ARCHITECTURAL STRUCTURE

Week 12: Low rise vs high rise structure

Photo by Samuel-Elias Nadler on Unsplash

Outline

1

INTRODUCTION

Aims

LOs

2

LECTURE:

- **RECAP ON LOW RISE BUILDING'S STRUCTURE**
- **ACTIVITY 1**

3

LECTURE

- HIGHRISE STRUCTURE
- ACTIVITY 2

4

SUMMARY REFLECTION

- LOWRISE VS HIGHRISE STRUCTURE
- ACTIVITY 3

Aims and objectives

- To provide a snapshot of what we have learnt from Week 1
- To contextualise differences between low-rise and high-rise structure
- To gain understanding on structural considerations in different scope of project

Learning outcomes

Students will be able to..

01 Infer differences between low-rise and high-rise structure

02 Gain understanding of applying tectonic thinking in different scope of architecture

03 Apply the knowledge in future design projects

Part 1: Recap on low-rise structure

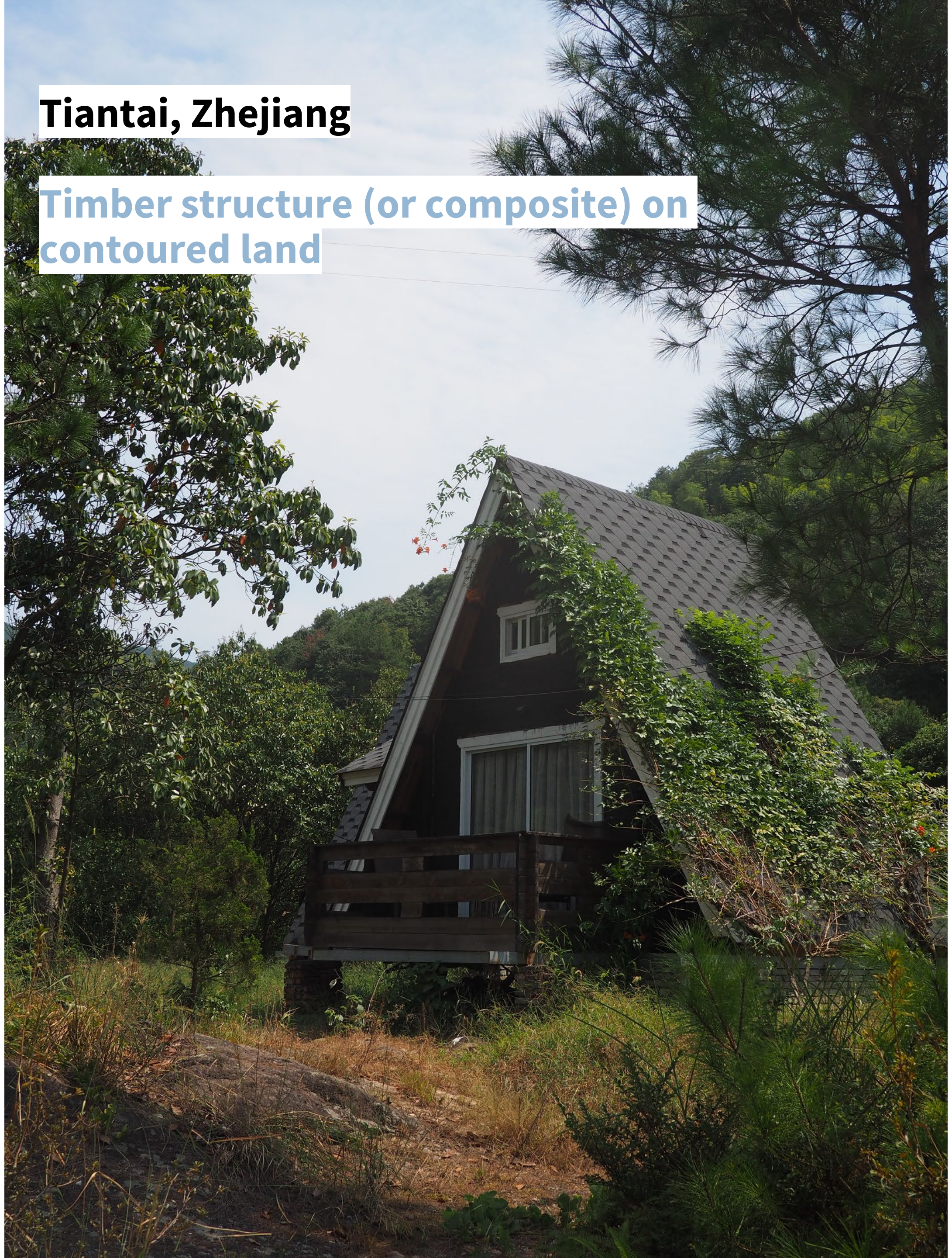
Photo by Sebastian Grochowicz on Unsplash

Tiantai, Zhejiang

Timber structure (or composite) on contoured land

Tiantai, Zhejiang

Timber structure (or composite) on contoured land

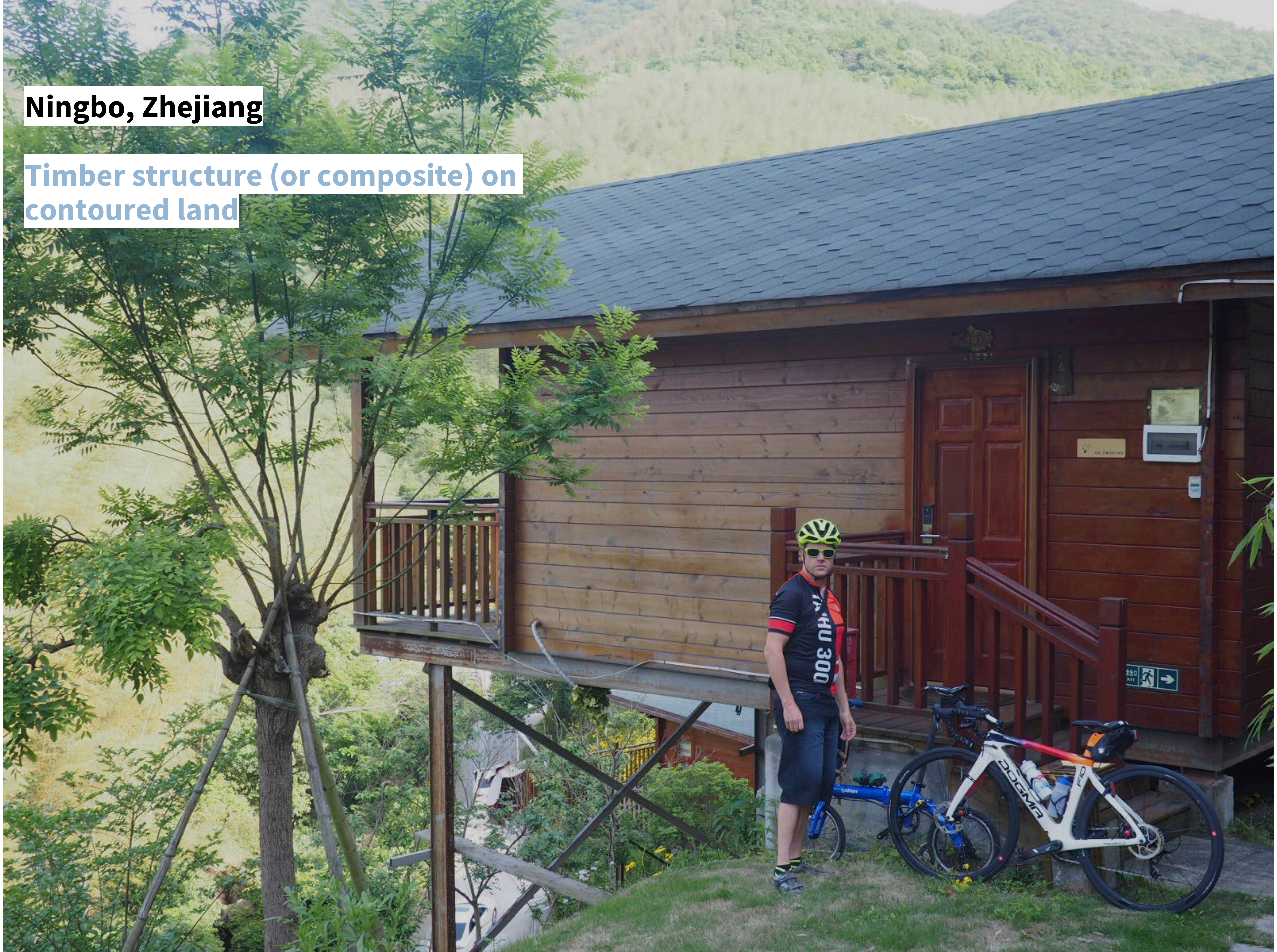


Ningbo, Zhejiang

Timber structure (or composite) on contoured land

Ningbo, Zhejiang

Timber structure (or composite) on contoured land



Ningbo, Zhejiang

Timber structure (or composite) on contoured land

Activity 1: QUIZ 1

https://forms.gle/C3cWEbsa41TdwJXKA

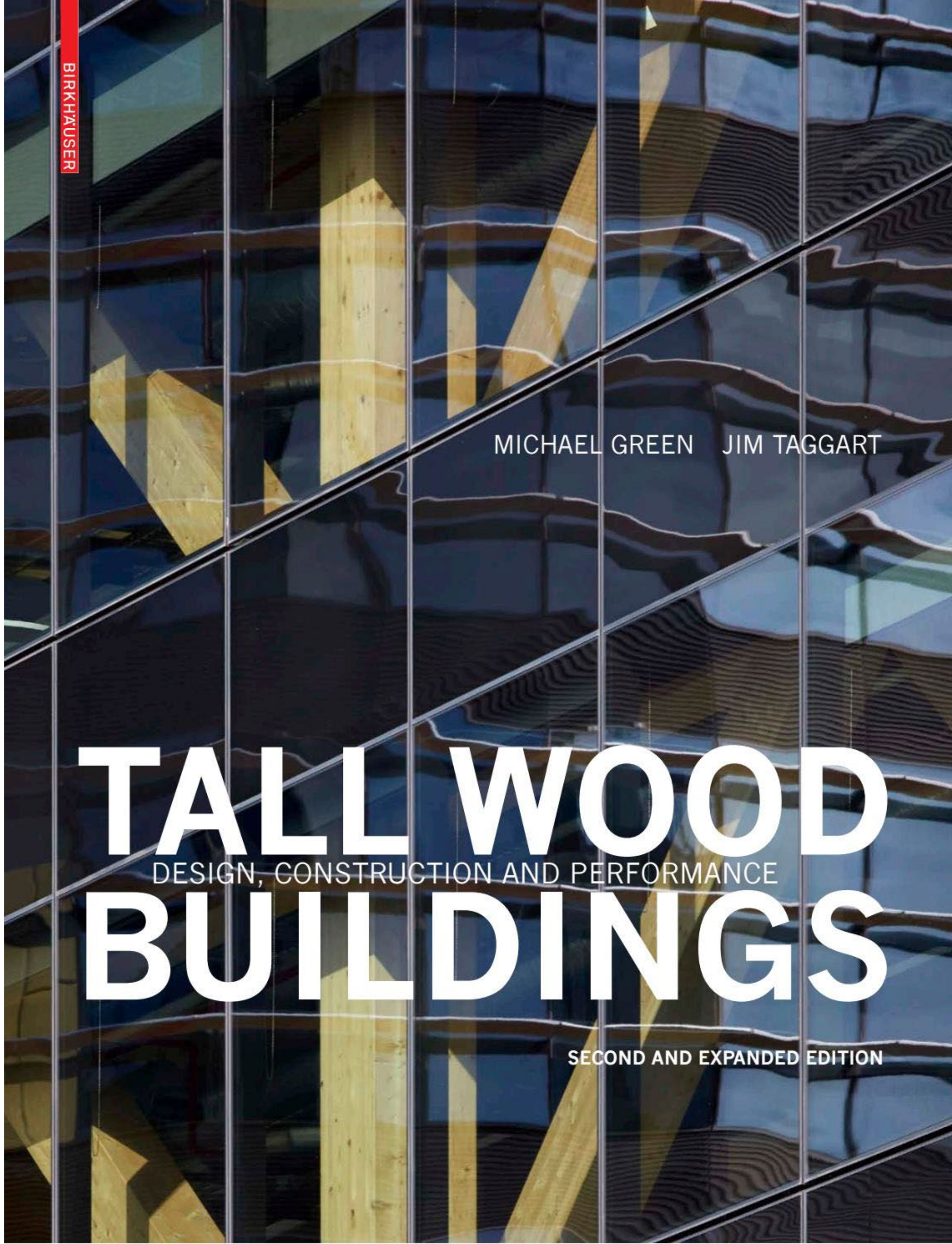
A quick engagement task

SPEND
20 MINS

Photo by lucas Favre on Unsplash

Part 2: High-rise structure

Photo by Sebastian Grochowicz on Unsplash



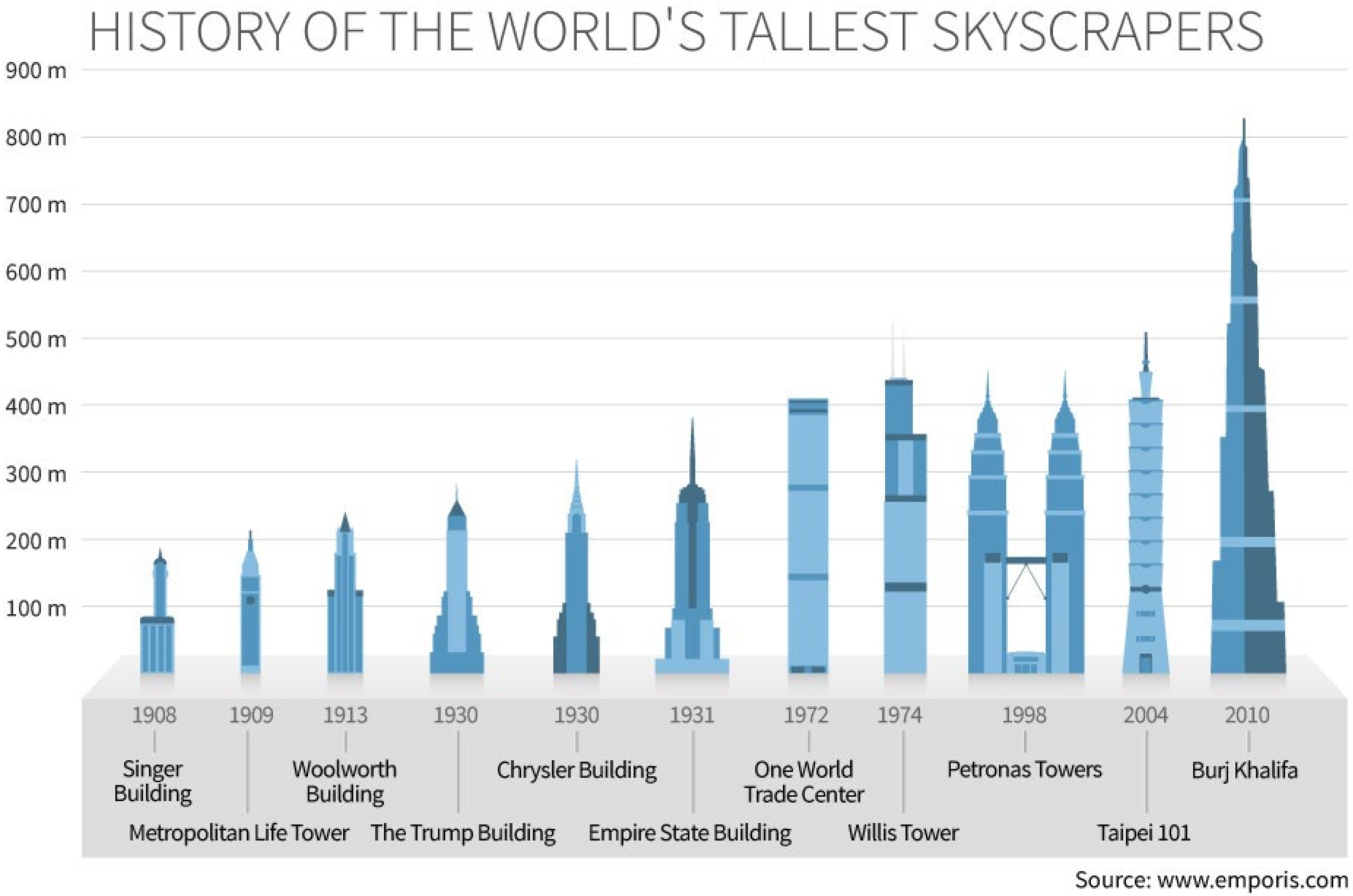
BIRKHÄUSER

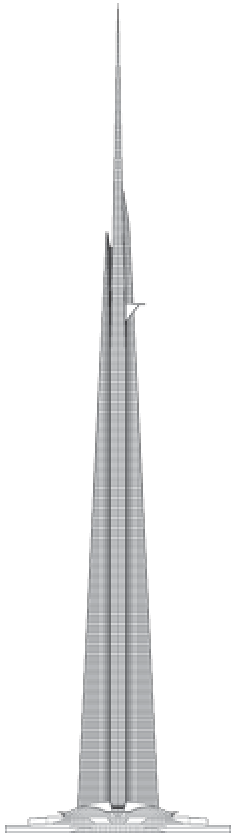
MICHAEL GREEN JIM TAGGART

TALL WOOD BUILDINGS

DESIGN, CONSTRUCTION AND PERFORMANCE

SECOND AND EXPANDED EDITION





Jeddah Tower
(under construction)

2.1. INTRODUCTION

- Common definition of high-rise, skyscraper buildings
- Historical perspective
- Activity 2: QUIZ 2

Definition of tall buildings, high-rise buildings, and skyscraper

In general,
Structural engineers see tall buildings as buildings which require unusual structural system. Also wind loads are prominent in analysis and design.

Beedle (1971) defines 'tall building' as a multi-storey building that requires **additional construction techniques** due to its extraordinary height.

Architectural designers see buildings which require interdisciplinary work (in particular with structural engineer, also with aerodynamics, mechanics and urban planning) and civil engineer as they need unusual and sophisticated construction techniques.

Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

Definition of tall buildings, supertall buildings, and megatall buildings

[Council on Tall Buildings and Urban Habitat (ctbuh.org)]

There is no absolute definition of what constitutes a '**tall building**'. Definition is subjective according to:

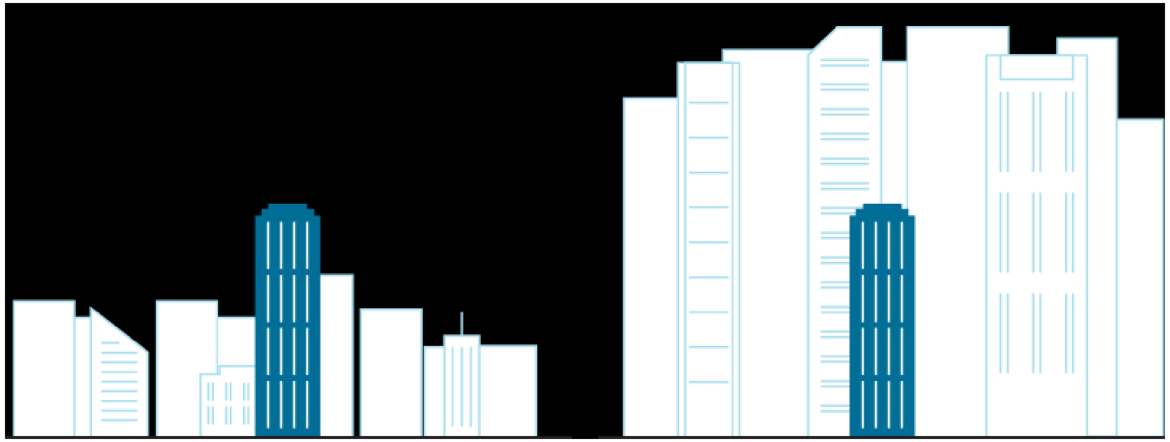
- Height relative to Context
- Proportion
- Embracing technologies relevant to tall buildings

Poor indicator uses no of stories (14) or more than 50m in height.

Definition of tall buildings, supertall buildings, and megatall buildings

Council on Tall Buildings and Urban Habitat (ctbuh.org)

- Height relative to Context
- Proportion
- Embracing technologies relevant to tall buildings



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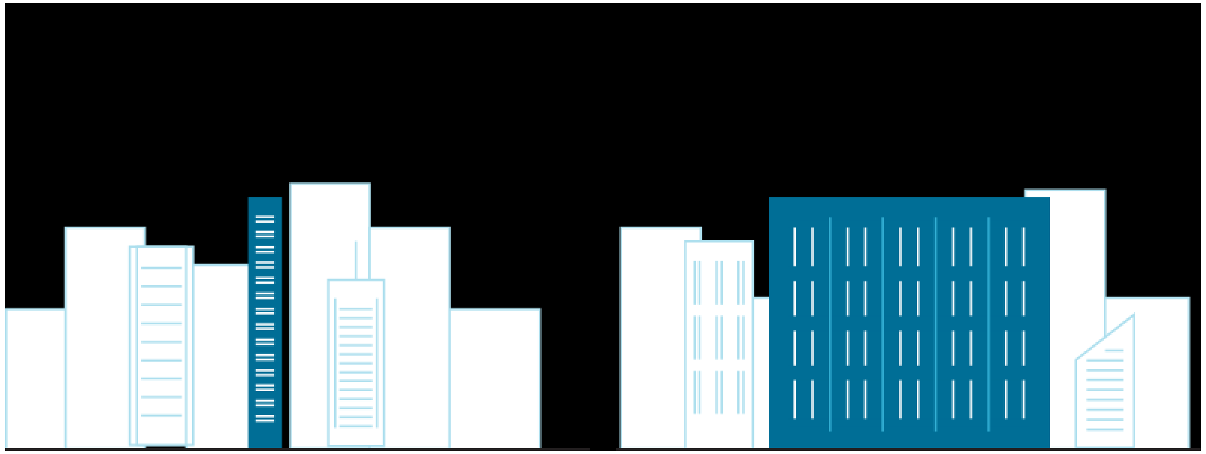

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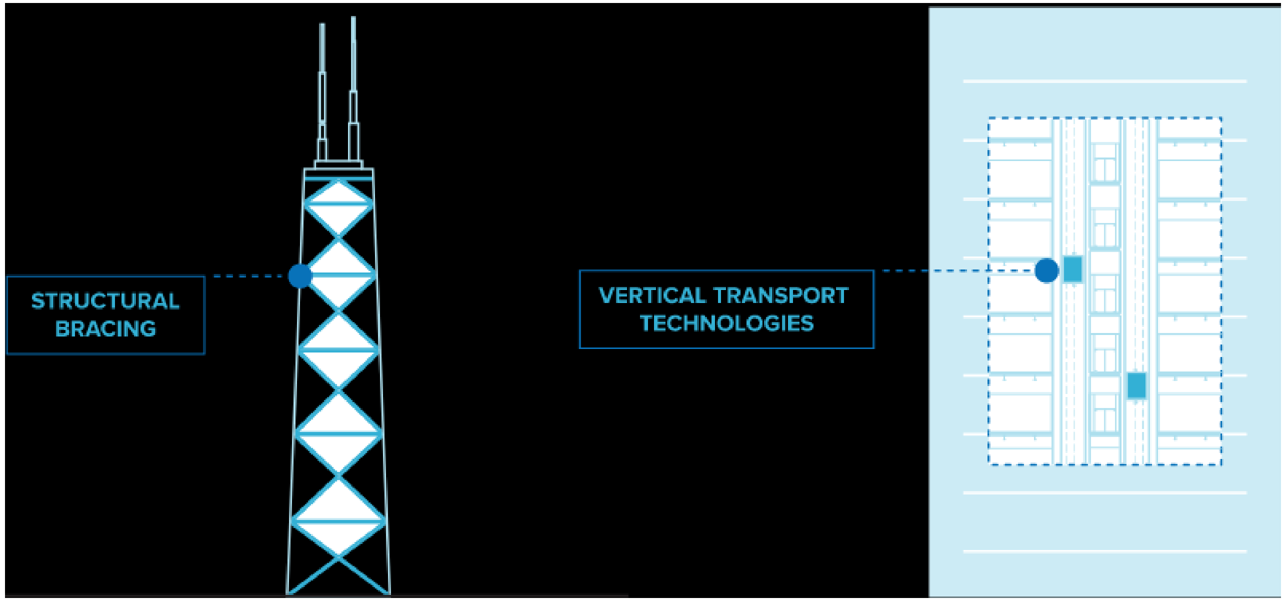
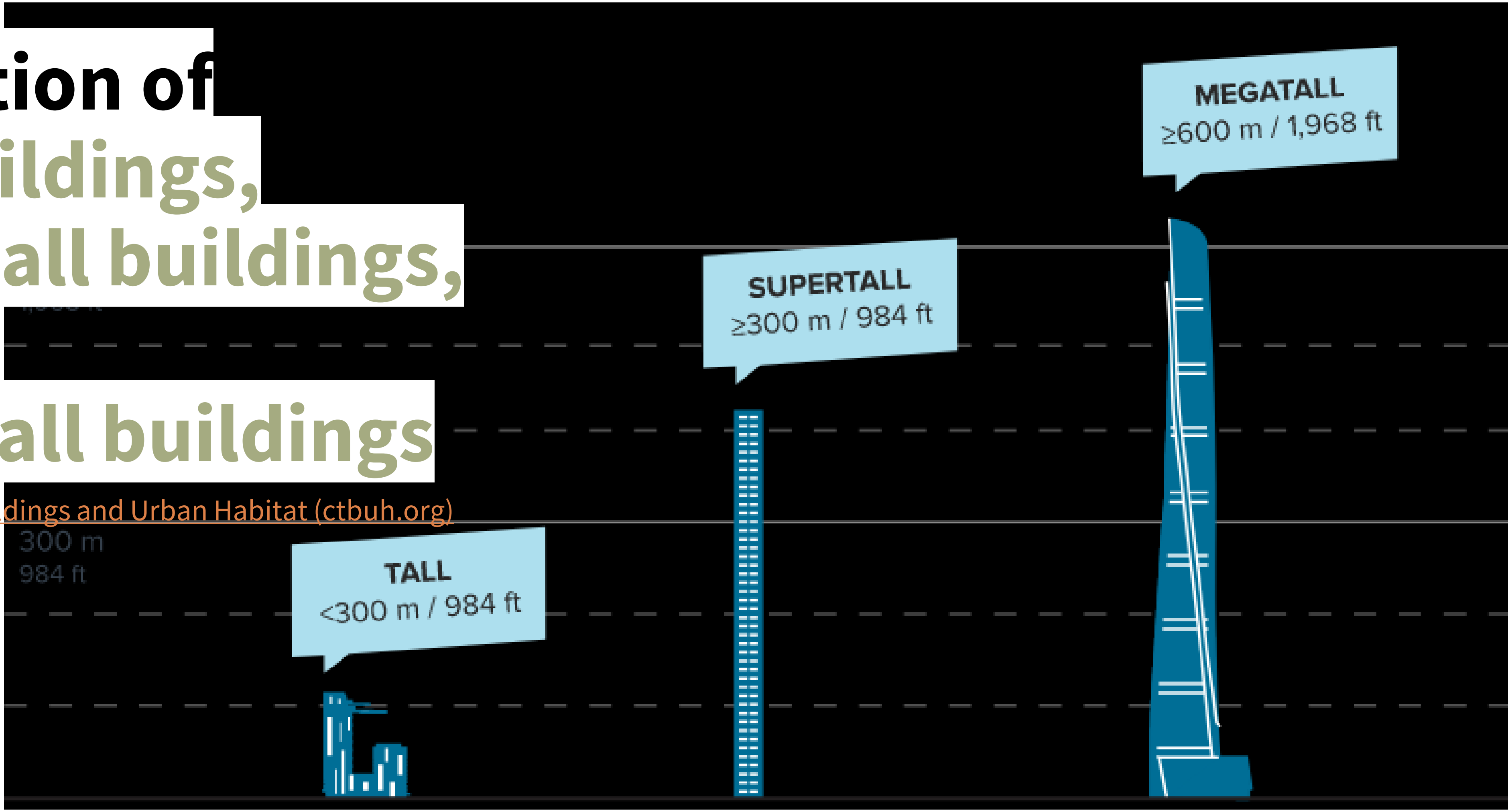


Definition of **tall buildings, supertall buildings,** and **megatall buildings**

[Council on Tall Buildings and Urban Habitat (ctbuh.org)](ctbuh.org)



ONE CENTRAL PARK
SYDNEY, AUSTRALIA
117M

432 PARK AVENUE
NEW YORK CITY, USA
426M

SHANGHAI TOWER
632M

Historical perspectives

No other symbols of the modern era are more convincing than the gravity defying, vertical shafts of steel, glass, and concrete that are called “skyscrapers.”

(Harbert, 2002)

Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

Historical perspectives

Similarly with Greek temples or Gothic cathedrals, skyscrapers **become iconic structures** of industrial societies.

First appearances of skyscrapers in Chicago (in 1880s) was a **social transformation** triggered by economic boom and the increase in value of urban building plots.

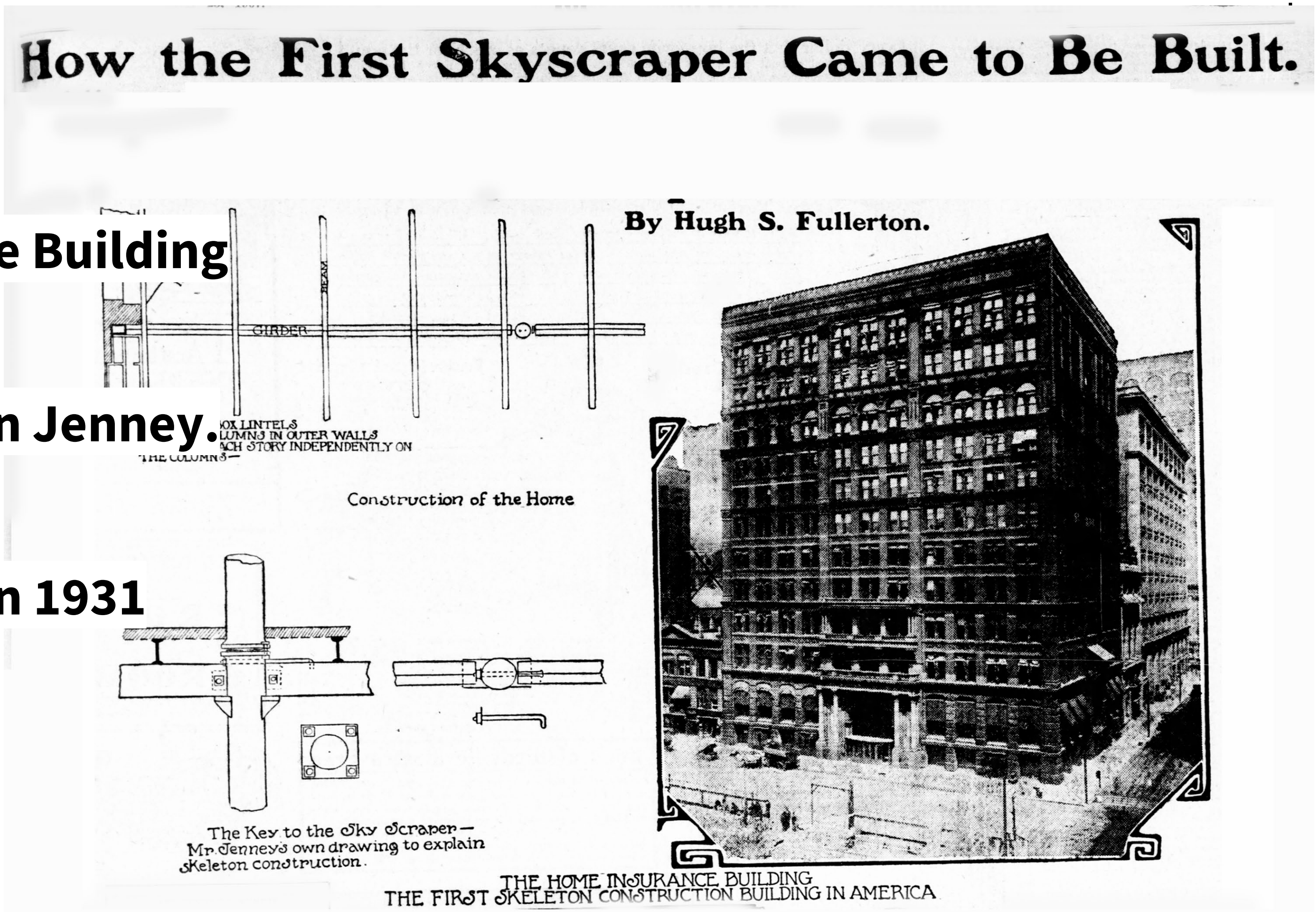
Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

Historical perspective

The Home Insurance Building
Chicago, 1885

By: William Le Baron Jenney.
12 storeys, 55m tall

It was demolished in 1931



[rare interior photographic images of the home insurance building shortly before its untimely demolition | Urban Remains Chicago News and Events]

Historical perspectives: Monadnock Building Chicago, USA

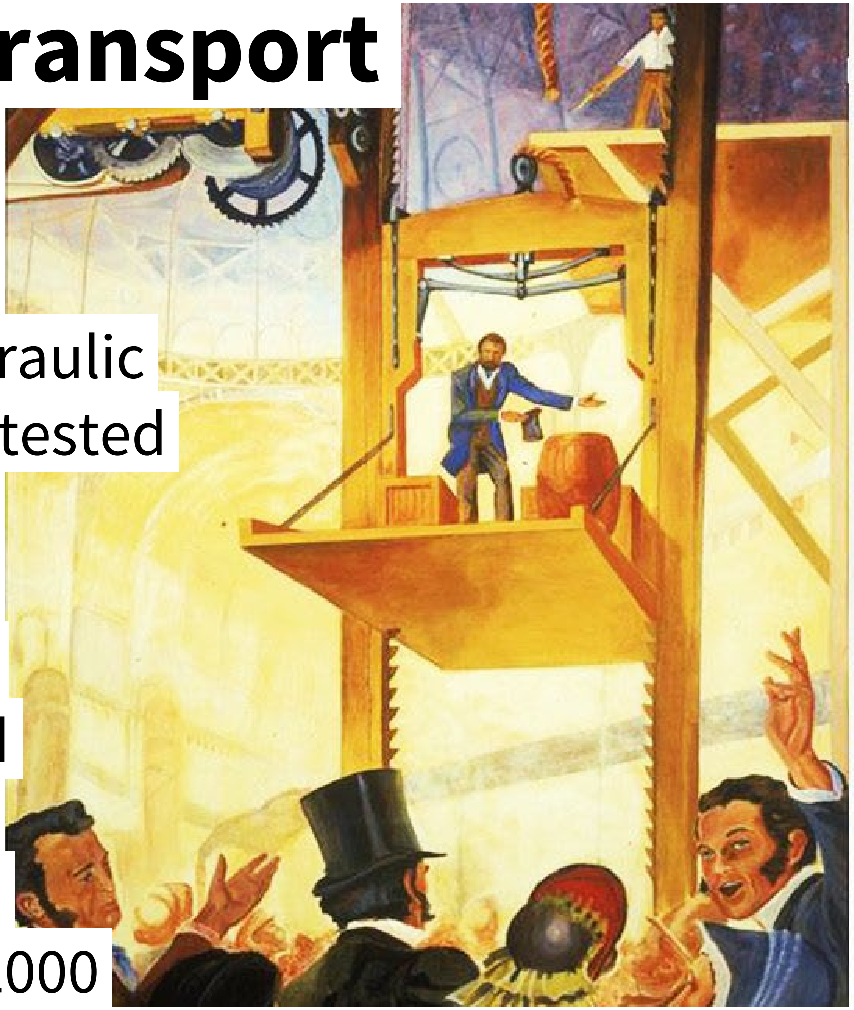
16 stories. The world's last and largest **'masonry skyscraper'.** It was considered as structural achievement. Steel + masonry.

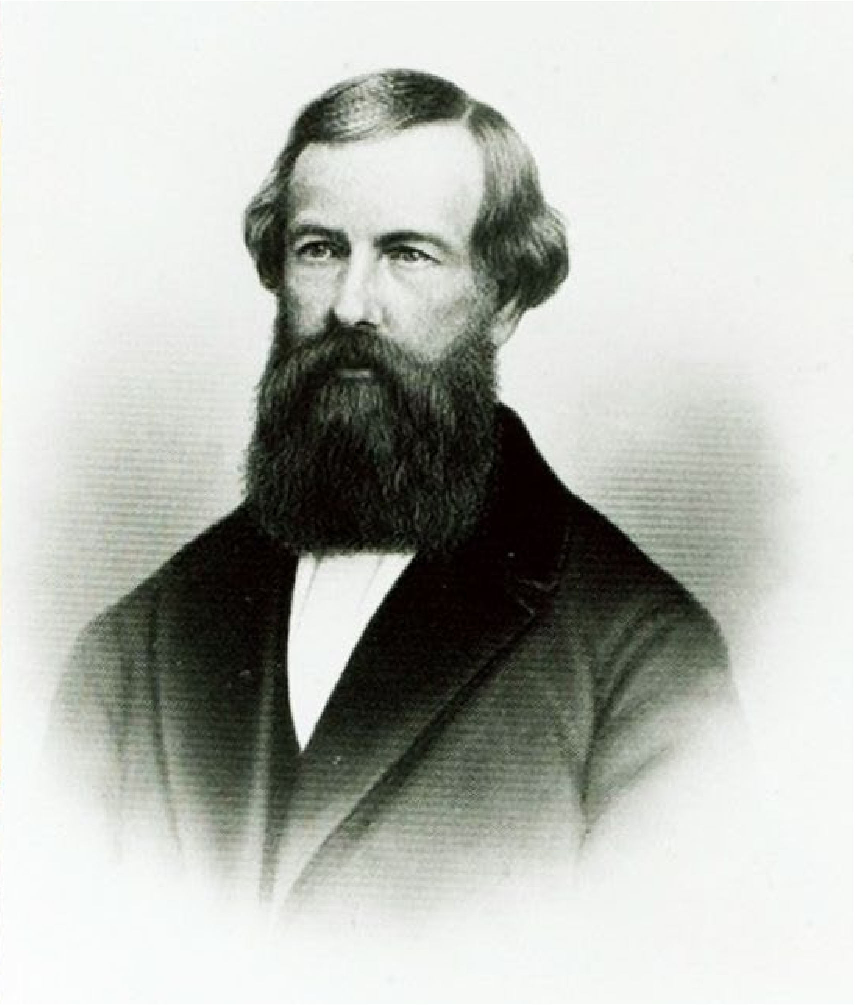
Reliance Building. Chicago, USA

1895

Introduced **the first curtain wall system.** Buildings could be conceived as clad structural skeletons with building skins erected after the frame was constructed.

Vertical transport system





Steam and hydraulic elevators were tested for use in 1850.

By **1873**, Elisha Graves Otis had developed and installed steam elevators into 2000 buildings across America.

How Otis' Elevator Made Modern Skyscrapers Possible | 6sqft

Chrysler Building, New York.

The world’s tallest in 1930

Photo by Stephan Kelle on Unsplash

Late 1960s and early 1970s:

New development in tall building analysis, design and construction.

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

Economical alternative to structural steel: reinforced concrete

Brunswick Building (1964)

SOM | Brunswick Building

Activity 2: QUIZ 2

https://miatedjosaputro.com/2022/04/02/as-week-13-2/

1. Do an online research on **aspects architects need to consider** when designing a high-rise building
2. List them down on the class material link. Enter **one aspect as bullet points.**

SPEND

25 + 5 MINS

2.2. DESIGN PRINCIPLES

- Guiding principles
- Concepts
- Major design issues
- Primary considerations

Guiding principles:

Simplicity
Structural clarity
Sustainability

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

Guiding principles:

Simplicity

Structural clarity

Sustainability

- Simplicity in **form**, according to architectural program, soil conditions, potential imposed lateral loads, etc
- Purity of **concept**, includes a structural engineering response that is sympathetic to architectural goals.
- Avoiding frivolous materials
- Multiple purposes system if possible
- Uniformity of mass, symmetry, control of force flow within the structure
- Example: Development of moment frame → tubular frame → braced tubular frame to increase height without substantial increase in structural materials.

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

Guiding principles:

Simplicity
Structural clarity
Sustainability

- **Clear load paths**
- Creating **certainty** in environments with potentially very uncertain events (seismic motions, displacements, etc) might occur.

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

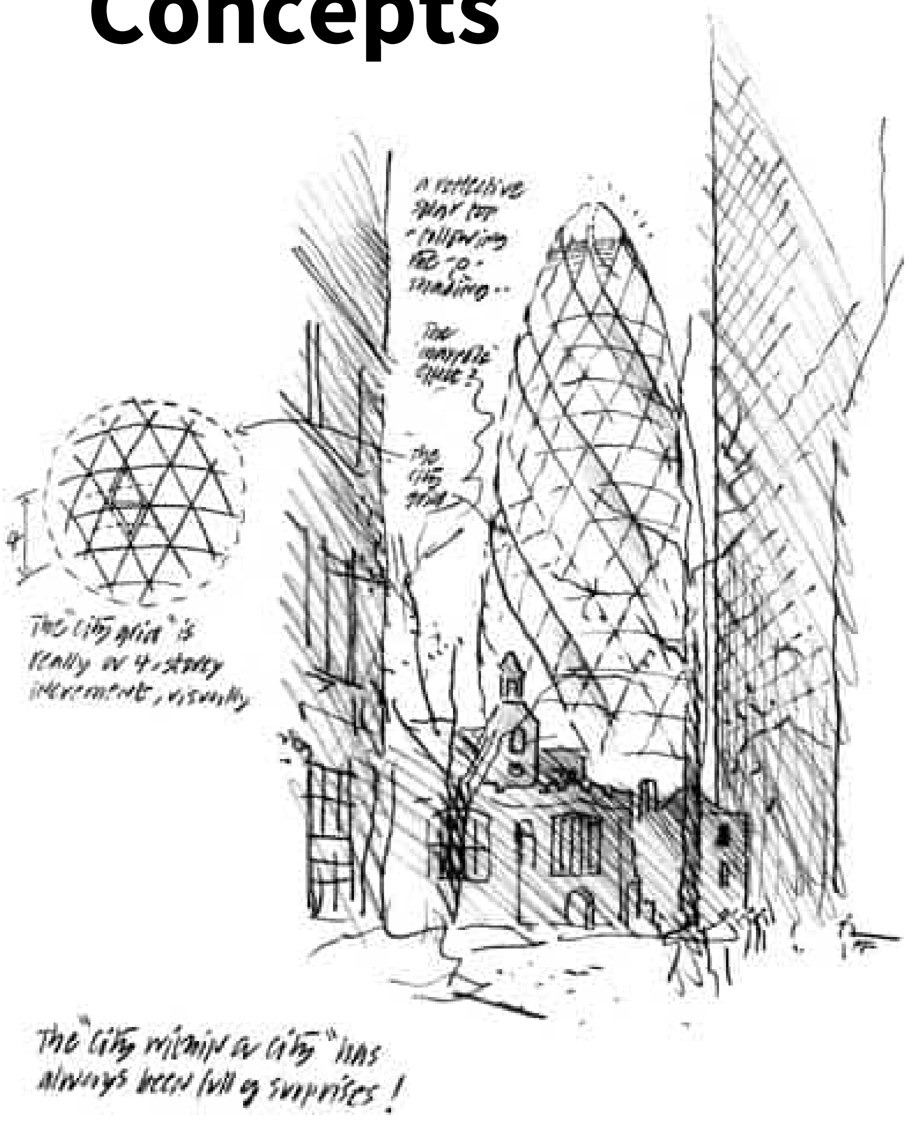
Guiding principles:

Simplicity
Structural clarity
Sustainability

- Tall buildings should be designed and constructed to be **self-sufficient**, if not regenerative.
- The structure should be designed to generate power to fully operate, capture rainwater, treat and reuse wastewater, and even produce food.
- If possible, structures should include **recycled materials** and be supplied **locally**.
- Every major building component should be designed for at least two purposes. For example: structure can be designed to control heat gain, façade system can be designed to generate electricity.

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

Concepts



- Structural systems are important to be defined conceptually in early design process.
- They include: horisontal framing , vertical gravity and lateral load-resisting elements.
- Integration of systems, between mechanical and exterior wall systems.
- Important consideration during concept design: floor-to-floor heights, height limit, estimation of material quantities for project costs, prefabrication system.

Sarkisian, M. (2016). *Designing tall buildings: Structure as architecture*, Routledge.

Major design issues

- Lateral stability system
- Gravity system for the superstructure

Primary design target:
To provide sufficient **stiffness** to **resist lateral or gravity loadings**.

Fu, F. (2018). *Design and analysis of tall and complex structures*, Butterworth-Heinemann.

Primary considerations

- Lateral stability system
- Wind and wind-induced vibration
- Seismic loads
- Foundation design
- Fire and blast loading

Fu, F. (2018). *Design and analysis of tall and complex structures*, Butterworth-Heinemann.

Primary considerations

- Lateral stability system
- Wind and wind-induced vibration
- Seismic loads
- Foundation design
- Fire and blast loading

Development of structural system for tall buildings in history:

1. Rigid frame
2. Bracing system
3. Shear wall system, to
4. Core-outrigger
5. Tube structures
6. Diagrid structures
7. Superframe structures

Fu, F. (2018). *Design and analysis of tall and complex structures*, Butterworth-Heinemann.

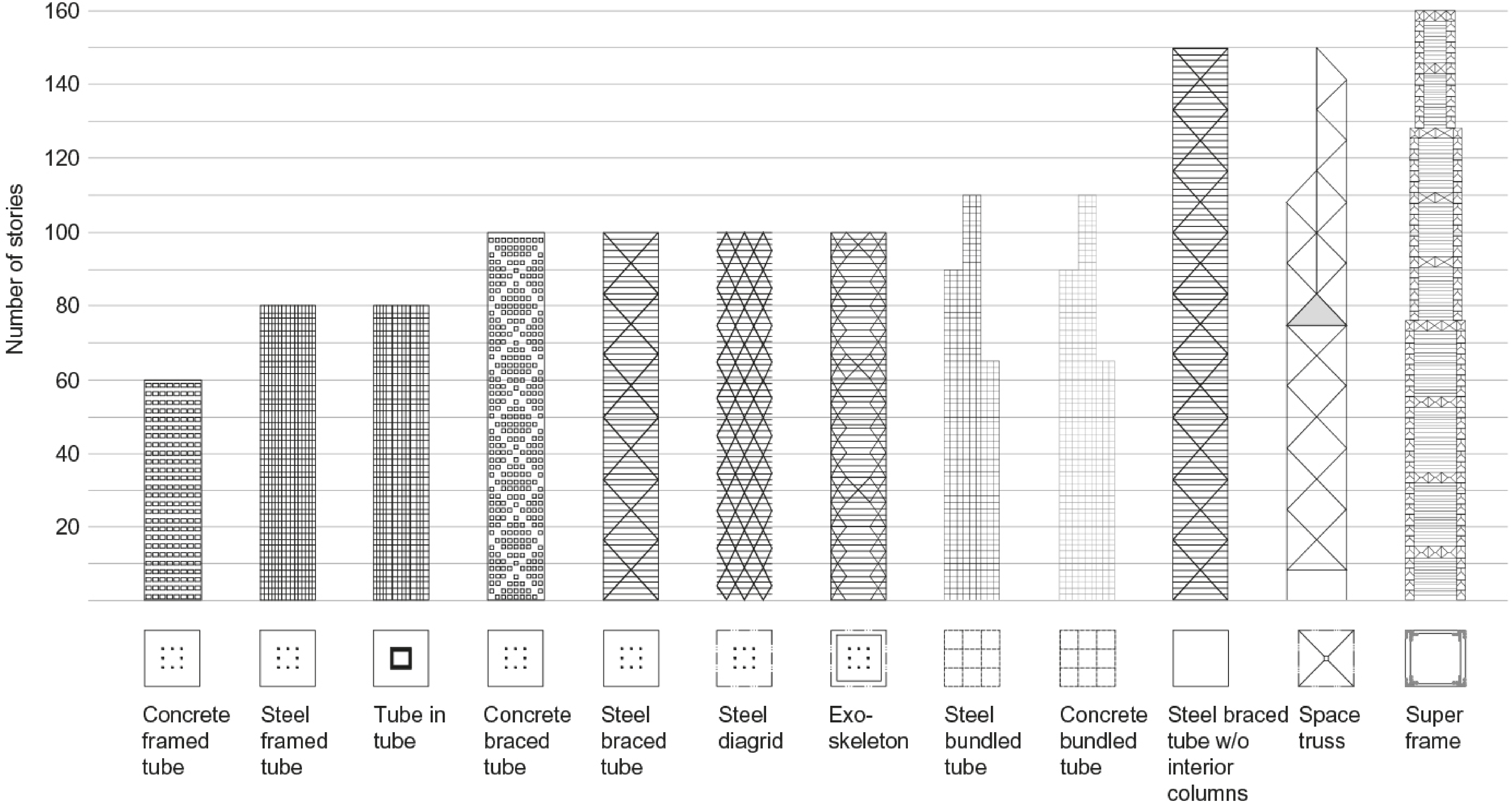
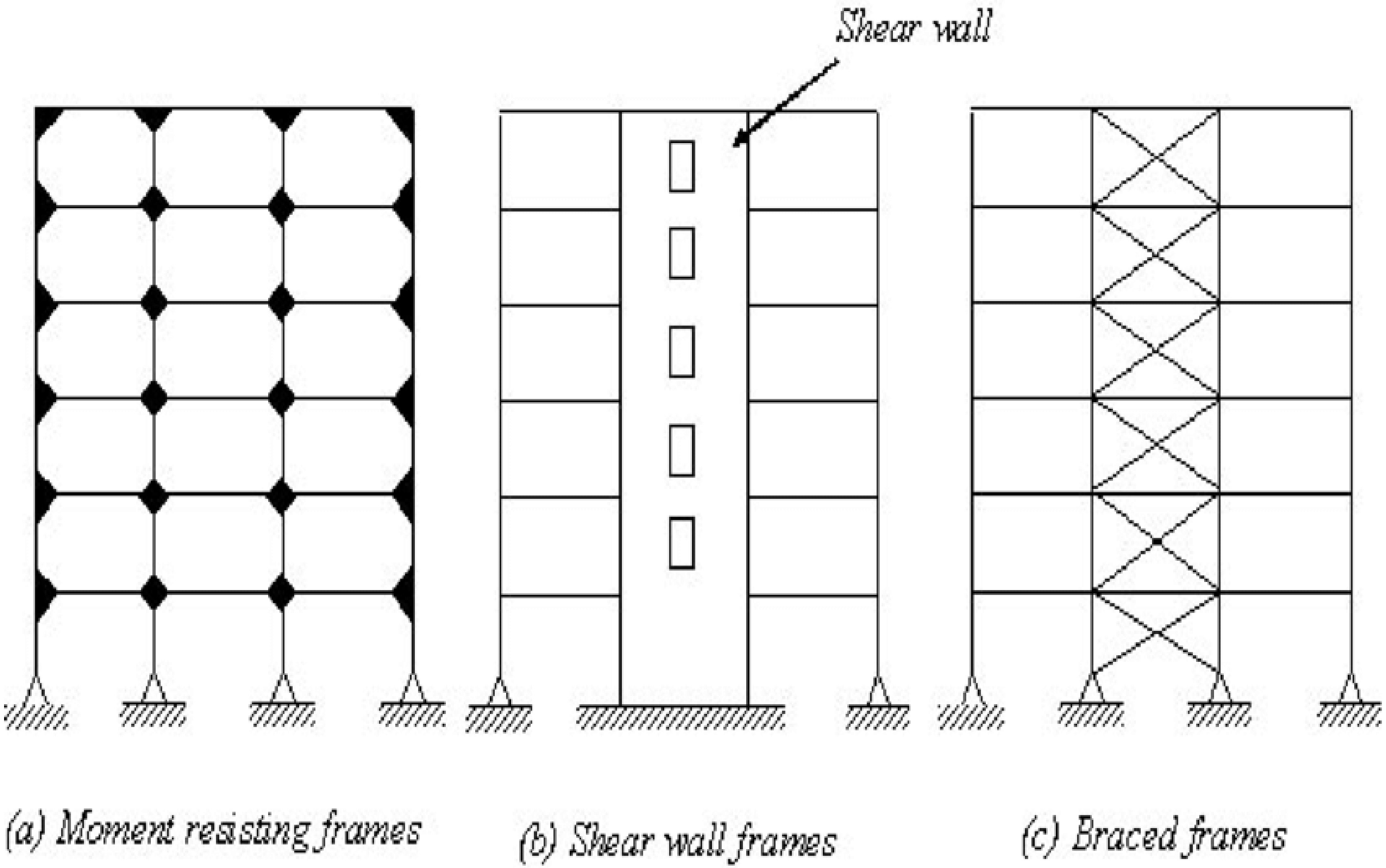
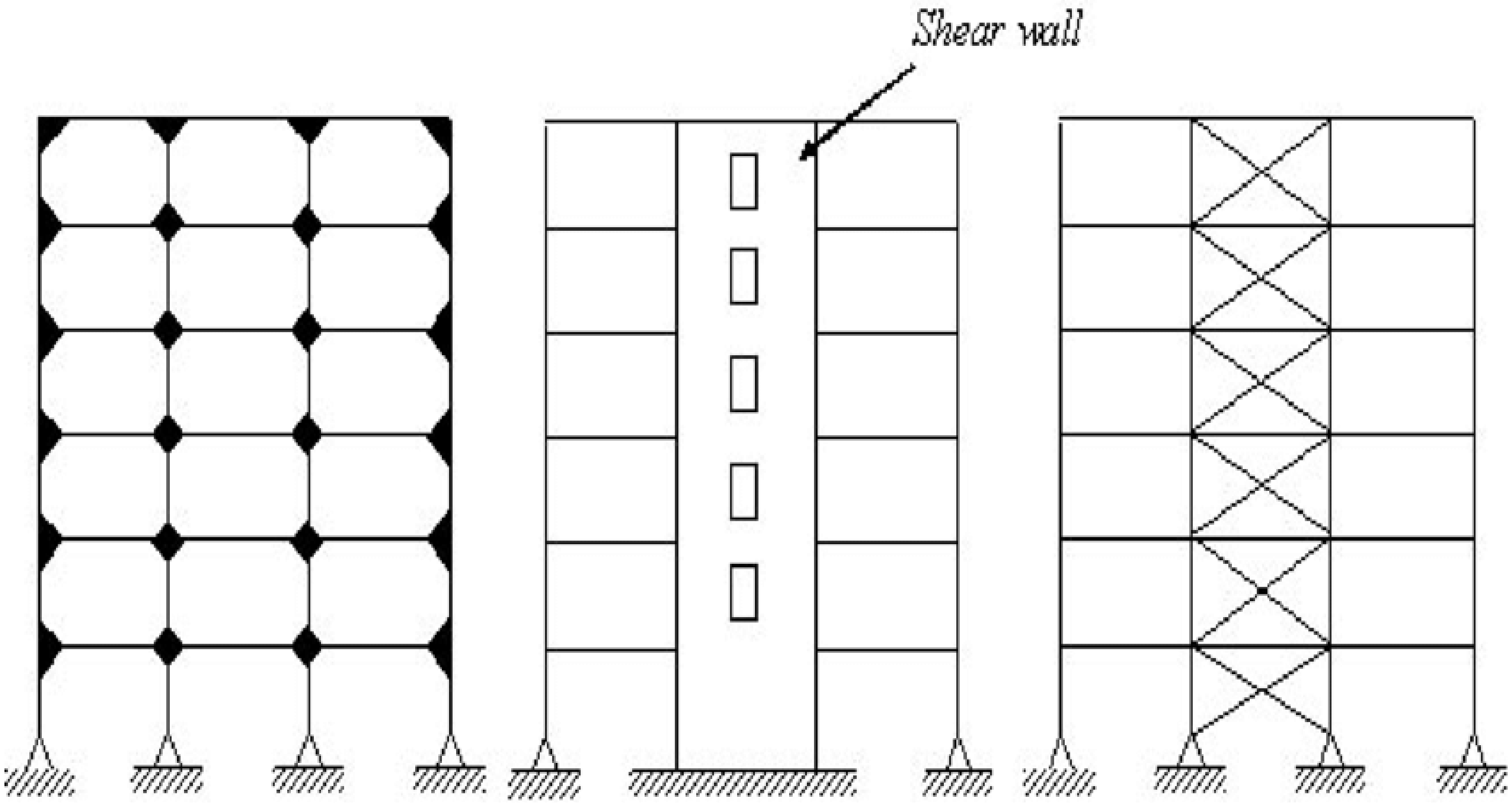


Fig. 2.4 List of different lateral stability system in tall buildings [4]. Fu, F. (2018). *Design and analysis of tall and complex structures*, Butterworth-Heinemann.



Moment resisting frame (MRF)/ rigid frame

A system where the beams and columns are rigidly connected to provide lateral resistance. Moments are transferred through the connection.



(a) Moment resisting frames (b) Shear wall frames (c) Braced frames

Bracing system

Bracing and shear walls (b) and (c), often work together.
Braced frames: pin connection to form beam-column joints. The connection does not transfer moments.

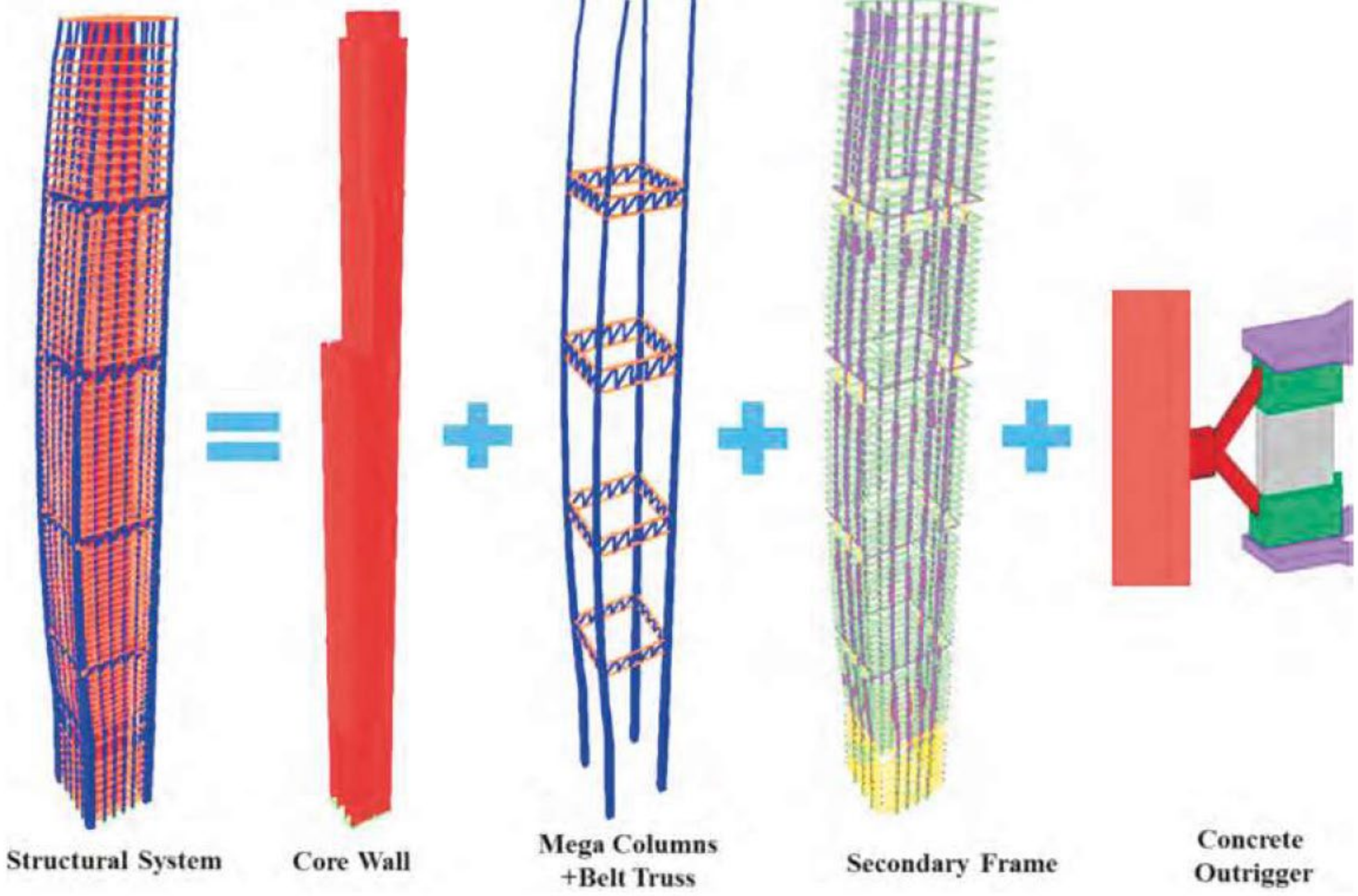


Figure 12. Structural System for CQ Raffles City Project (with courtesy of Arup).

Core-outrigger

Connecting main core to exterior columns.

Ho, G. W. (2016). The evolution of outrigger system in tall buildings. *International Journal of High-Rise Buildings,* 5**,** 21-30.

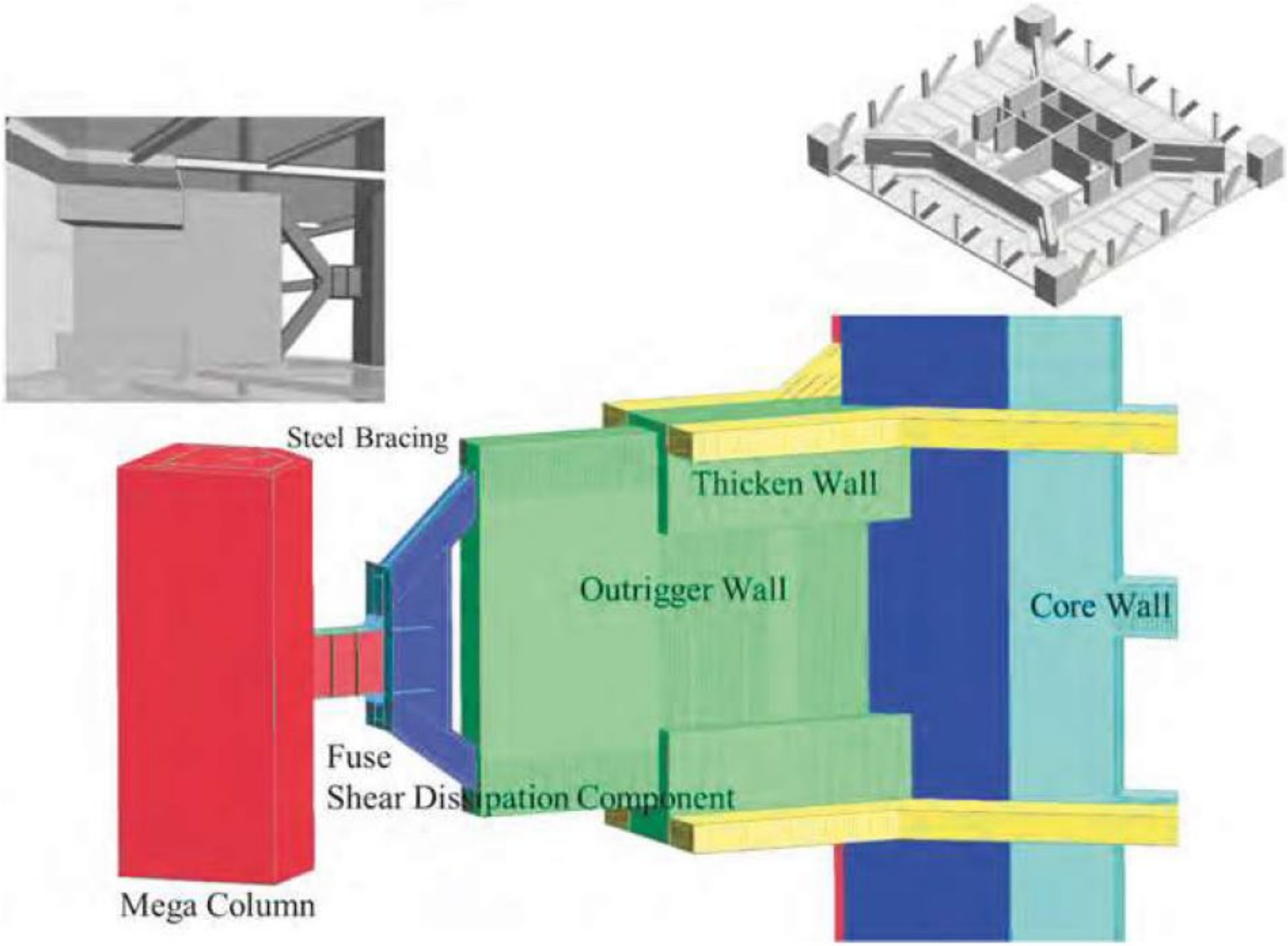
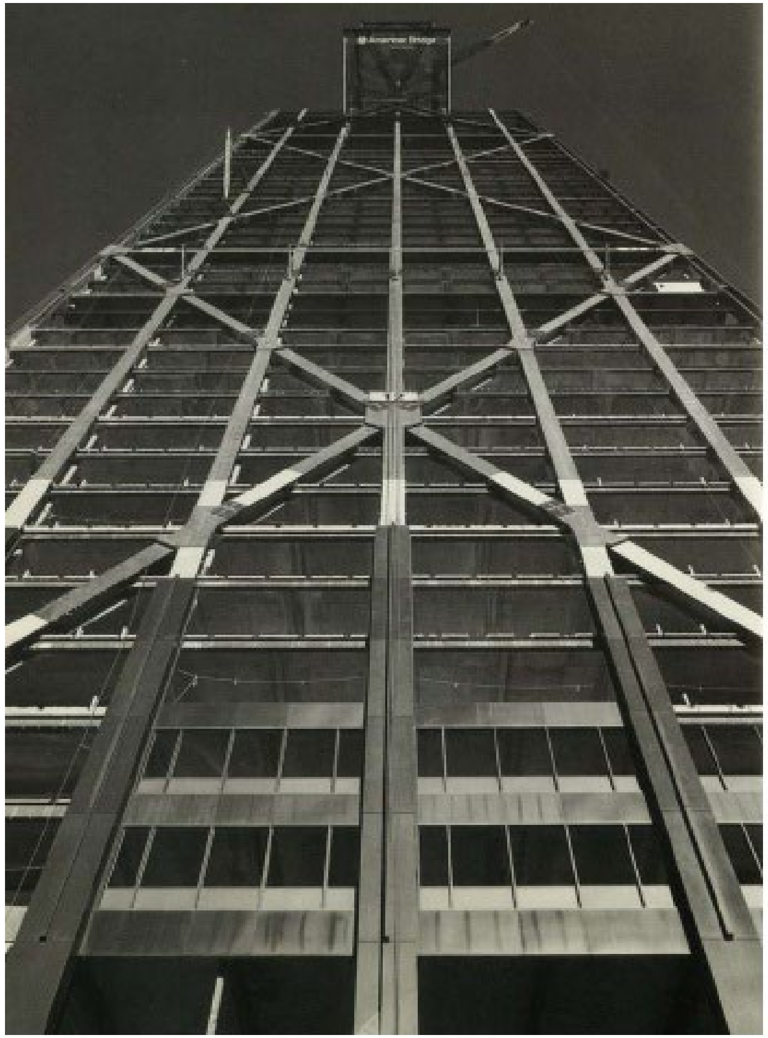


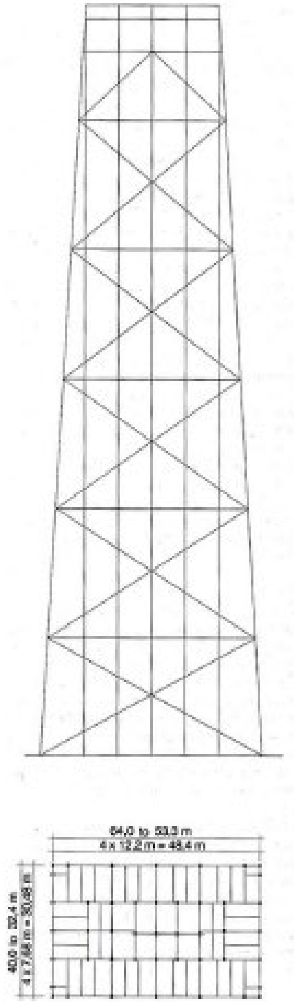
Figure 13. Component List for Fused Outrigger (with courtesy of Arup).

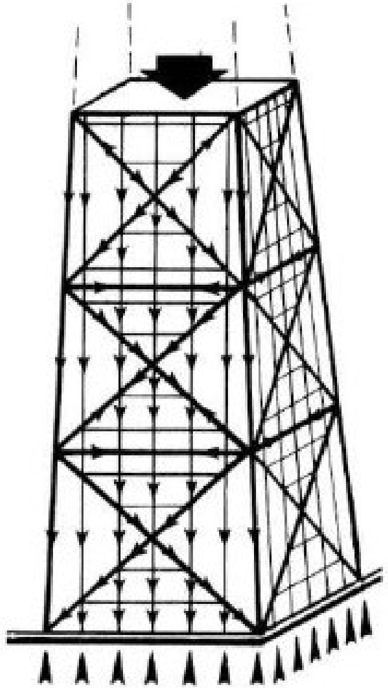
Core-outrigger

Connecting main core to exterior columns.

Ho, G. W. (2016). The evolution of outrigger system in tall buildings. *International Journal of High-Rise Buildings,* 5**,** 21-30.



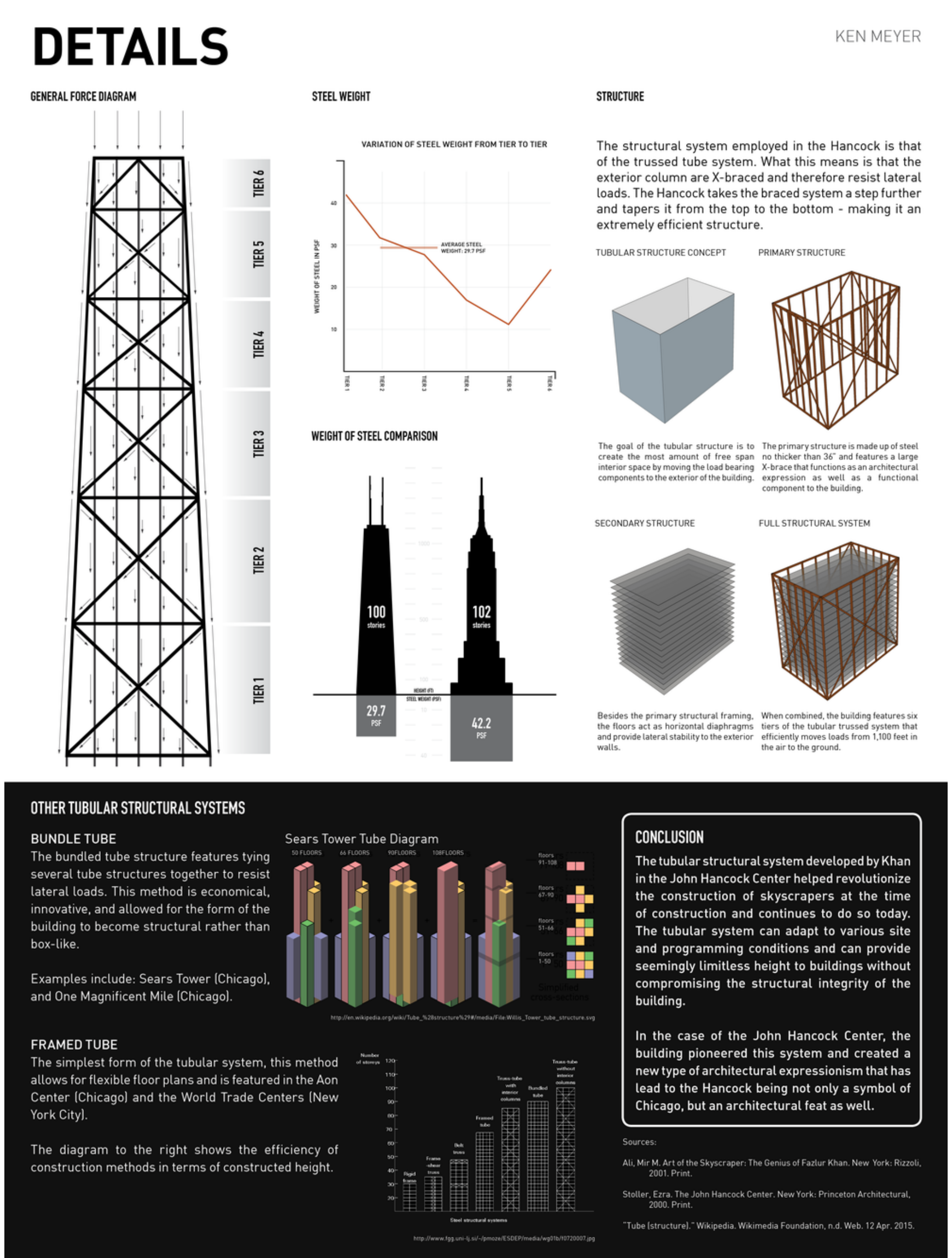




John Hancock Center SOM / Bruce Graham / Fazlur Khan Chicago 1970

Tube structures

A building is designed to act like a hollow cylinder, cantilevered perpendicular to the ground in order to resist lateral loads.



Tube structures

John Hancock Structural Analysis — KEN MEYER

Diagrid system

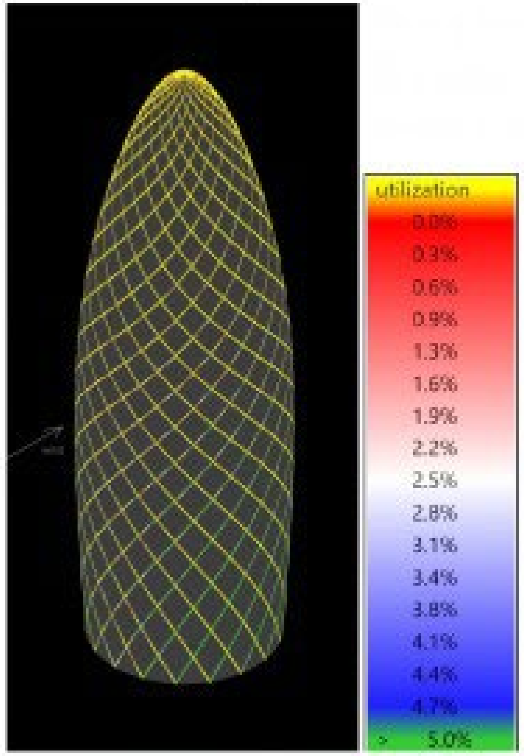
Structural efficiency as an adapted version from bracing systems. The triangular geometry effectively prevent structural failure.

PROPOSAL I

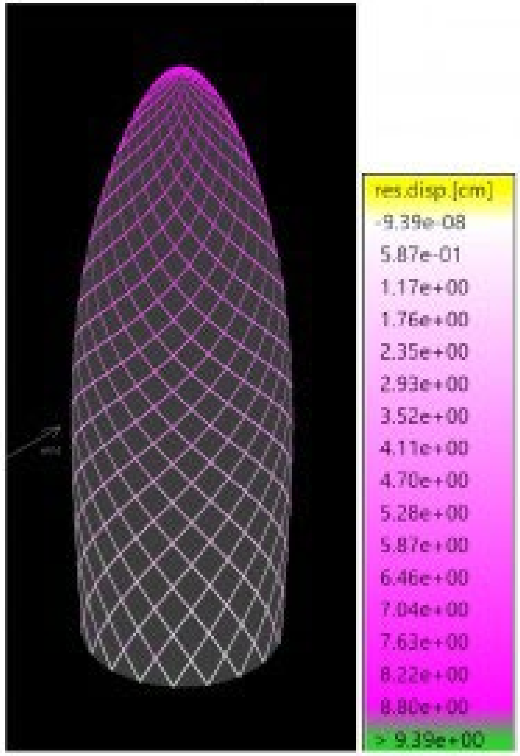
-with wind load

Under wind load, utilization remains lowest at the top and generally well distributed, but areas of higher utilization are seen spiralling up the building from its base, away from the wind. Displacement is more concentrated towards the top of the building and larger in magnitude (9.4 cm vs 1.8 cm at maximum). Bending moment analysis shows primarily the same behaviour as in the scenario without wind, though axial forces are affected and largest in areas adjacent to the area of initial wind contact.

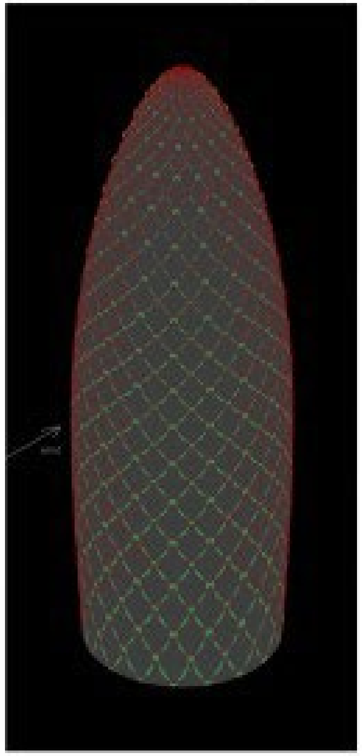
Utilization Analysis



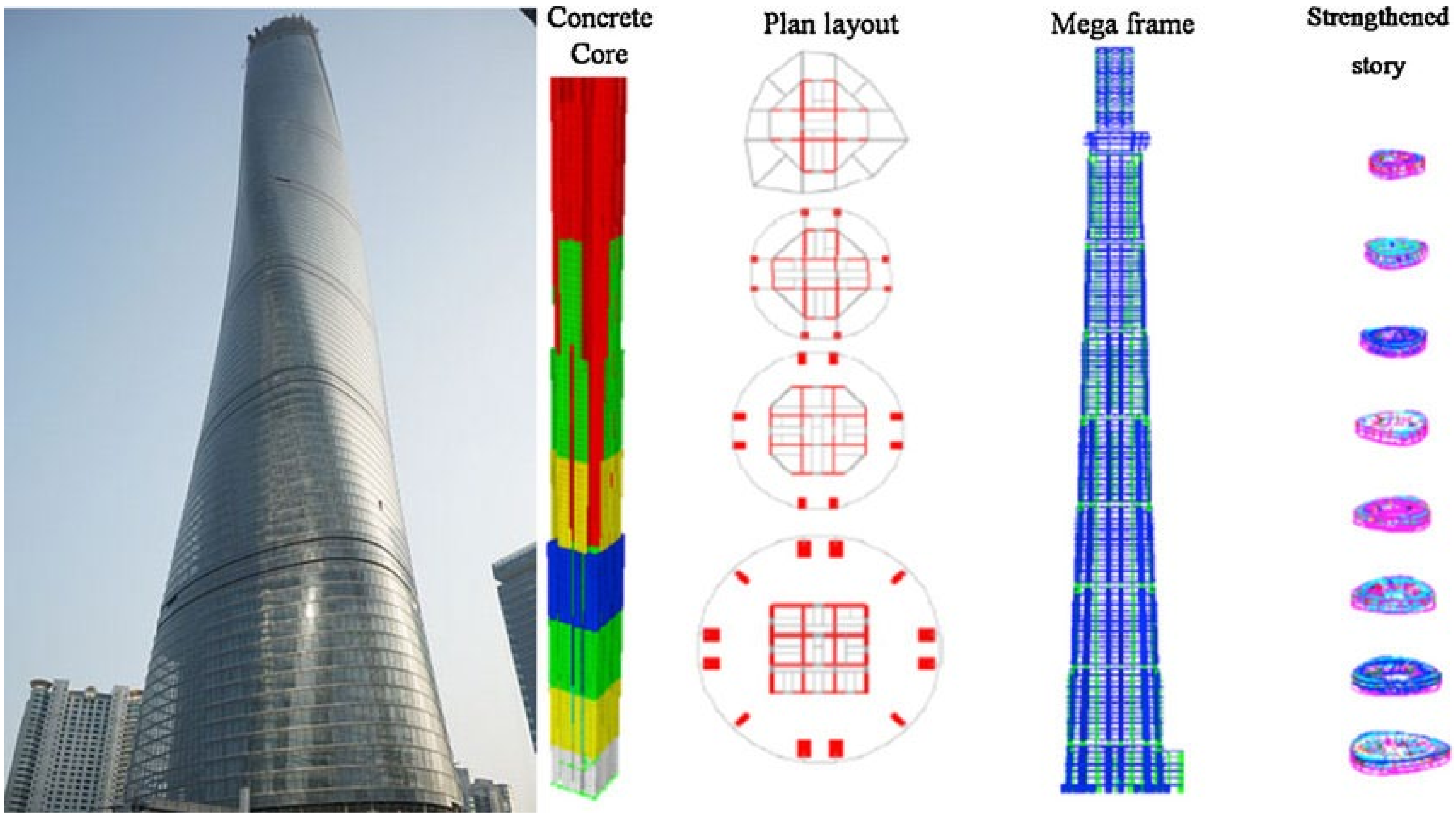
Displacement Analysis



My Analysis



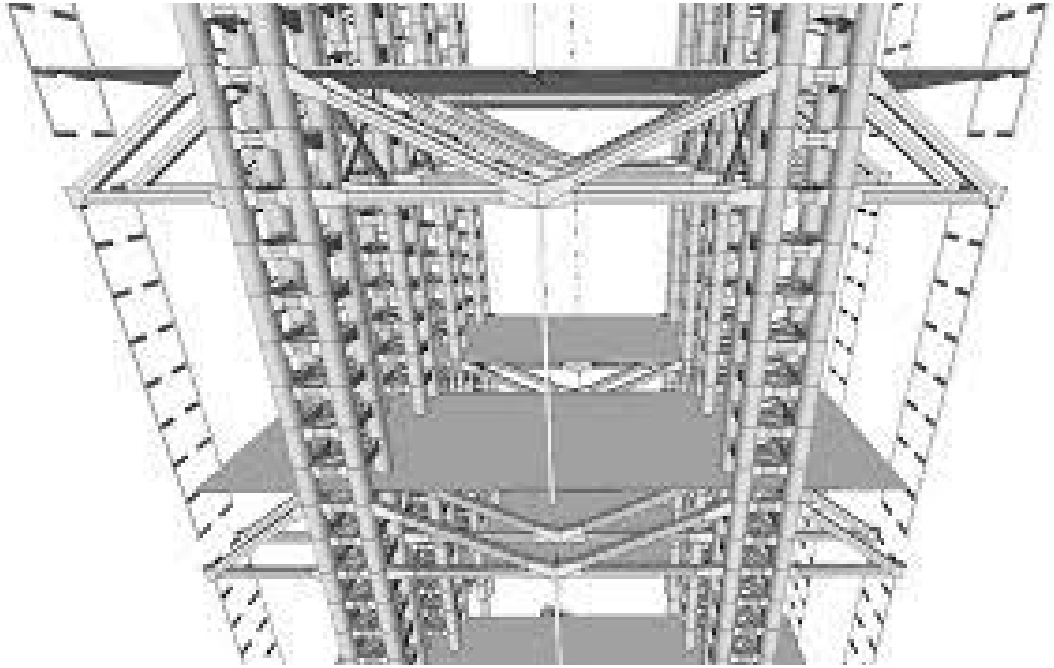
Nx Analysis



Superframe structure

Shanghai Tower

Using mega columns and mega girders to work together as the primary lateral resisting structural system.



Superframe structure

HSBC headquarters, HK

2.3. STRUCTURAL STRATEGY

- Material based
- Tall building structural system

Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

Classifications based on the materials:

Structural materials such as columns, beams, shear trusses, shear walls and outriggers

1. Steel: superiority for high-rise buildings
2. Reinforced concrete: the ability to be cat in any form, much greater natural resistance to fire compared with steel, and naturally better in dampening wind induced building sway. Concrete pumping technology.
3. Composite

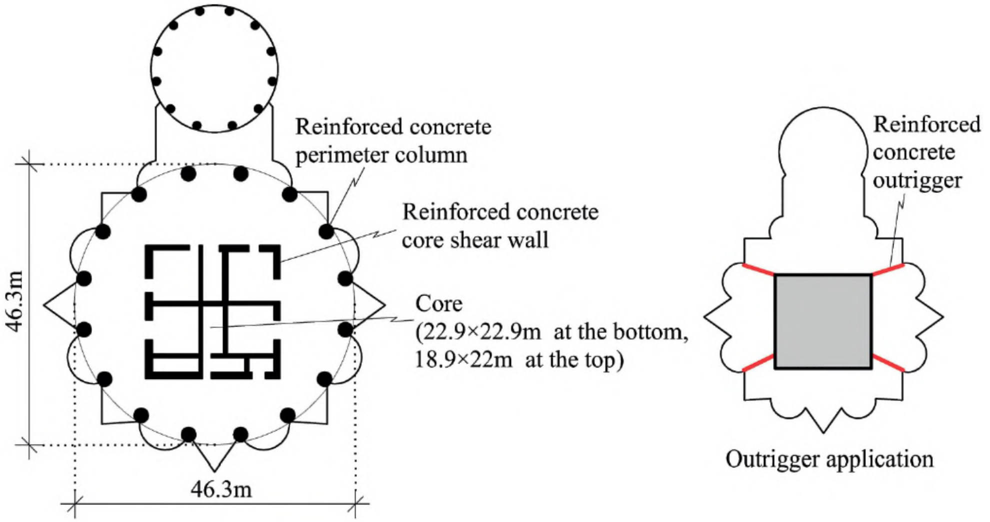


FIGURE 3.31 The Petronas Twin Towers, Kuala Lumpur, Malaysia, 1998

Tallest RC building in 1998

Petronas Twin Towers

Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

Structural systems

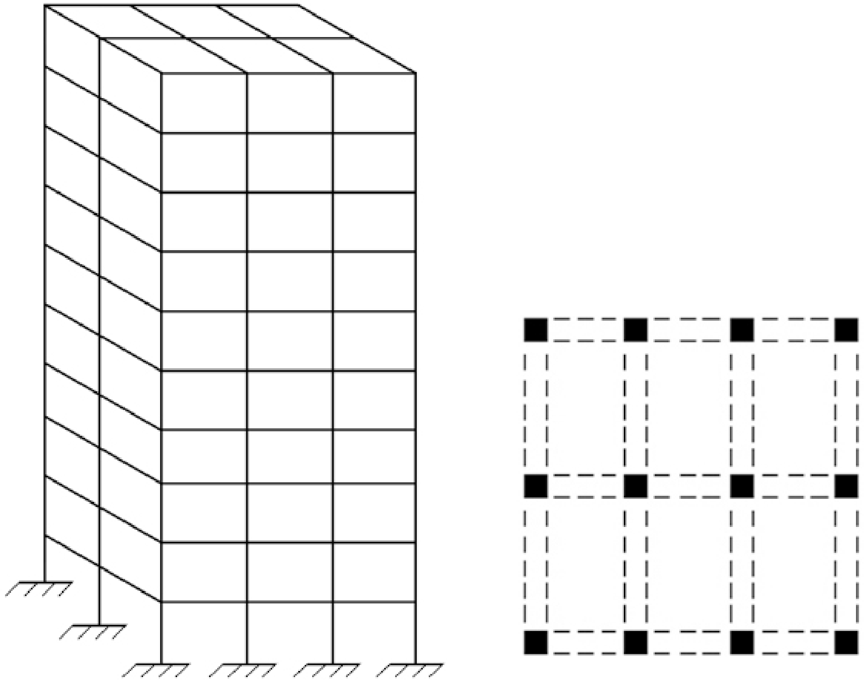
1. Rigid frame systems
2. Flat plate/slab systems
3. Core systems
4. Shear wall systems
5. Shear-frame systems
   - shear trussed frame (braced frame) systems
   - shear walled frame systems
6. Mega column (mega frame, space truss) systems
7. Mega core systems
8. Outriggered frame systems
9. Tube systems
   - framed-tube systems
   - trussed-tube systems
   - bundled-tube systems

TABLE 3.1 Tall building structural systems and the number of floors they can reach

Tall building structural systems, and tentatively the number of floors they can reach efficiently and economically	*10*	*20*	*30*	*40*	*>40*
Rigid frame systems					
Flat plate/slab systems with columns and/or shear walls					
Core systems					
Shear wall systems					
Shear-frame systems (shear trussed / braced frame and shear walled frame systems)					
Mega column (mega frame, space truss) systems					
Mega core systems					
Outriggered frame systems					
Tube systems					

Günel, M. H. & Ilgin, H. E. (2014). *Tall buildings: structural systems and aerodynamic form*, Routledge.

1: Rigid frame systems



1. Rigid frame systems
2. Flat plate/slab systems
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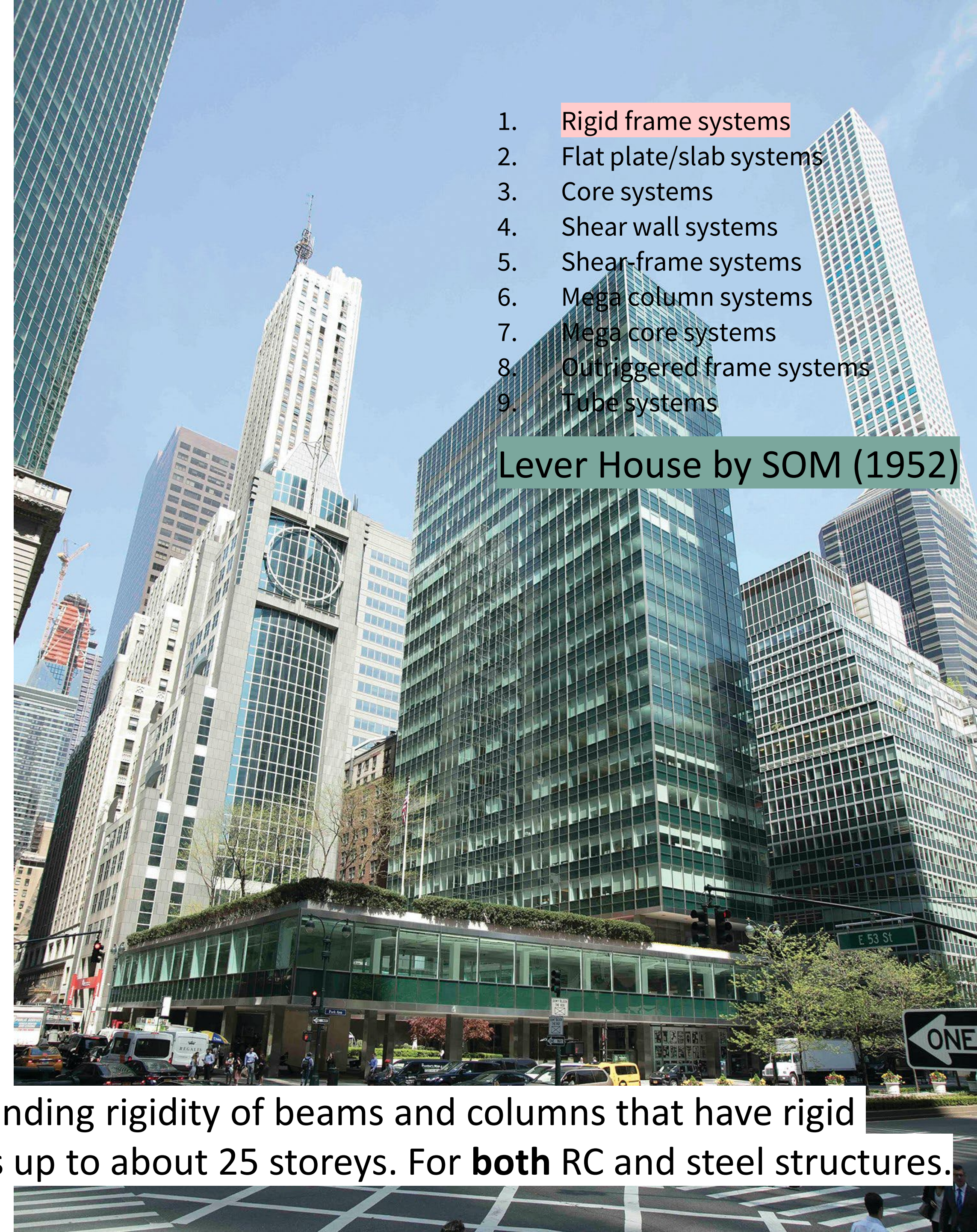
6. Mega column systems
7. Mega core systems
8. Outriggered frame systems
9. Tube systems



Lever House by SOM (1952)

Stiffness of the rigid frame is provided mainly by the bending rigidity of beams and columns that have rigid connections. The system can provide sufficient stiffness up to about 25 storeys. For **both** RC and steel structures.

2: Flat plate/ slab systems

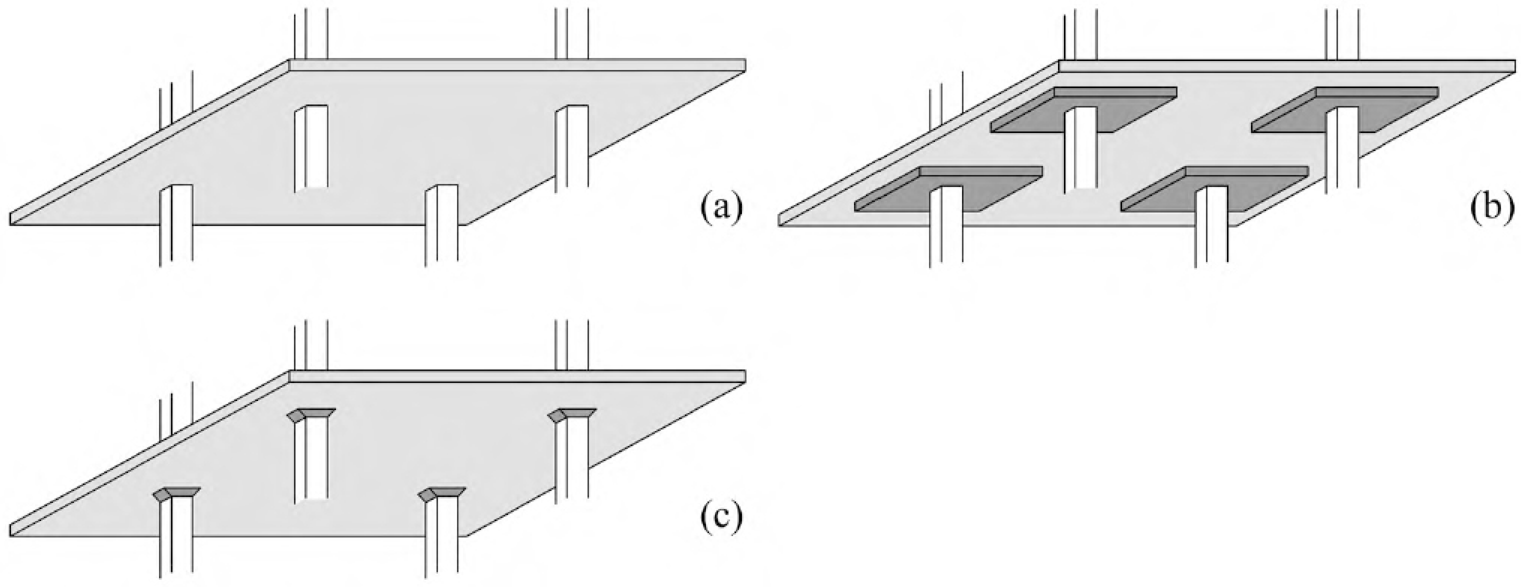
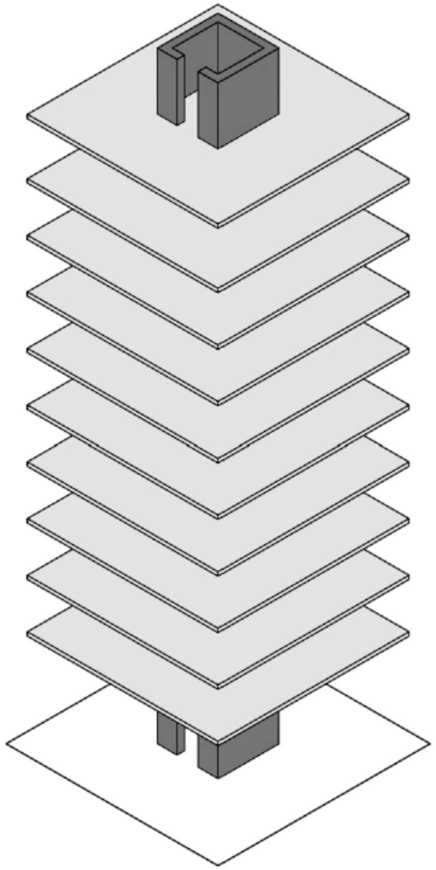
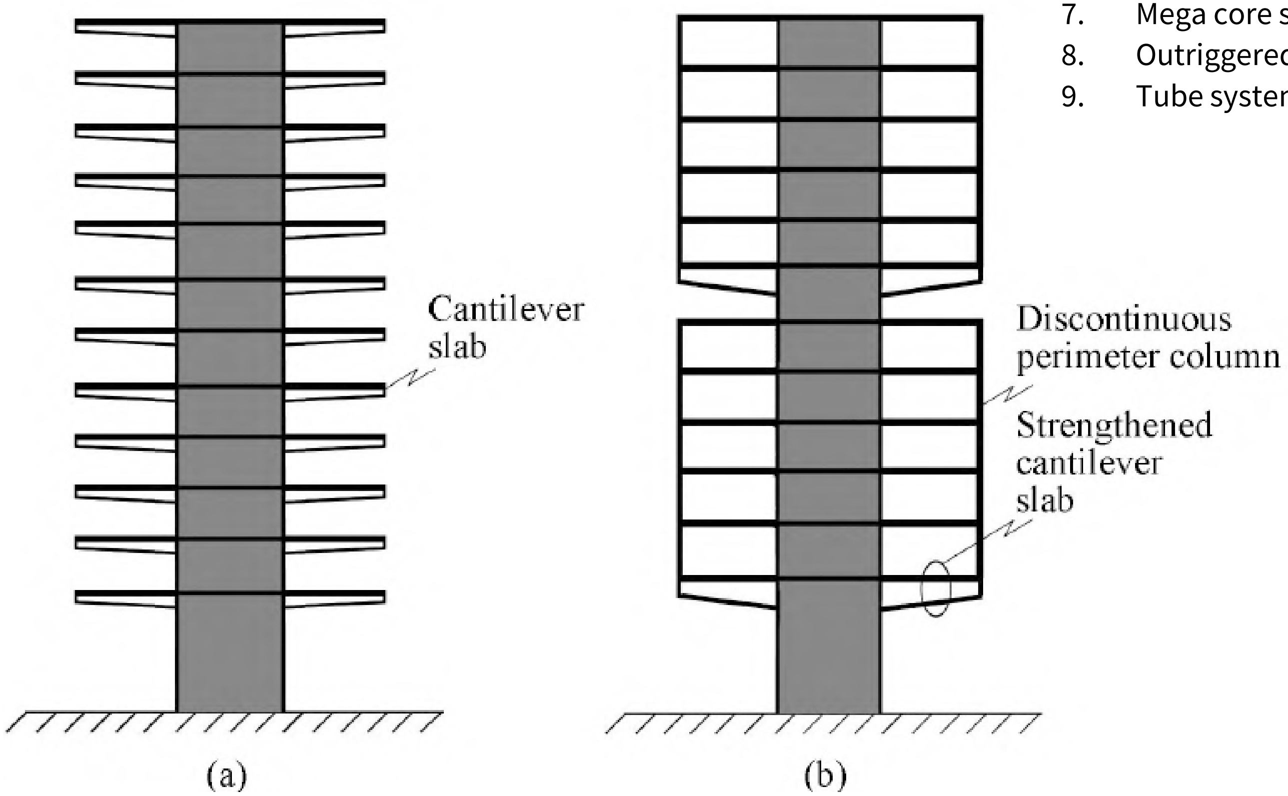


FIGURE 3.6 Flat plate/slab systems: (a) without column capitals, (b) with column capitals, (c) with gussets

The systems are used in reinforced concrete buildings. The system consists of **beamless floor slabs** of constant thickness and columns.

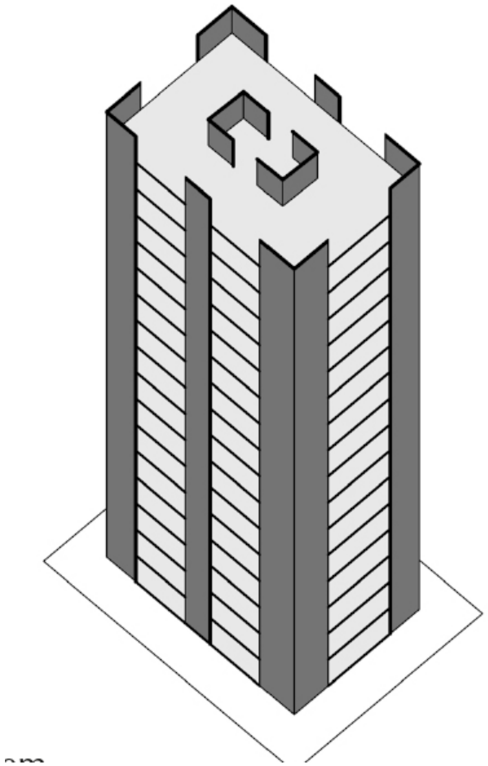
3: Core systems





Ditto with previous system, the systems are used in **reinforced concrete buildings**. The system consists of a reinforced concrete core shear wall resisting all vertical and lateral loads. Floor slabs are cantilevered from core independently. Can be used up to 20 storeys, but ‘mega core systems’ can be up to 40 storeys.

4: Shear wall systems



Ditto with previous system, the systems are used in **reinforced concrete buildings.** The system consists of a reinforced concrete ~~core~~ shear wall. Can be perforated (with openings) or solid. The system can be thought as vertical cantilever and can resist all vertical and lateral loads **without columns**. Up to 35 storeys.

5: Shear-frame systems

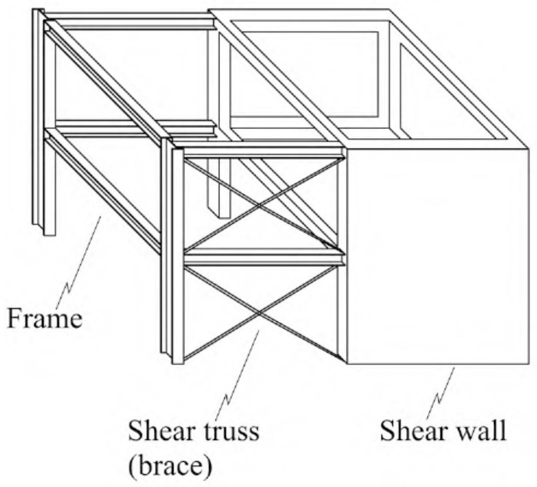


FIGURE 3.10 Rigid frame, shear truss (brace), and shear wall

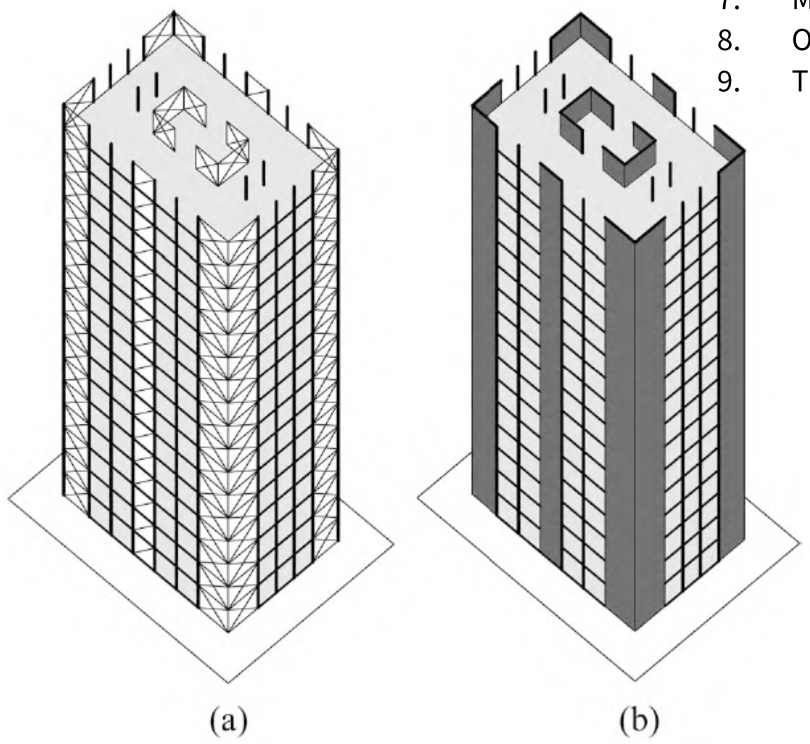
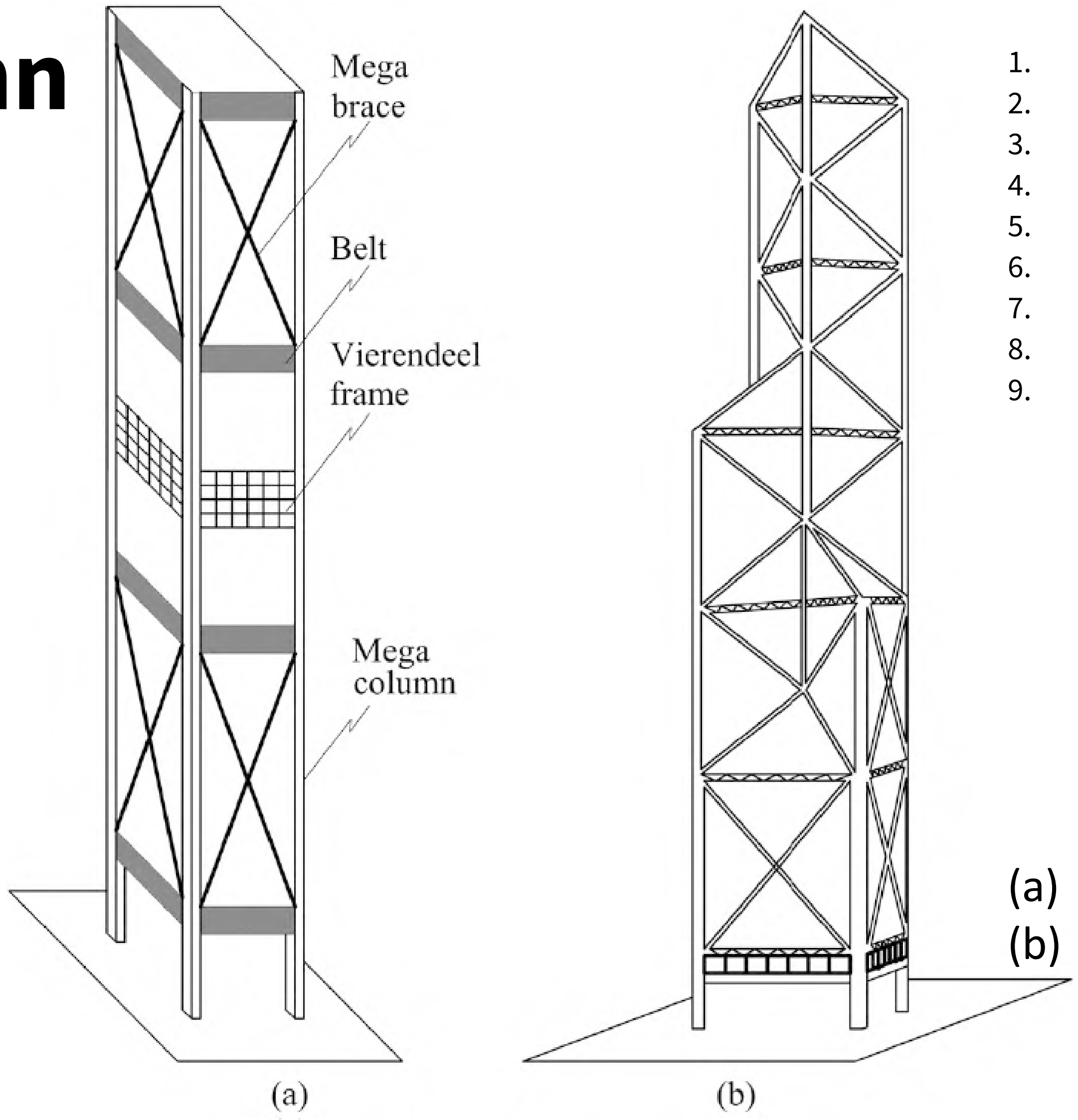


FIGURE 3.11 (a) Shear trussed frame (braced frame) system, (b) shear walled frame system

Rigid frame systems + **vertical shear trusses** (braces) and/or **shear walls**, to increase total stiffness and economical height of the building.

6: Mega column systems



(a) Mega column
(b) Space truss

Consist of reinforced concrete or composite columns and/or shear walls with much larger cross-sections than normal. Horisontal connections are of primary importance. Due to probable insufficient floor slabs; belts, Vierendeel frames and mega braces are used.

7: Mega core systems

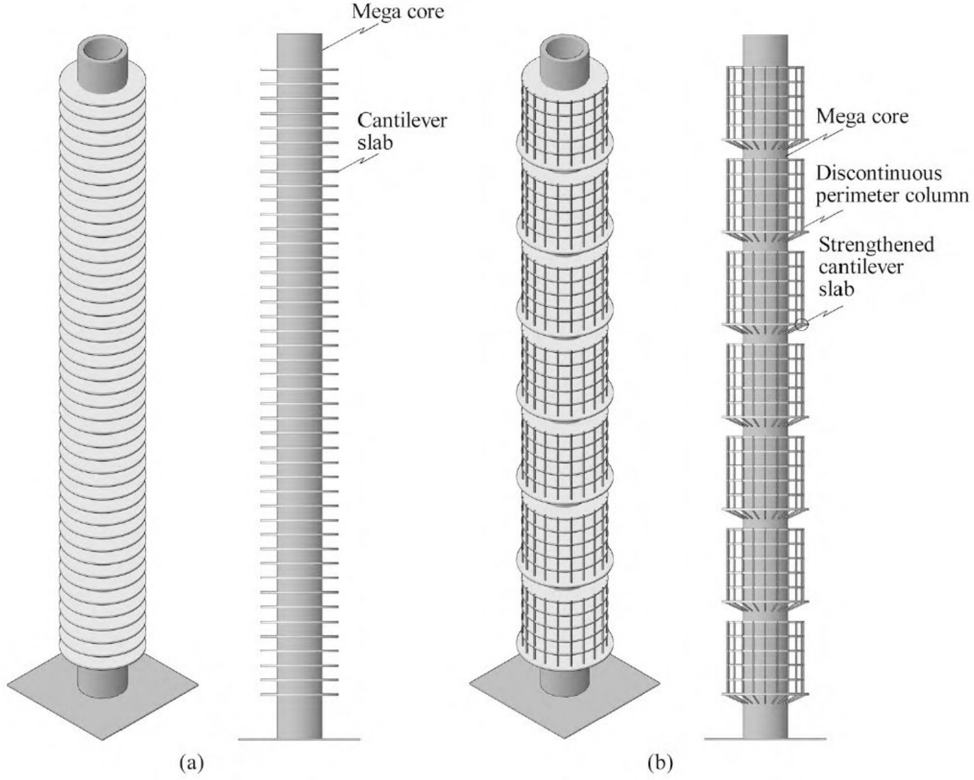


FIGURE 3.25 Slabs in the mega core system: (a) cantilever slab, (b) supported cantilever slab

FIGURE 3.26 Aspire Tower, Doha, Qatar, 2006
(credit for Photo: CTBUH)

Consist of reinforced concrete or composite core shear walls with much larger cross-sections than normal. Since mega core can resist all vertical and lateral loads in this system, there is no need for columns or shear walls on the perimeter of the building. Floor slabs are cantilevered.

8: Outrigged frame systems

1. Rigid frame systems
2. Flat plate/slab systems
3. Core systems
4. Shear wall systems
5. Shear-frame systems
6. Mega column systems
7. Mega core systems
8. Outriggered frame systems
9. Tube systems

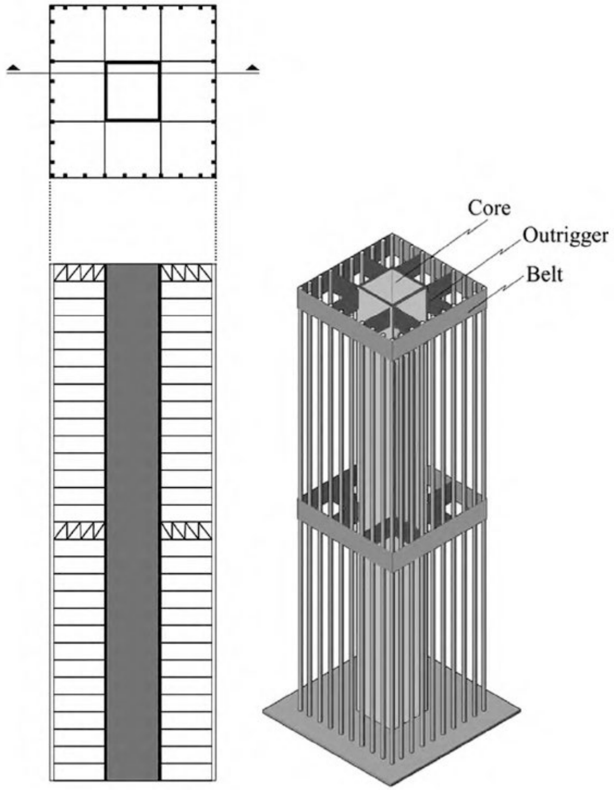


FIGURE 3.29 Outriggered frame system

Additional outriggers to shear—frame systems with the core so as to couple the core with perimeter (exterior) columns. An outrigger consists of a horizontal shear truss or shear wall (or deep beam). For building >40 storeys. Can be concrete or steel outriggers.

8: Outrigged frame systems

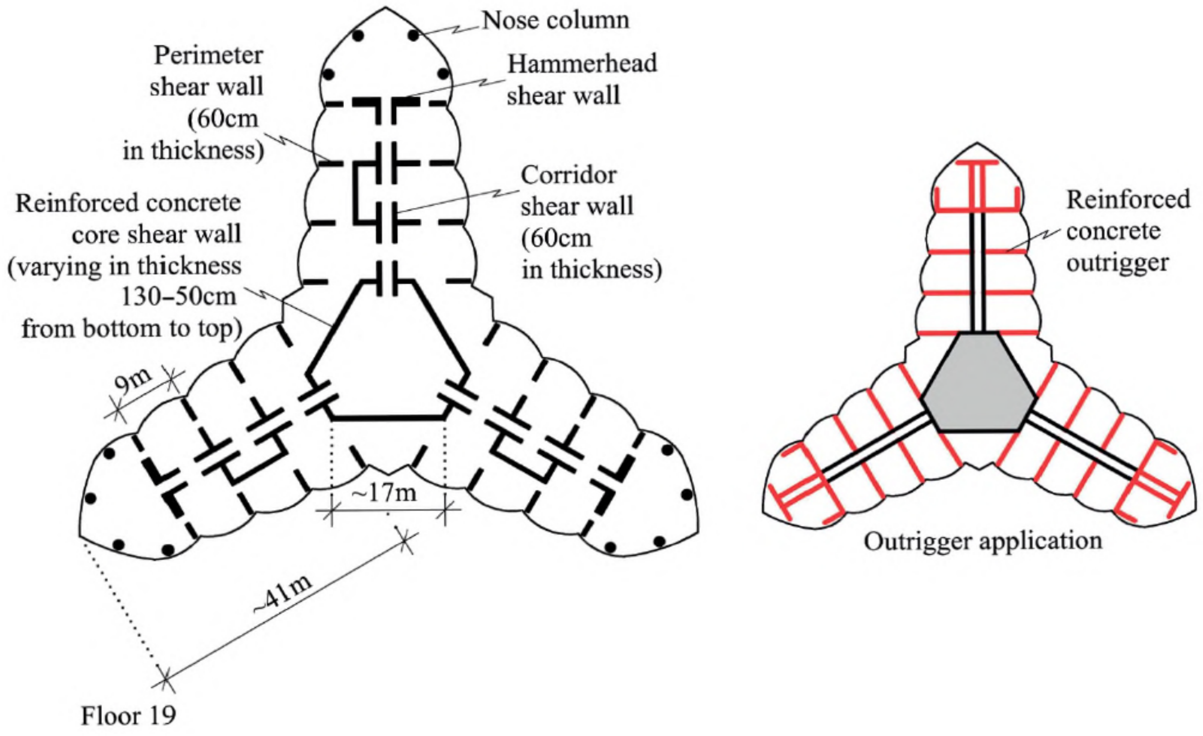


FIGURE 3.30 Burj Khalifa, Dubai, U.A.E, 2010
(photo courtesy of Adrian Peret, adrian.peret@gmail.com)

RC outriggers

8: Outrigged frame systems

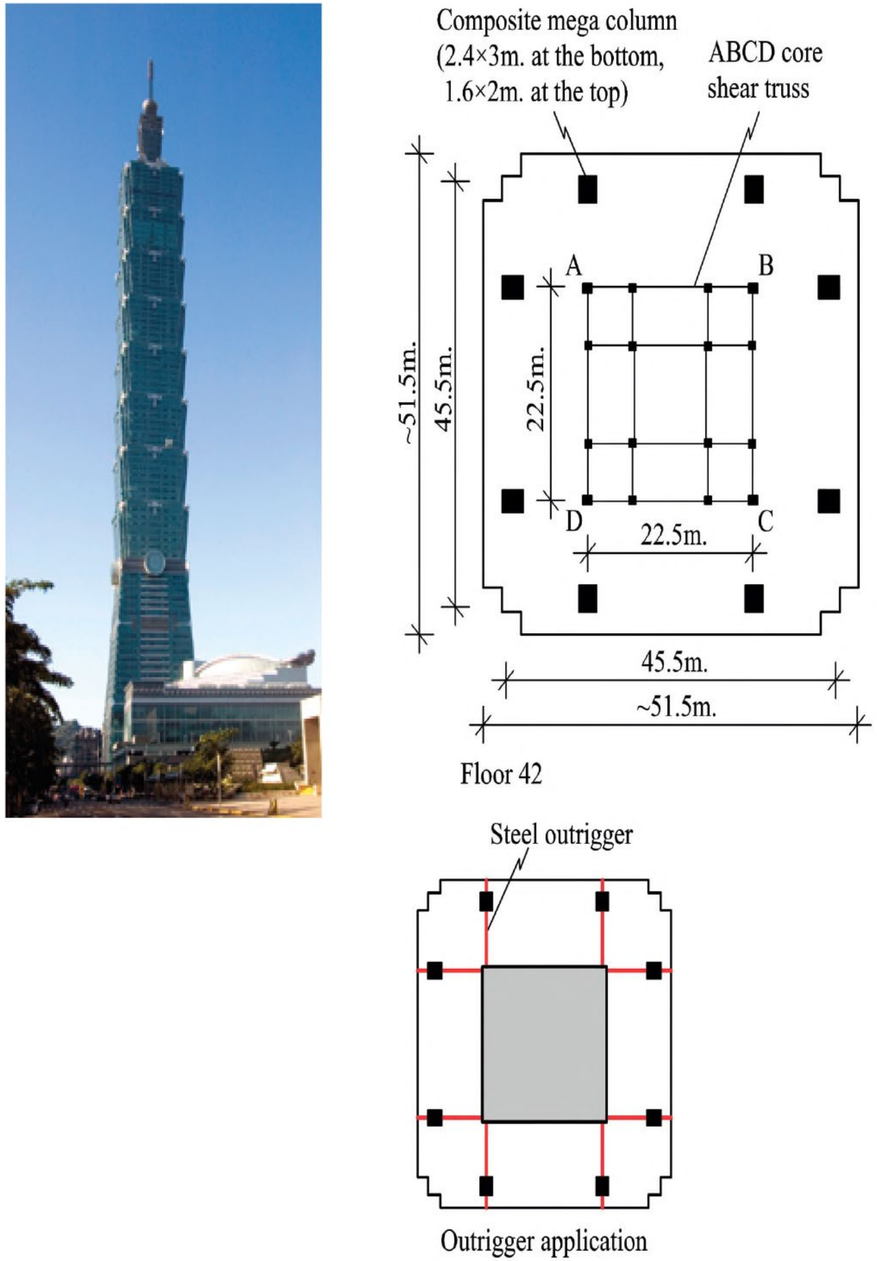


FIGURE 3.36 Taipei 101, Taipei, Taiwan, 2004

Steel outriggers

9: Tube systems

- framed-tube systems
- trussed-tube systems
- bundled-tube systems

Was innovated in the early of 1960s by structural engineer Fazlur Rahman Khan, who is considered as 'father of tubular design'. It is a system in which a hollow box column is cantilevering from the ground, and so the building exterior exhibits a tubular behaviour against lateral loads. Suitable for >40 storeys.

9: Tube systems

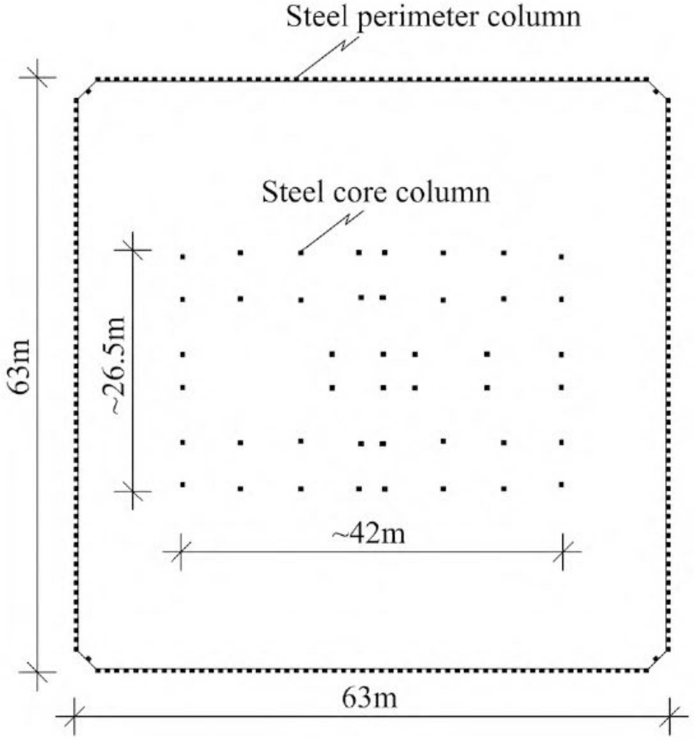
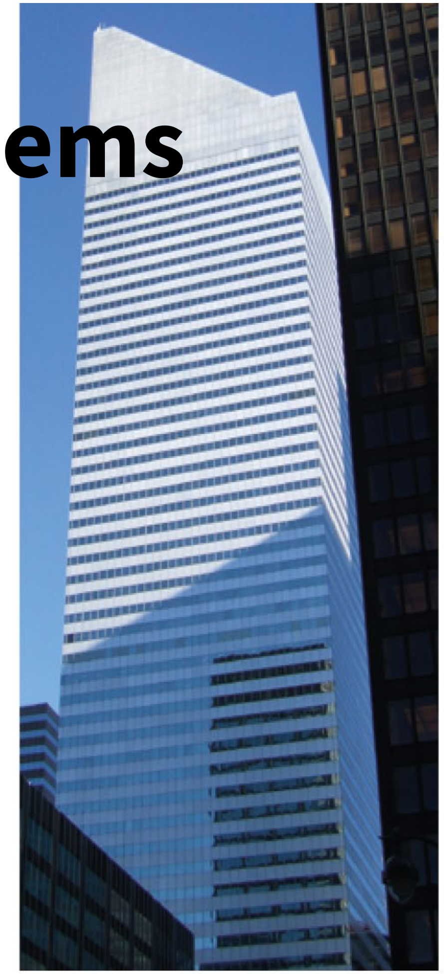


FIGURE 3.55 World Trade Center Twin Towers, New York, USA, 1972

110 storey WTC New York

Framed- tube system

9: Tube systems



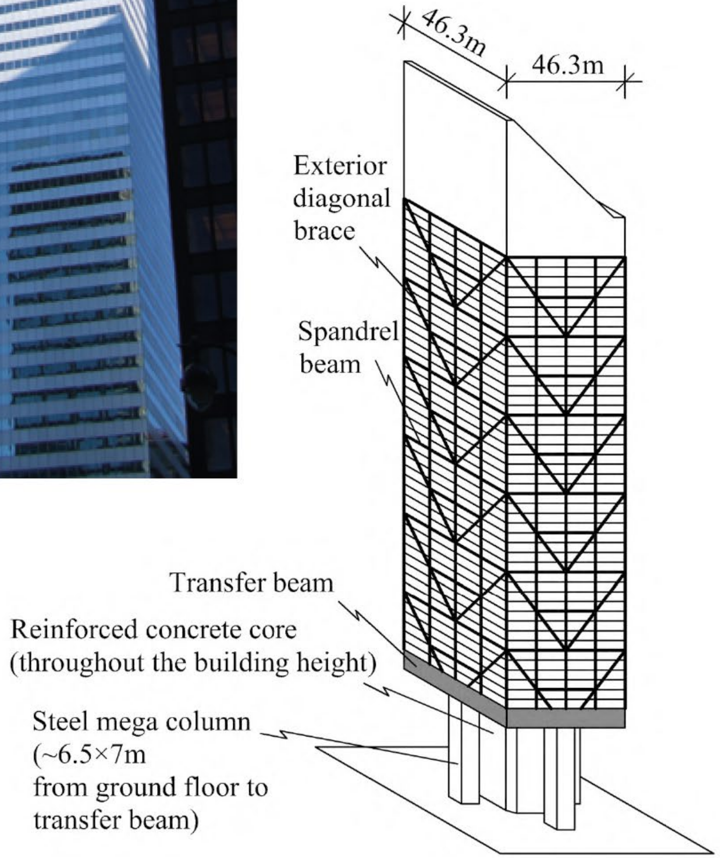
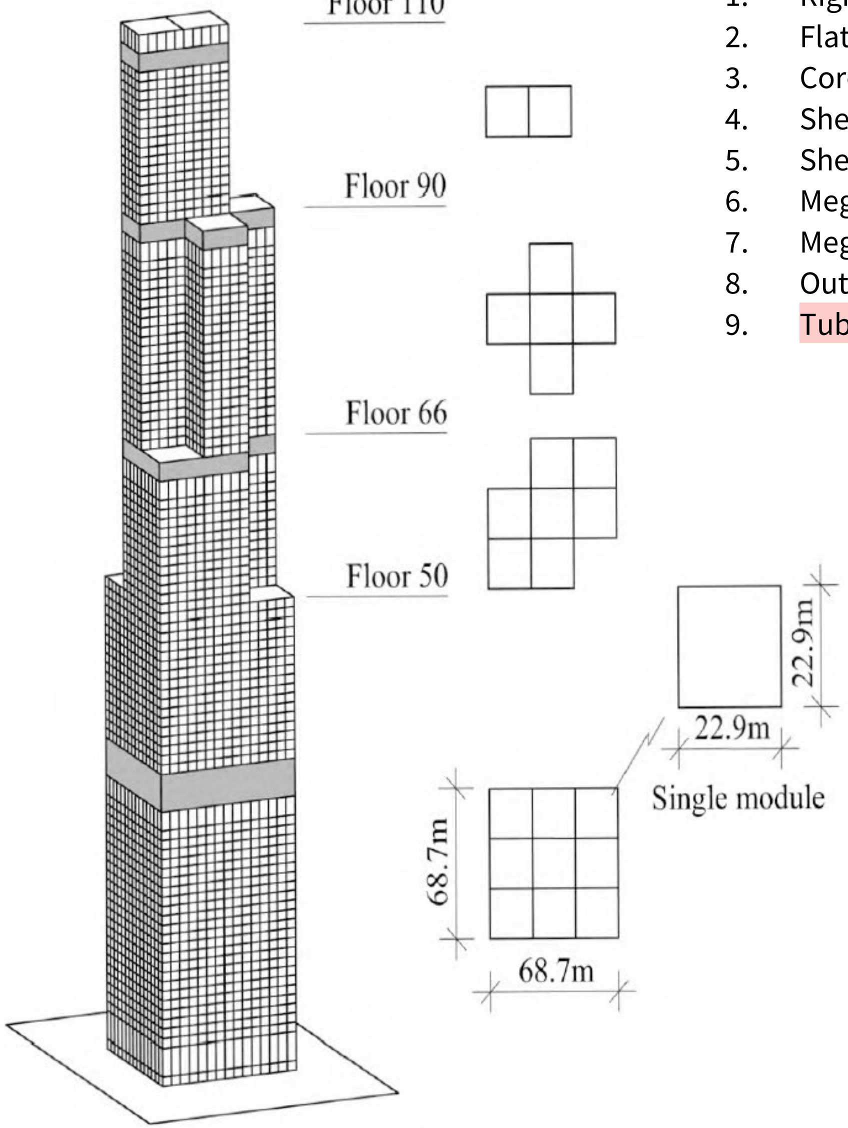


FIGURE 3.66 Citigroup Center, New York, USA, 1977

Trussed- tube system

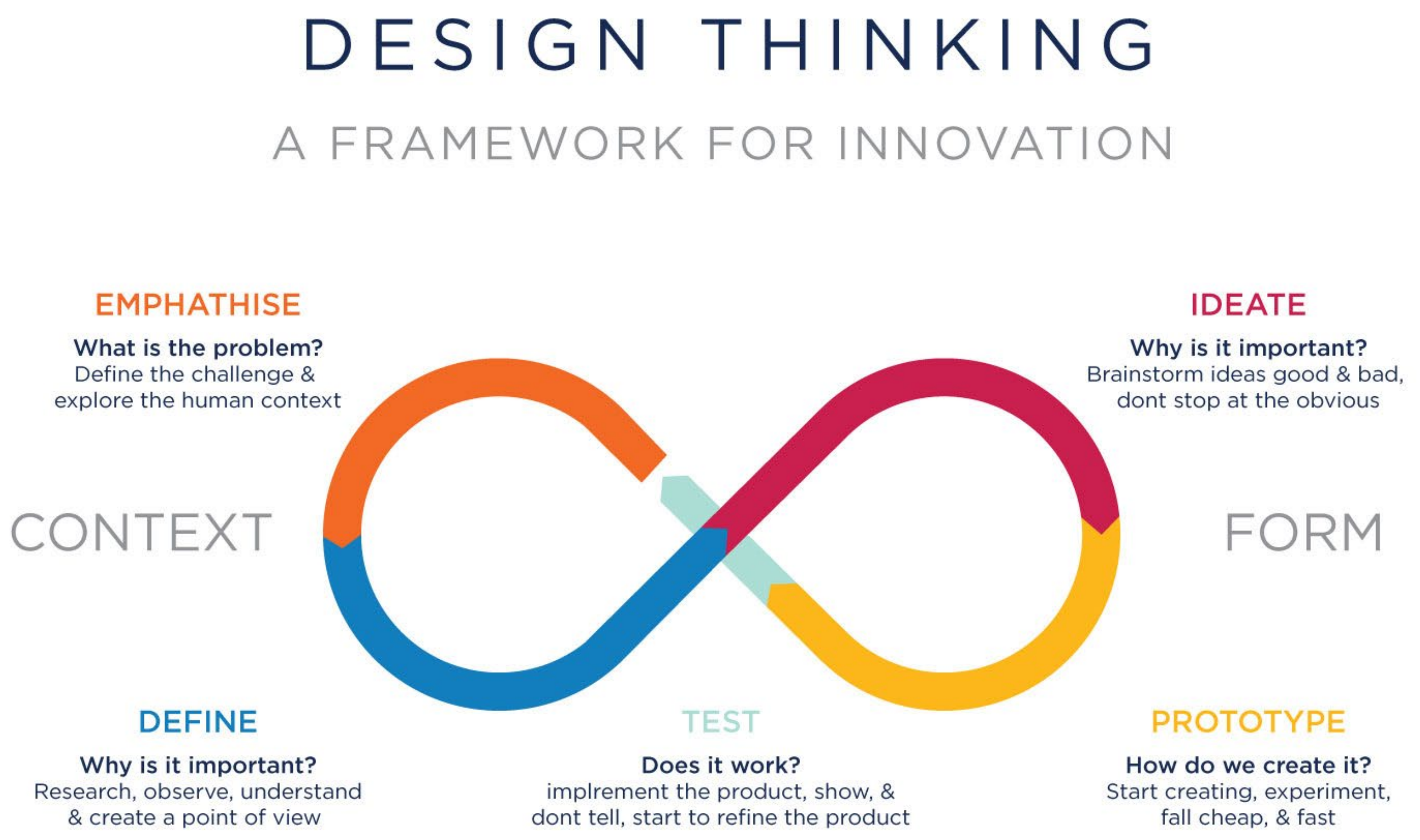
9: Tube systems



Bundled- tube system

FIGURE 3.73 Willis Tower, Chicago, USA, 1974
(photo courtesy of Antony Wood/CTBUH)

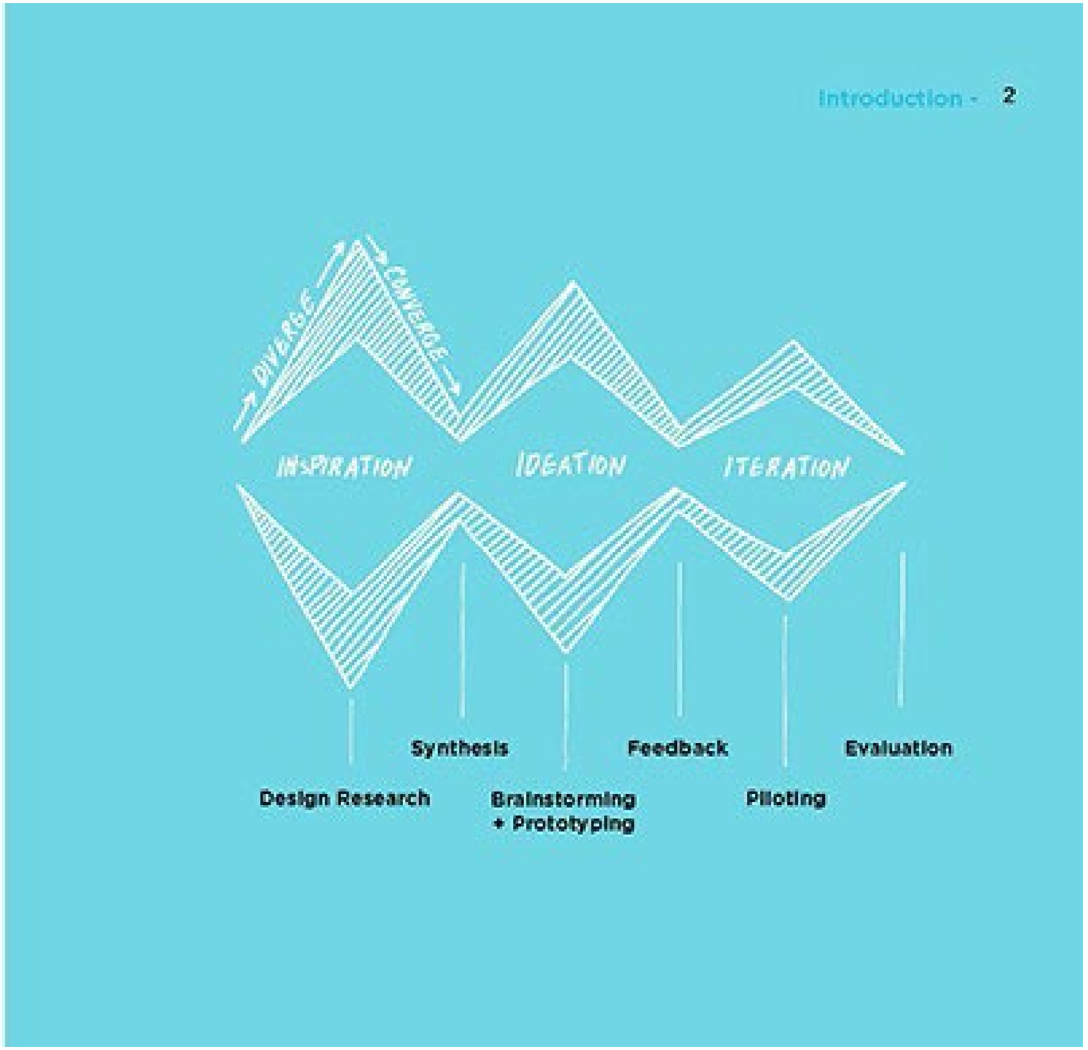
2.4. DEVELOPING A SYSTEMATIC APPROACH: WHY?



What is Human Centered Design

We use Divergent & Convergent thinking intentionally to quickly explore possibility, test insights and iterate.

openIDEO



The Process of Design Squiggle by Damien Newman, thedesignsquiggle.com

The Design Squiggle

Design guidelines

Concept Design

Simplicity of concept based on existing design perimeters (location, climate, restrictions, topography, spatial programs- look at tectonics diagram). Redefine the design brief and problems to suit your site-specific conditions.

Form finding

Form which answers design criteria and solve design problems . Look at many design precedents with similar design characters. Analyse them to inform your main structural elements. Outcomes: general form and structural elements. Engaging tectonic thinking means these two go hand-in-hand.

Test out main structural elements

Structural clarity. As a rule of thumb practice, make a 3D physical model to test the stiffness. Just the main structure system. You can rock your model to analyse your structure. Add or remove structural elements in your physical model, if necessary, until your test is satisfactory

Architectural language

Once your structural system is sound, you can explore the architectural characteristics. If major changes happen, repeat the previous step and make 3D model again. If you can't perform digital structural analysis, refrain from making digital model before you do a physical model. Also it is worth looking at Mechanical and Electrical system.

Optimisation

At this point you can add layers of other analysis, such as environmental analysis, spatial analysis, life cycle analysis, sustainability analysis etc. M&E system can potentially be optimised or partially integrated with structural system. For instance, service shafts by the elevators core.

Final design

At this stage you will already have a structurally sound design (you are very sure that it will stand against loads with sufficient system), architecturally sound and have been optimised according to clients' need or the design brief.

Part 3: Low-rise VS high-rise structure

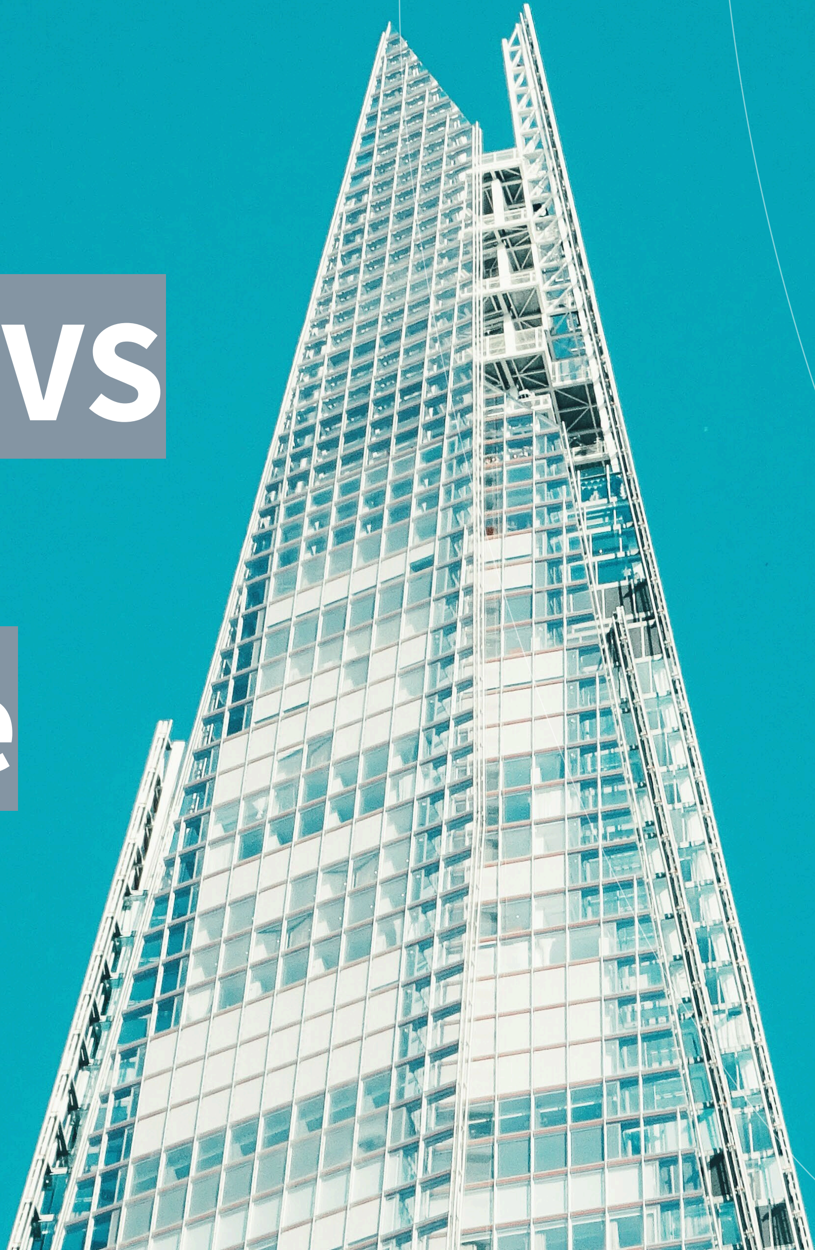
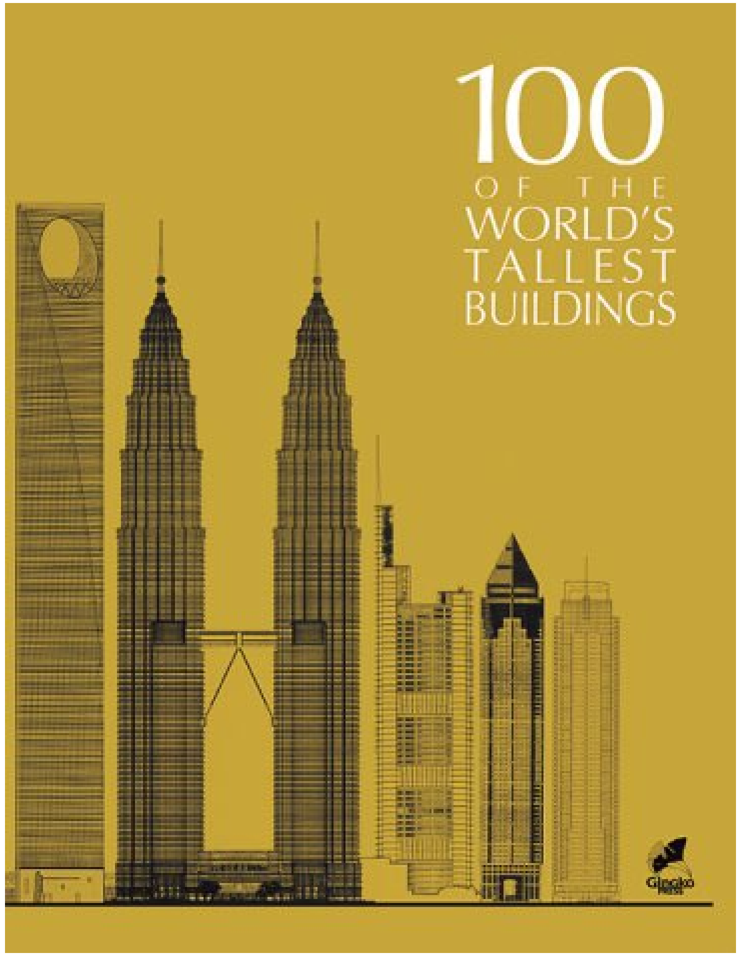
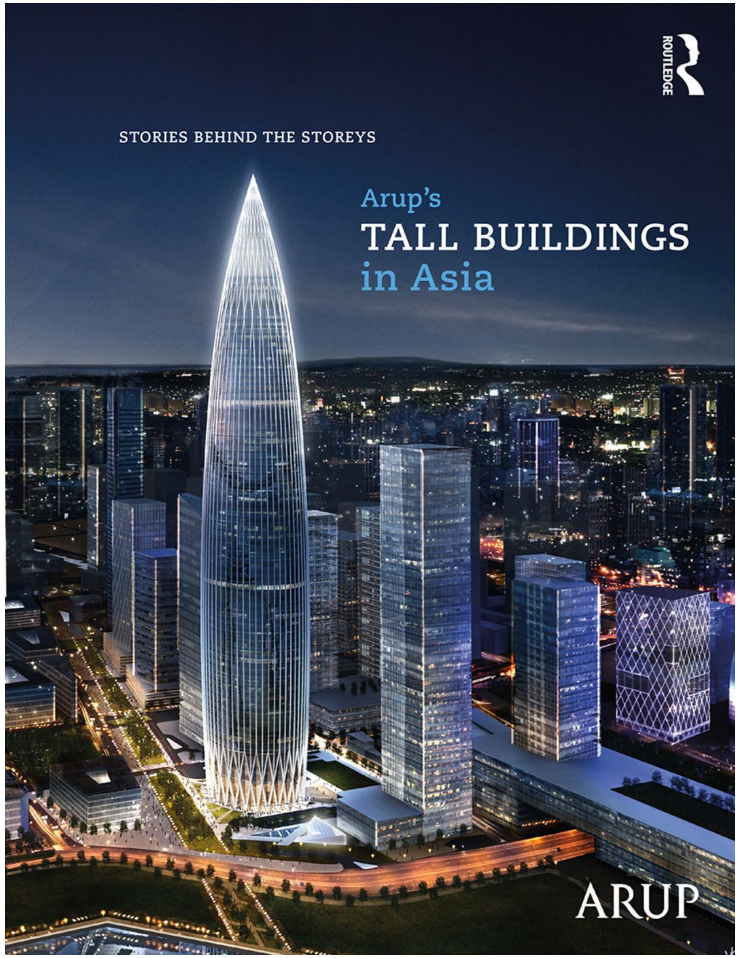


Photo by Sebastian Grochowicz on Unsplash





Žaknić, I. (1998). *100 of the World's Tallest Buildings*, Images Publishing
Ho, G. W.-M. (2017). *Arup's Tall Buildings in Asia: Stories Behind the Storeys*, Routledge.

Activity 3: ENGAGEMENT TASK

https://miatedjosaputro.com/2022/04/02/as-week-13-2/

1. Find one built project (high-rise building) as a design precedent
2. Explore the main structural system
3. Make your own (honest) **summary** regarding the structural system, approximately 300 words
4. Next, make **reflections** on what are the differences between designing high-rise building and low-rise building, from the point of view of an architect.
5. *Think about how would you approach a new high-rise project, in comparison to a low-rise project*
6. Submit: 1) summary and 2) reflections via **Disqus**

SPEND

40 MINS

+ HOMEWORK

Re-iterating aims and objectives

- To provide a snapshot of what we have learnt from Week 1
- To contextualise differences between low-rise and high-rise structure
- To gain understanding on structural considerations in different scope of project