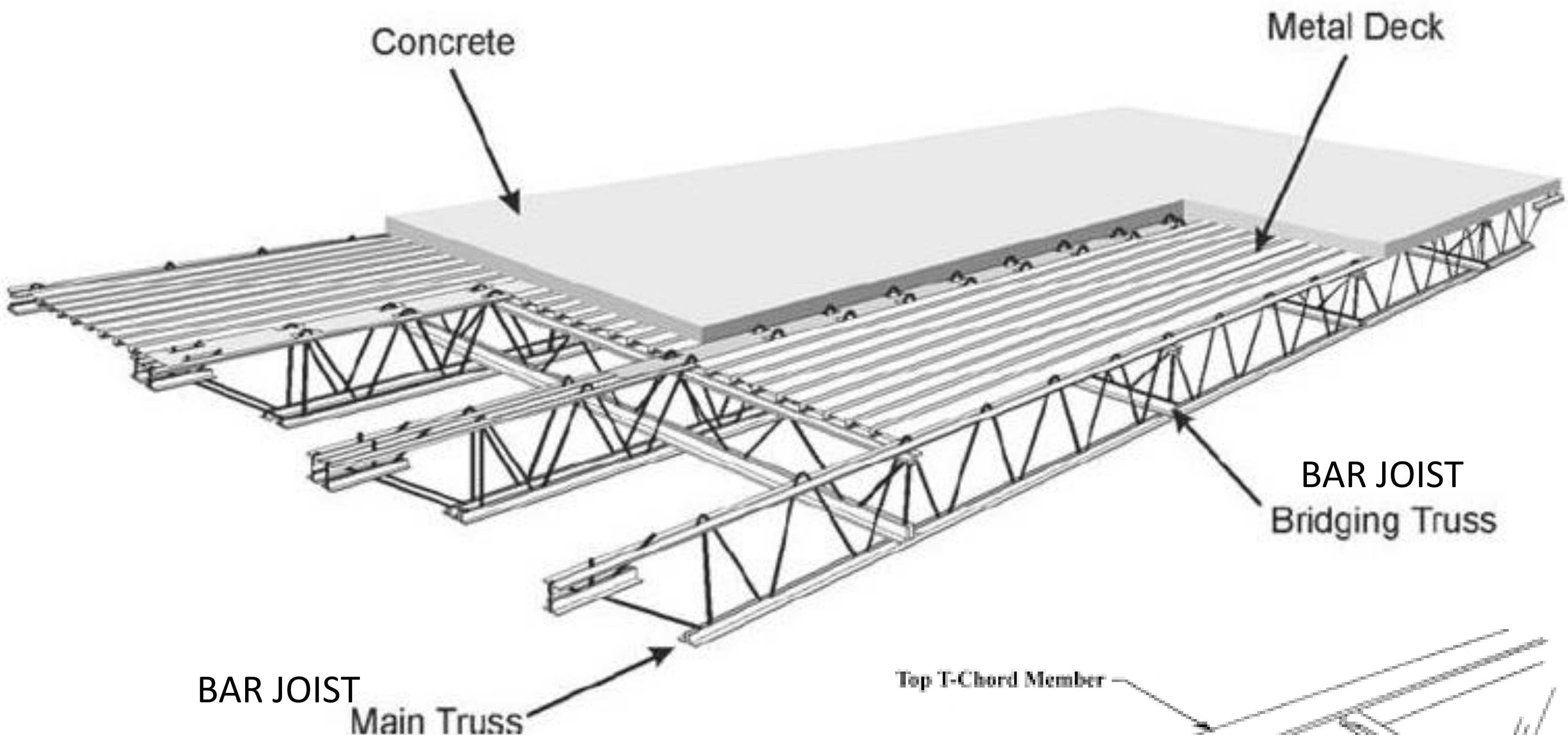
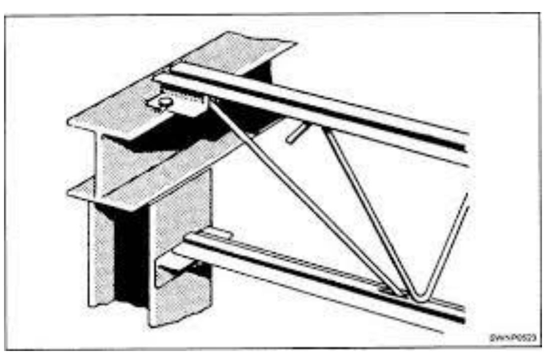


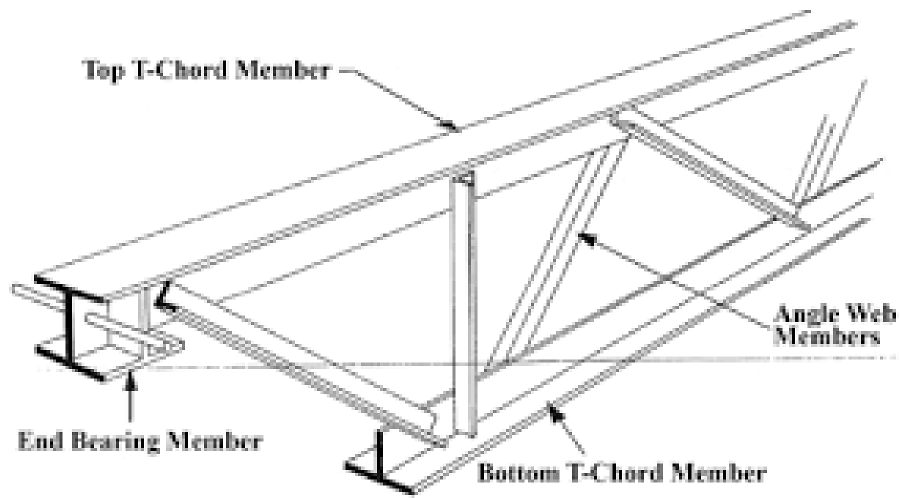
FIGURE 11.41 A typical framing plan for a multistory steel-framed building



STEEL STRUCTURAL ENGINEERING
BAR JOIST







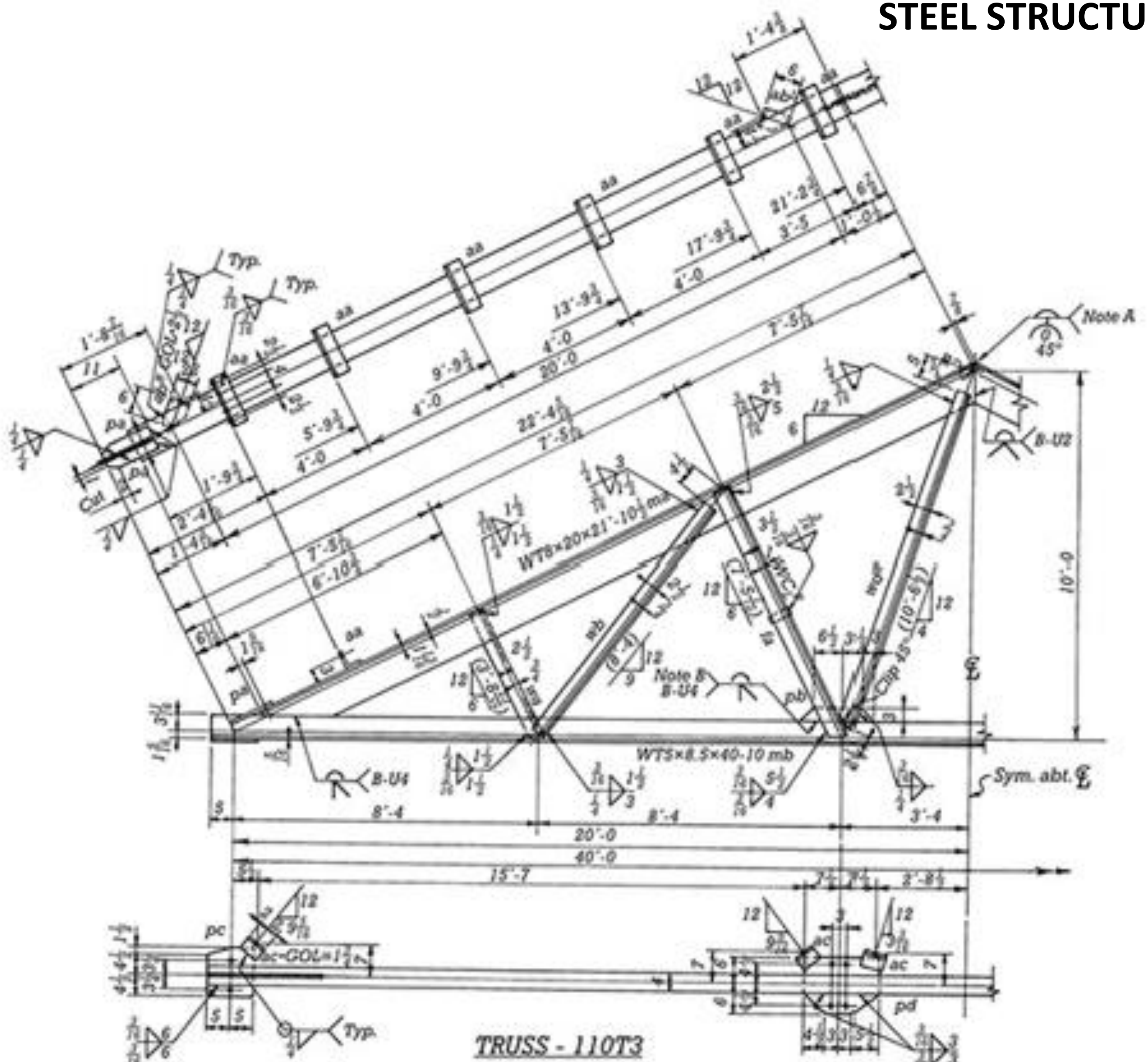
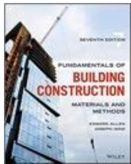


FIGURE 11.79 A fabricator's shop drawing of a welded steel roof truss made of tees and paired-angle diagonals.

FIGURE 11.82 Assembling a space truss.



STEEL STRUCTURAL ENGINEERING COLUMN

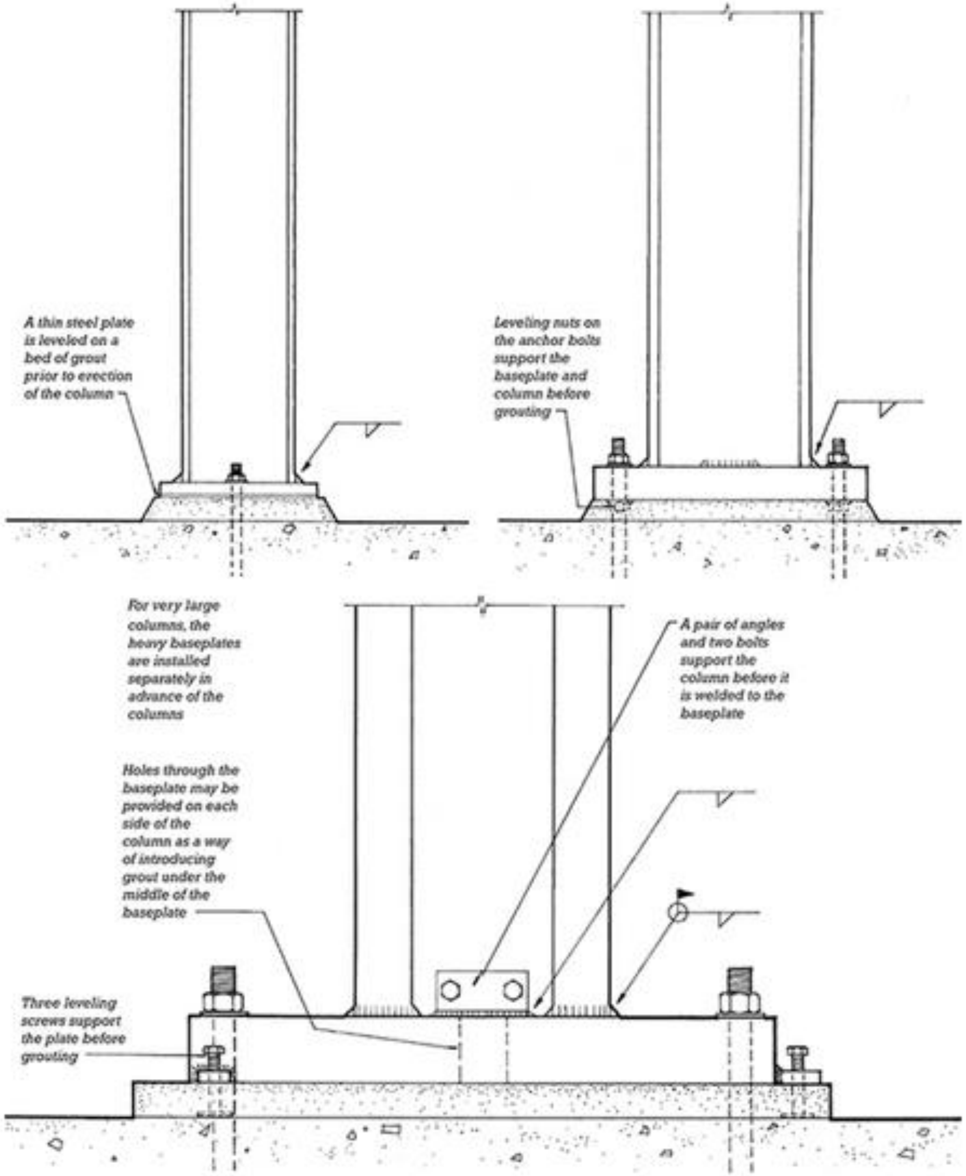
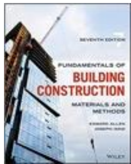


FIGURE 11.46 Three typical column base details. *Upper left*: A small column with a welded baseplate set on a steel leveling plate. *Upper right*: A larger column with a welded baseplate set on leveling nuts. *Below*: A heavy column field-welded to a loose baseplate that has been previously leveled and grouted.



STEEL STRUCTURAL ENGINEERING

CORREGATED DECK

FIGURE 11.58 There are three types of corrugated metal decking in this image. The roof decking above has smaller, more closely spaced corrugations than the composite floor decking on the level below. A single sheet of decking with even deeper, more widely spaced corrugations has been laid across the framing in the foreground, but not yet fastened in place.

STEEL STRUCTURAL ENGINEERING
Heat (FIRE)

1 Kip = 1000 Pounds

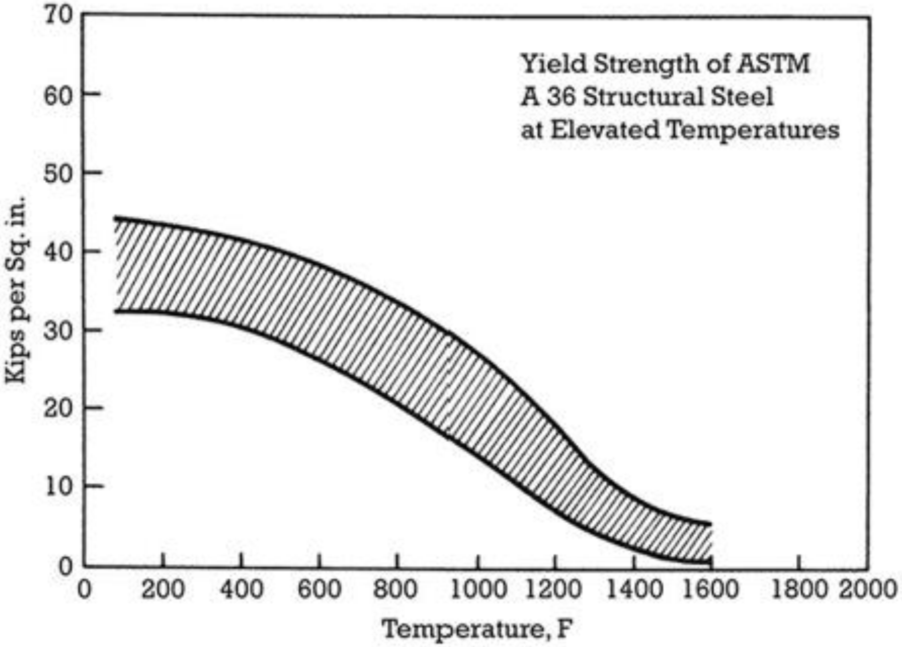
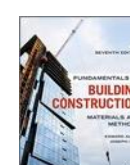


FIGURE 11.67 The relationship between temperature and strength in structural steel.

FIGURE 11.66 An exposed steel structure following a prolonged fire in the highly combustible contents of a warehouse.



STEEL STRUCTURAL ENGINEERING
Heat (FIRE)

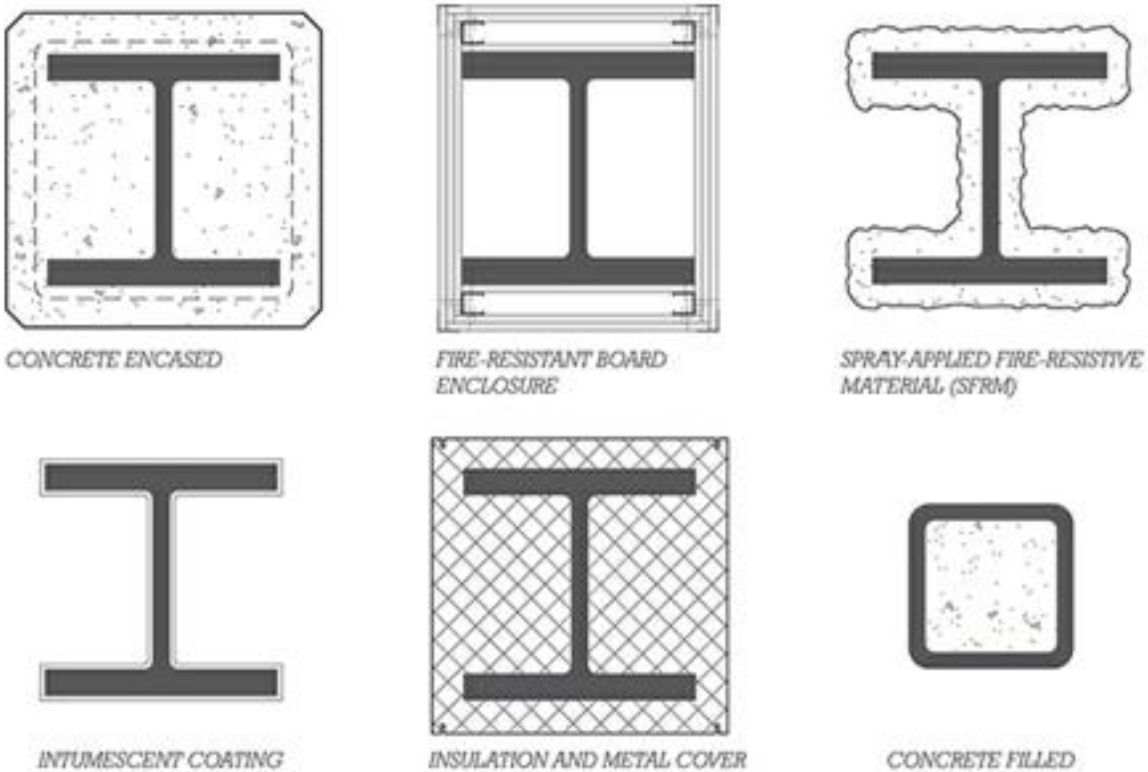


FIGURE 11.68 Methods for fire-protecting steel columns.

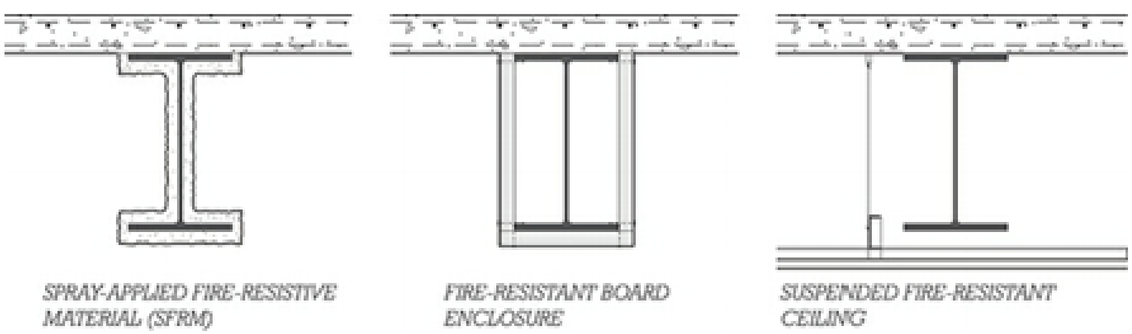


FIGURE 11.69 Methods for fireproofing steel beams and girders.

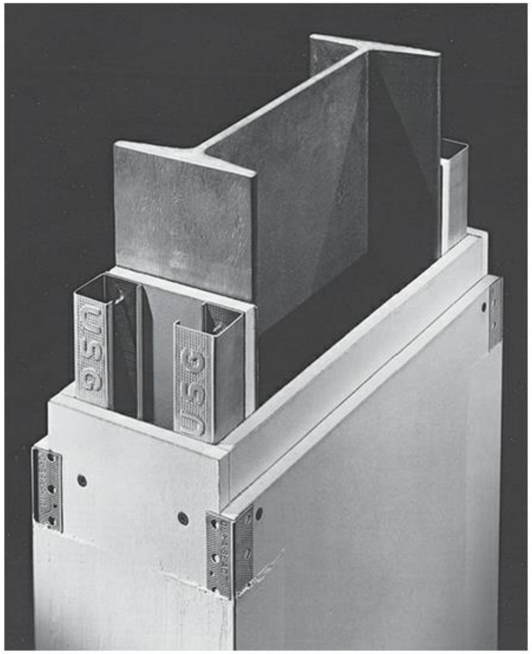


FIGURE 11.71 Gypsum board fireproofing around a steel column. The gypsum

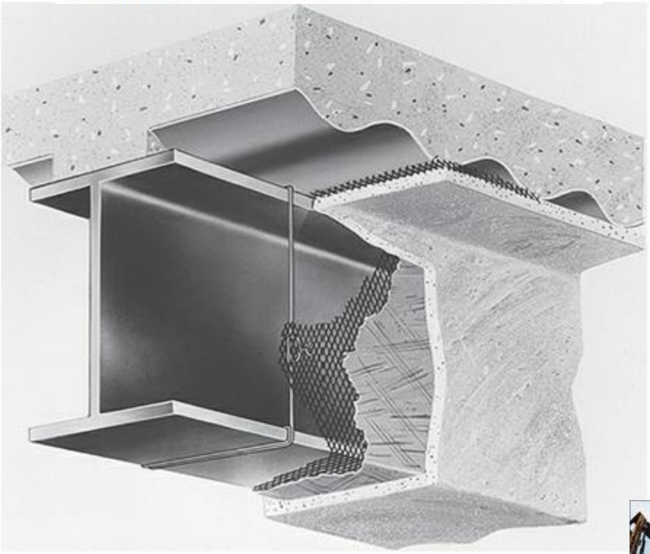
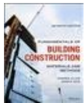


FIGURE 11.70 Lath-and-plaster fireproofing around a steel beam.

STEEL vs. Wood vs. Brick vs. Concrete

Material	Strength in Tension	Strength in Compression	Modulus of Elasticity	Density
Wood (framing lumber)	270–4100 psi (1.9–28 MPa)	1400–4400 psi (9.7–31 MPa)	1,100,000–1,900,000 psi (7600–13,000 MPa)	27 pcf (430 kg/m^3)
Brick masonry (including mortar, unreinforced)	30–80 psi (0.21–0.55 MPa)	1000–4000 psi (6.9–28 MPa)	800,000–3,000,000 psi (5500–21,000 MPa)	120 pcf (1900 kg/m^3)
Structural steel	60,000–90,000 psi (415–620 MPa)	60,000–90,000 psi (415–620 MPa)	29,000,000 psi (200,000 MPa)	490 pcf (7800 kg/ m^3)
Concrete (unreinforced)	300–700 psi 2.1–4.8 MPa	3000–6000 psi (20–40 MPa)	2,000,000–6,000,000 psi (14,000–41,000 MPa)	145 pcf (2300 kg/m^3)

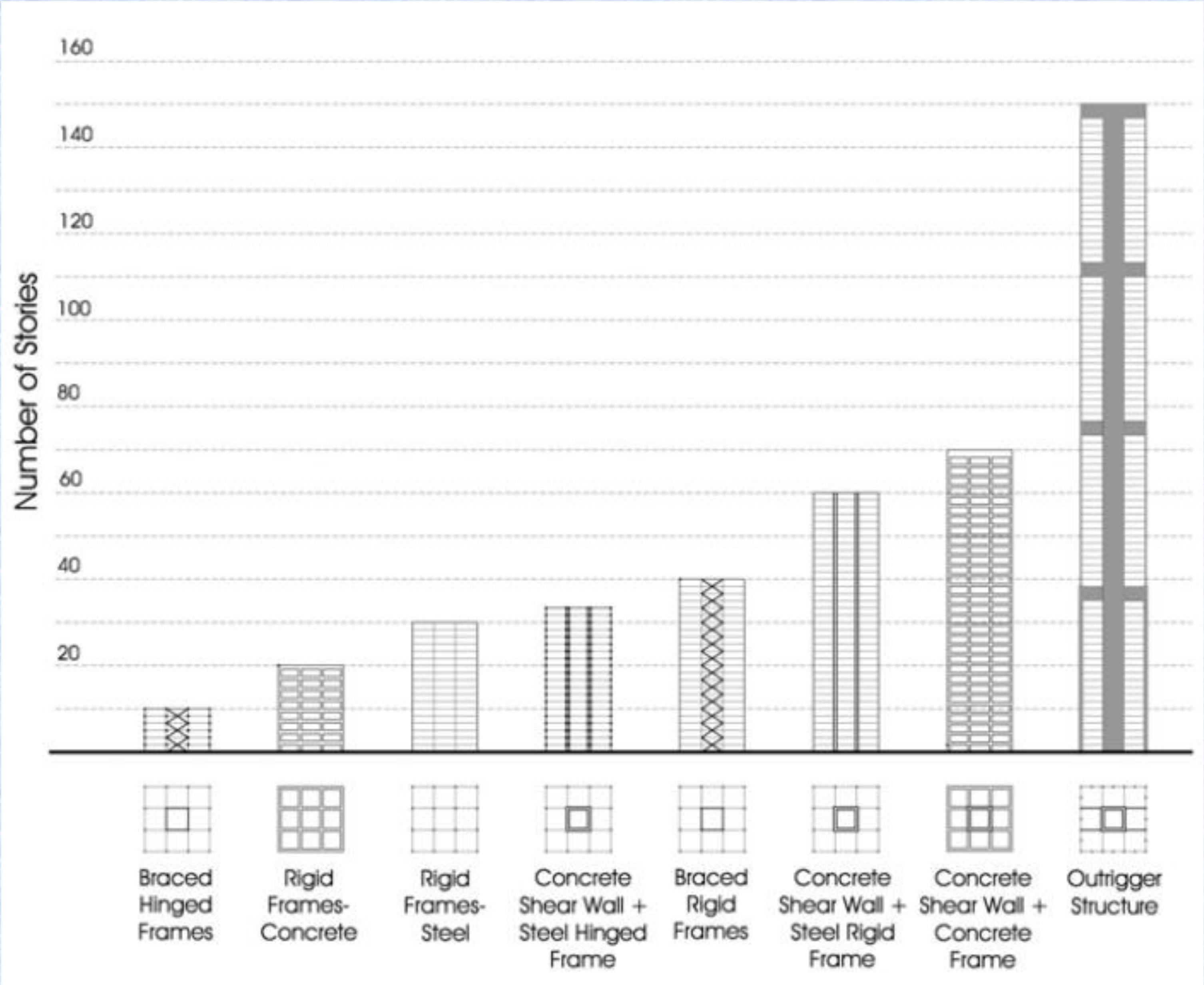
FIGURE 11.86 Comparative ultimate strength properties of four common structural materials: wood, brick masonry, steel (shaded row), and concrete. On a volumetric basis, steel is the strongest. Wood values are for stresses parallel to the grain of the wood.



MasterFormat Sections for Steel Frame Construction

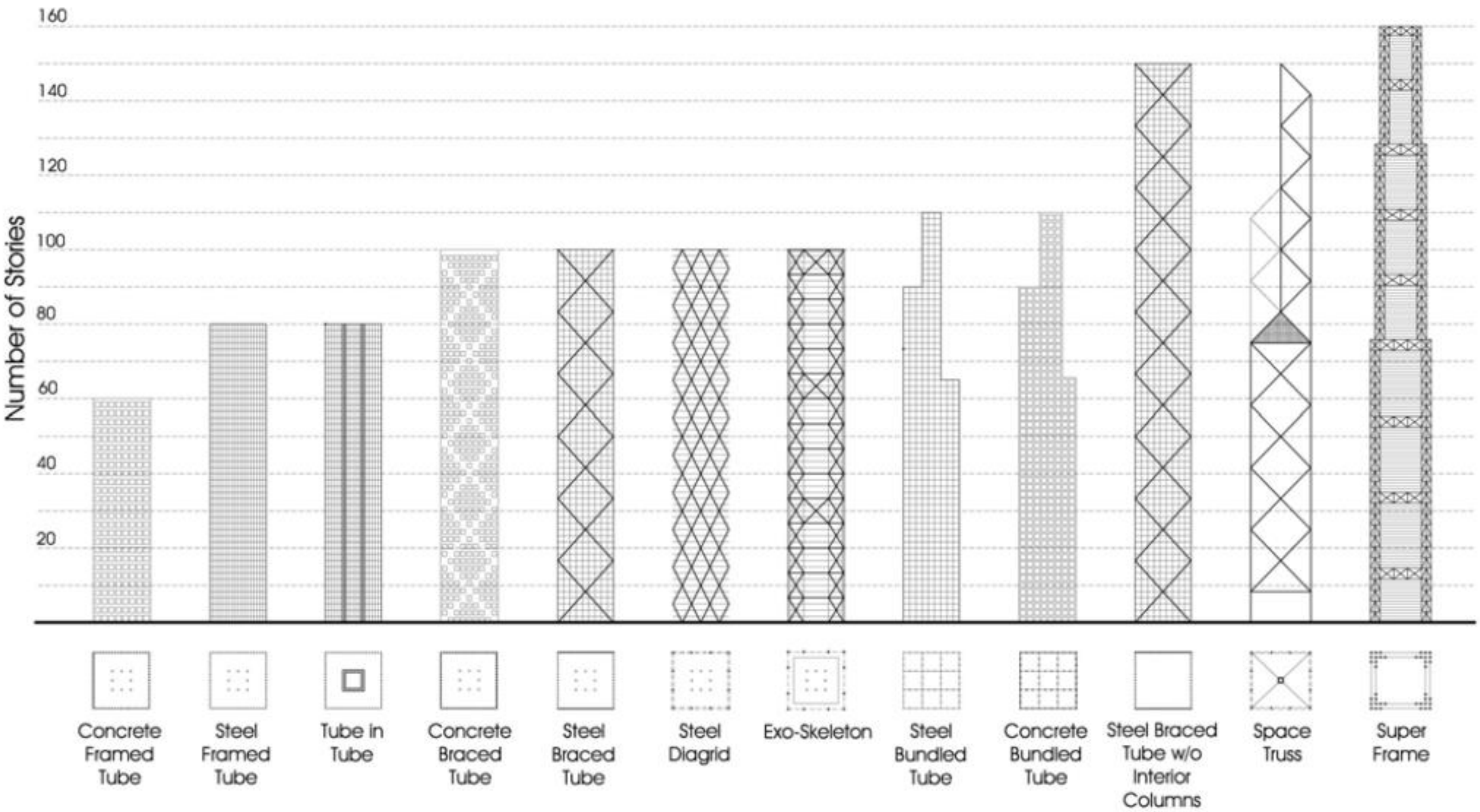
05 12 00	**STRUCTURAL STEEL FRAMING**
05 12 13	Architecturally Exposed Structural Steel Framing
05 12 19	Buckling Restrained Braces
05 16 00	**STRUCTURAL CABLING**
05 21 00	**STEEL JOIST FRAMING**
05 21 19	Open-Web Steel Joist Framing
05 31 00	**STEEL DECKING**
05 31 13	Steel Floor Decking
05 31 23	Steel Roof Decking
05 31 33	Steel Form Decking
05 36 00	**COMPOSITE METAL DECKING**
05 56 00	**METAL CASTINGS**
07 81 00	**APPLIED FIREPROOFING**
07 81 16	Cementitious Fireproofing
07 81 23	Intumescent Fireproofing
07 81 29	Mineral-Fiber Cementitious Fireproofing
07 81 33	Mineral-Fiber Fireproofing
07 82 00	**BOARD FIREPROOFING**

INTERIOR STRUCTURES and corresponding building heights



http://sydney.edu.au/architecture/documents/publications/ASR/Structural%20Developments%20in%20Tall%20Buildings.pdf

EXTERIOR STRUCTURES and corresponding building heights



http://sydney.edu.au/architecture/documents/publications/ASR/Structural%20Developments%20in%20Tall%20Buildings.pdf

FIGURE 12.11 Flexible metal conduit runs through prepunched openings in metal wall studs. The junction box is supported on metal bracket spanning between studs.

STEEL
STUDS

for
COMMERCIAL CONSTRUCTION

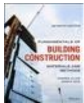
For INTERIOR PARTITIONS
And typically not "Load Bearing"

STEEL STUDS

for COMMERCIAL CONSTRUCTION

FIGURE 12.17 Light gauge steel stud infill between concrete and structural steel will support the exterior cladding. Note the horizontal rows of steel strap bracing.

FIGURE 12.18 **Light gauge steel stud framing forms the exterior enclosure for this building structured with posttensioned concrete.**



Skyscrapers can be part of quality **URBAN DESIGN**

where buildings compliment each other,

and their surroundings

Austin Texas in early 1980's

- U Texas BS Architectural Engineering
  with many classes on the upper floors of high-rises
- Then worked for Developers

https://www.pinterest.com/pin/186195765819905266/ -meeting/san-diego-skyline/

Recent Austin skyline

San Diego 1980's: Office in hi-rise working for developers (in addition to office in La Jolla), then worked for Planning Commission while in 2nd degree UCSD program in Urban Design

https://nexstarnetwork.com/what-we-do/events/super-meeting/san-diego-skyline/

San Francisco in late 1980’s …. Frequent meetings in downtown San Francisco skyscraper , and lived in the city, while working for an A&E firm, and starting grad school in Physics (to lead to M.Eng and PhD in Hi-Tech, then IBM Research, Purdue Professor, Elizabethtown Professor)