AIT Technology Event

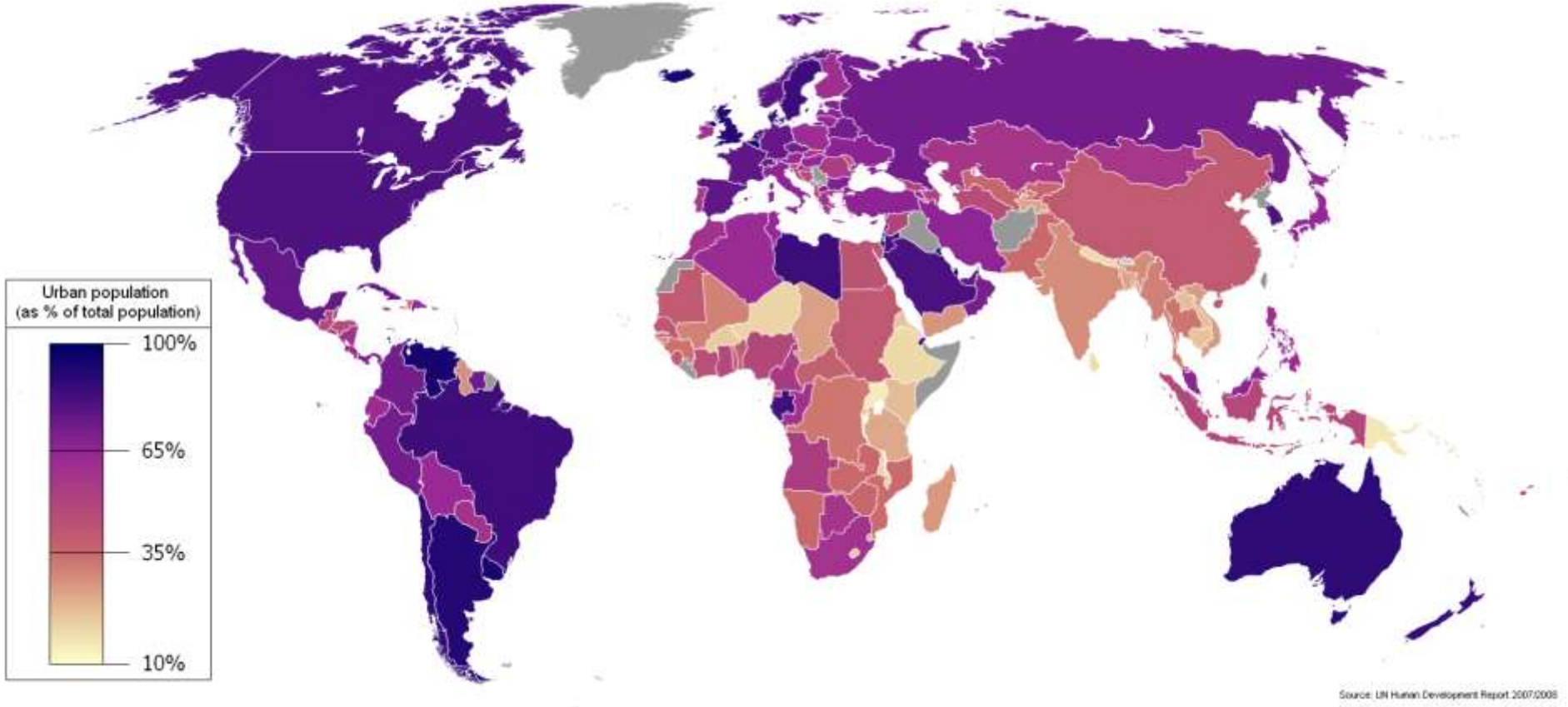
Designing and Constructing Tall Buildings for Higher Cost Effectiveness and Performance

Dr. Naveed Anwar

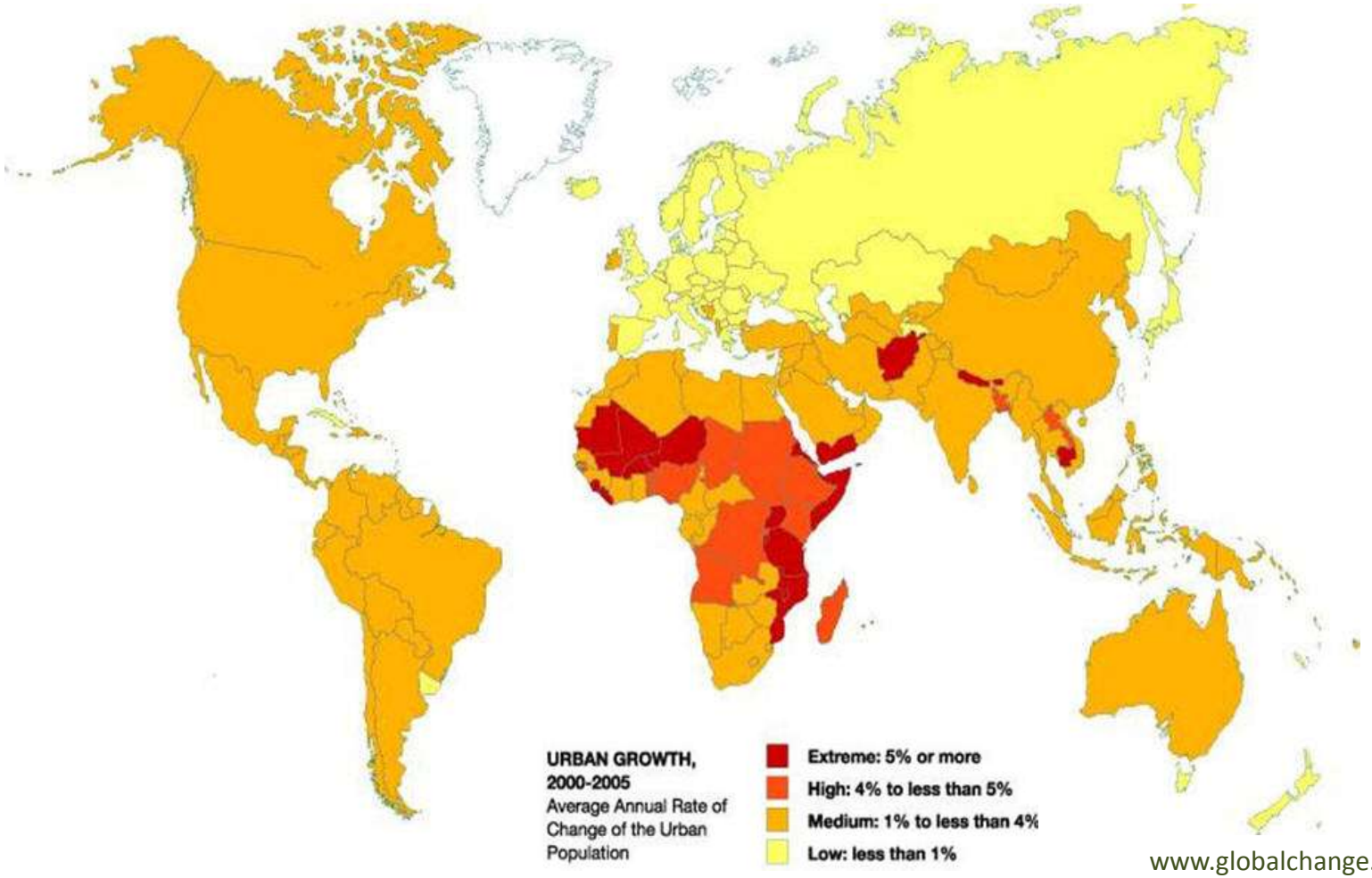
AIT
Asian Institute of Technology

Tall Buildings – The Need

Percentage of Urbanized World

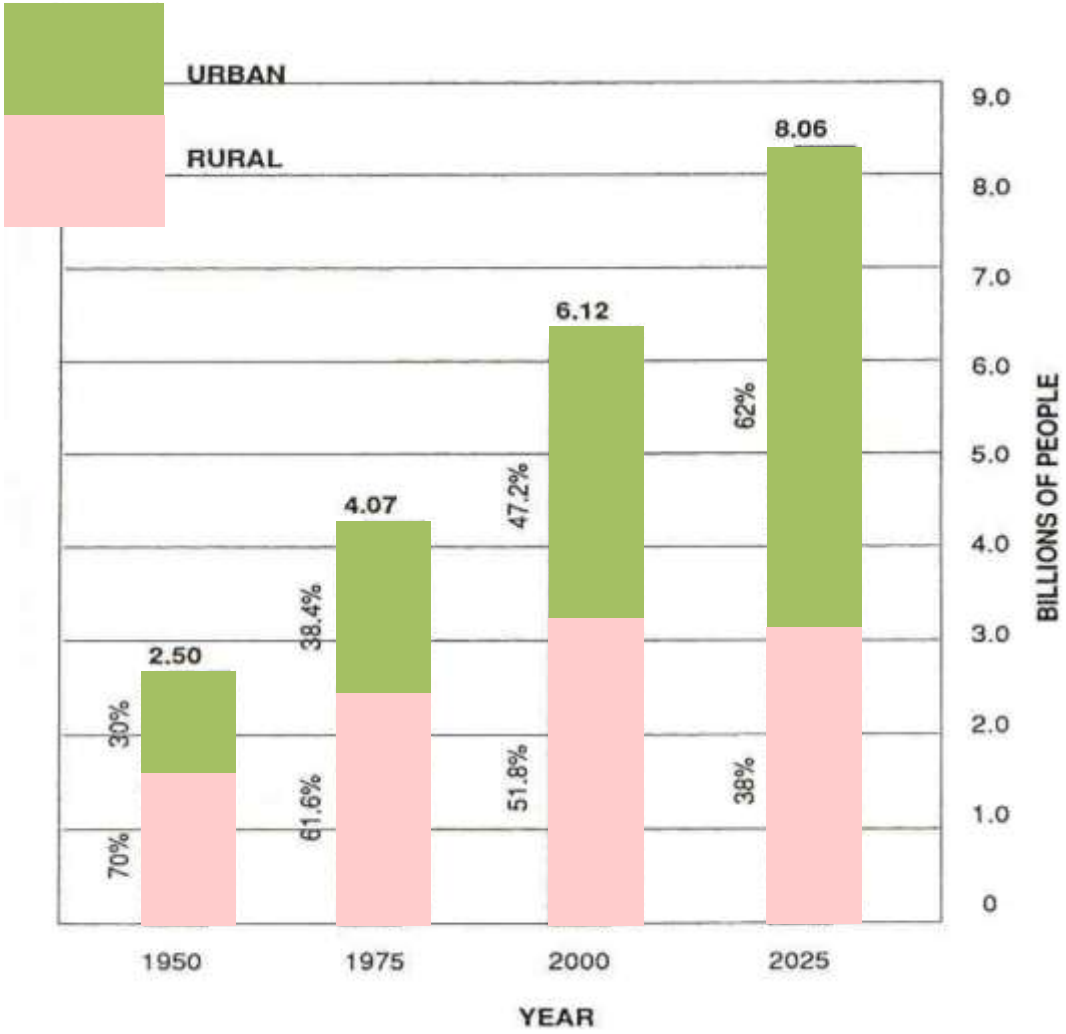


Rate of Urban Population Growth



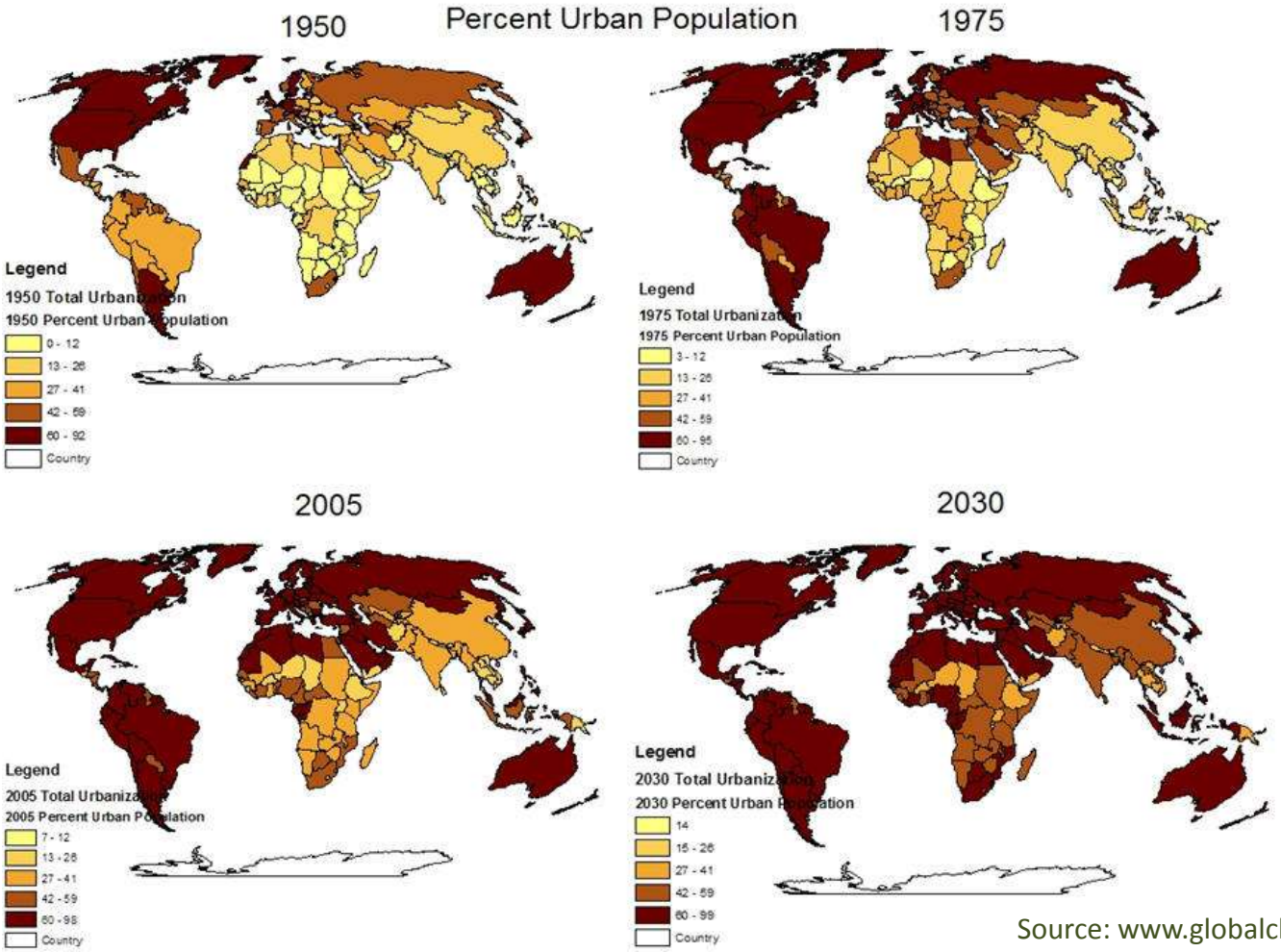
www.globalchange.umich.edu

World's Population Urban-to-Rural Ratio



(www.un.org)

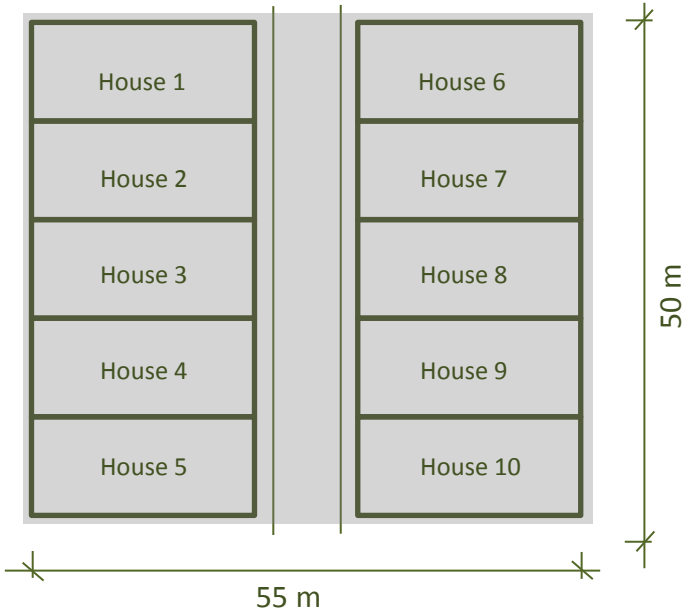
Urbanization - Future Trends



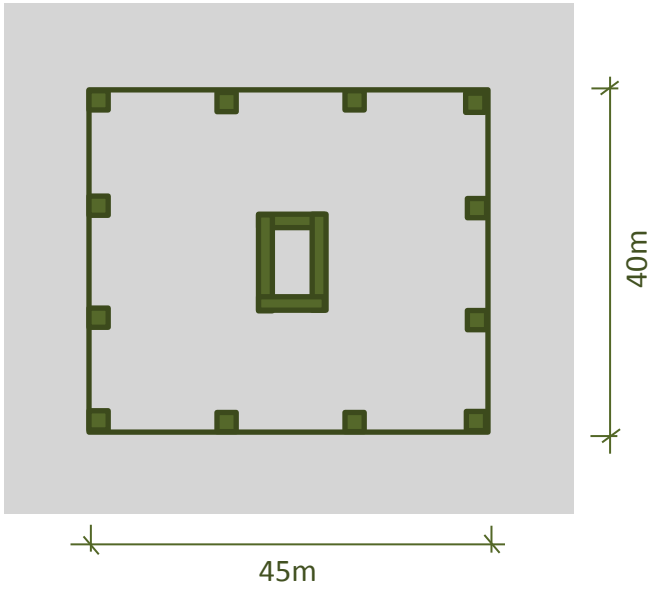
Source: www.globalchange.umich.edu

Urbanization → Growing Needs for built-up space

Why Tall Buildings?



Versus

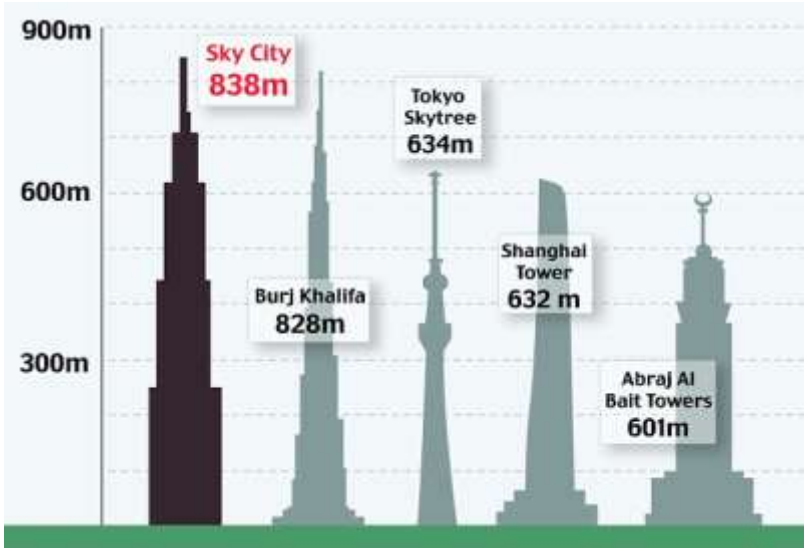


Single Family Dwelling
(Accommodating 10 Families)

A 40 story Tall Building on almost same area
(Accommodating up to 200 Families)

The Case of London

Sky City (Changsha, China)



Height	838 m
Floor count	220 total
Construction to be done in 7 months	

Systems and Components

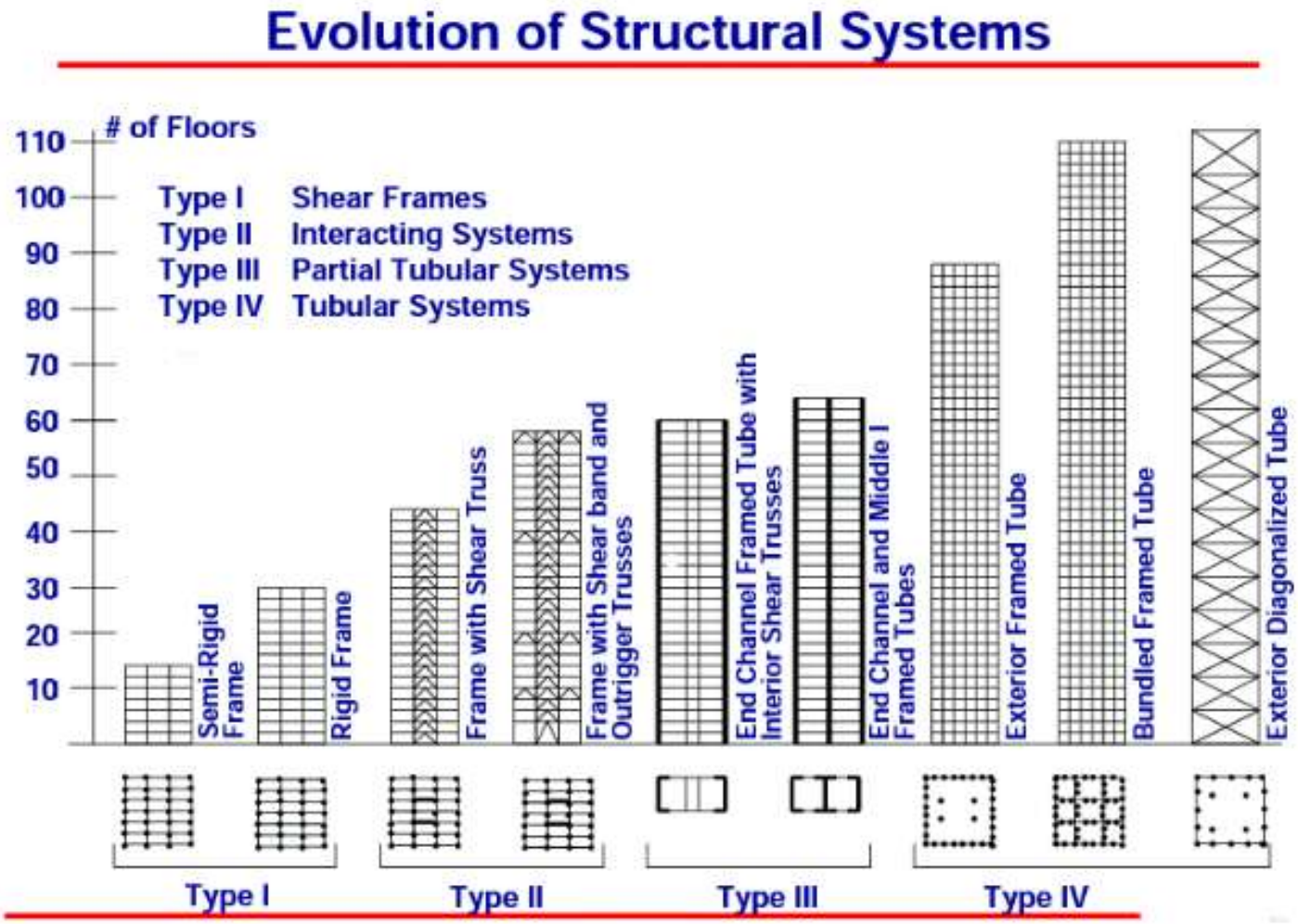
Building Systems

- **Building is an assemblage of various Systems**
  - Basic Functional Systems and Architecture
  - Structural Systems
  - Vertical Transport Systems - Elevators
  - HVAC Systems
  - Plumbing and Drainage Systems
  - Electrical, Electronic and Communication Systems
  - Foundations Systems
  - Fire Safety Systems
  - Cladding Systems
  - Security Systems
  - Other specialized systems

The Professionals Involved

- Architects – Team Leader
- Structural Engineers
- Geotechnical Engineers
- Electrical and Electronic Engineers
- Mechanical Engineers
- Plumbing Engineers
- Construction Engineers
- Communication Engineers
- Landscape Architects
- Fire Safety Engineers
- Security Consultants

Conventional Systems

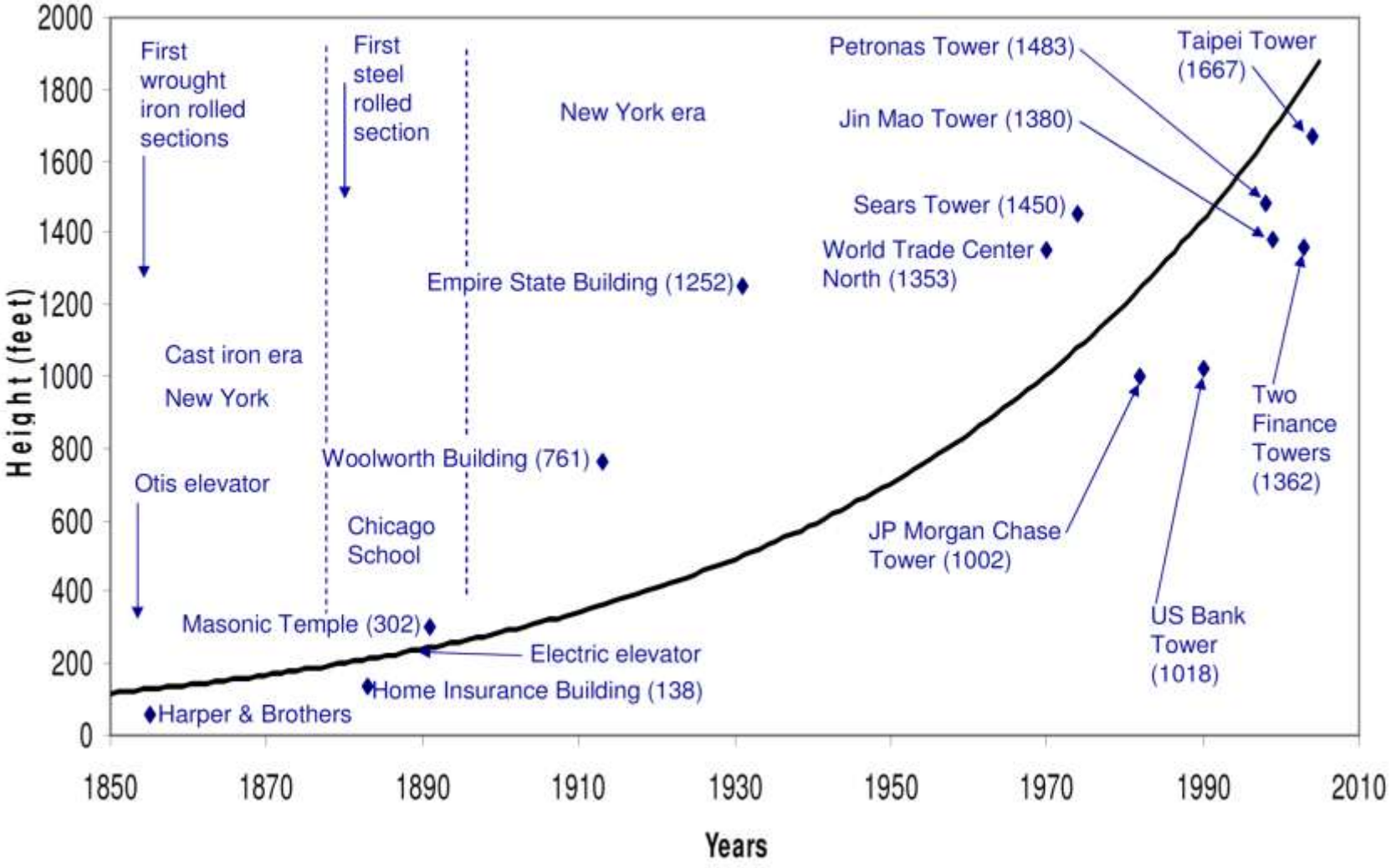


Range of Structural Systems

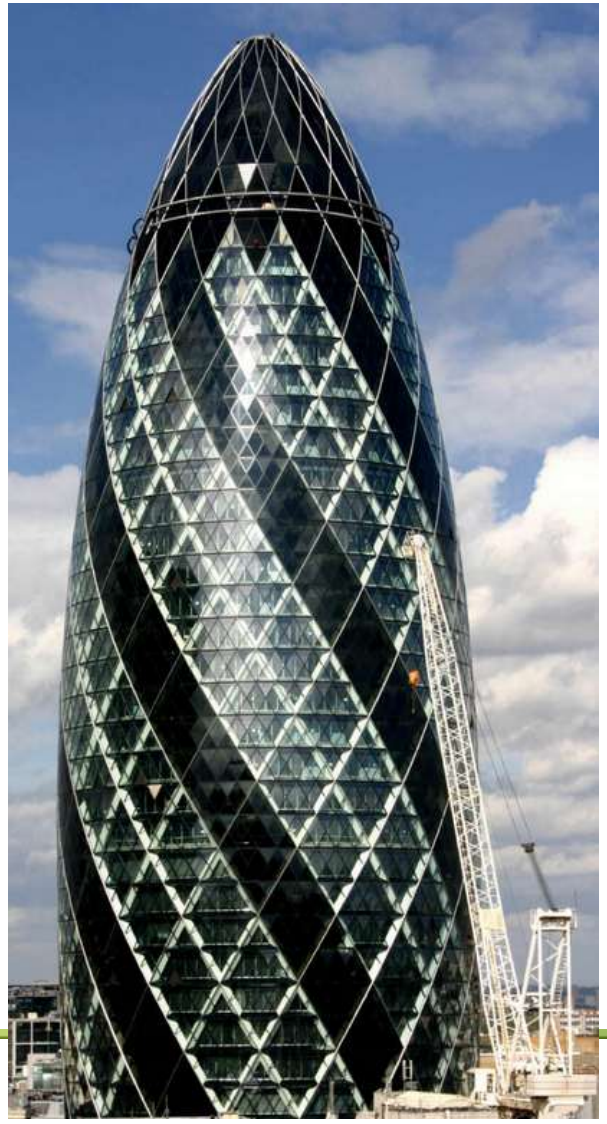
Structural systems for concrete buildings

No.	System	Number of stories 0 10 20 30 40 50 60 70 80 90 100 110	Ultra-tall buildings 120–200 stories
1	Flat slab and columns		
2	Flat slab and shear walls		
3	Flat slab, shear walls and columns		
4	Coupled shear walls and beams		
5	Rigid frame		
6	Widely spaced perimeter tube		
7	Rigid frame with haunch girders		
8	Core supported structures		
9	Shear wall—frame		
10	Shear wall—Haunch girder frame		
11	Closely spaced perimeter tube		
12	Perimeter tube and interior core walls		
13	Exterior diagonal tube		
14	Modular tubes, and spine wall systems with outrigger and belt walls		

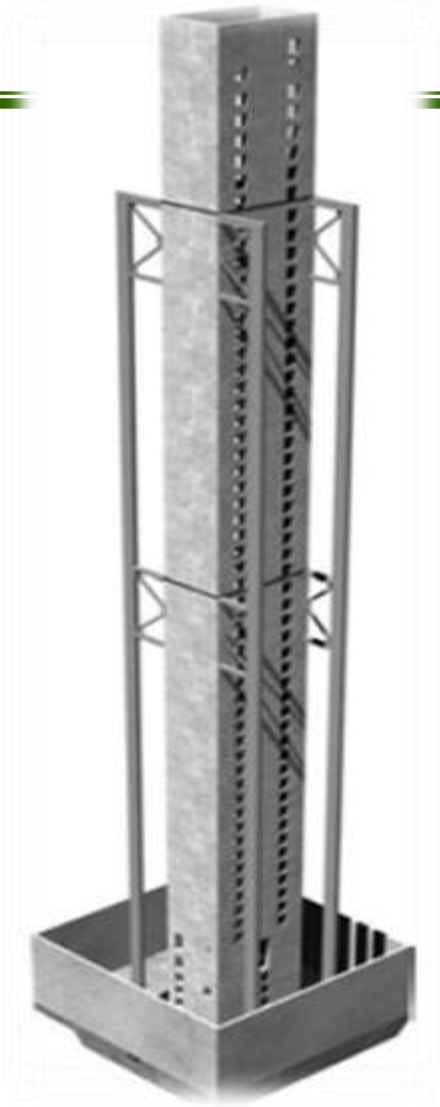
Growth in height between 1850 and 2005

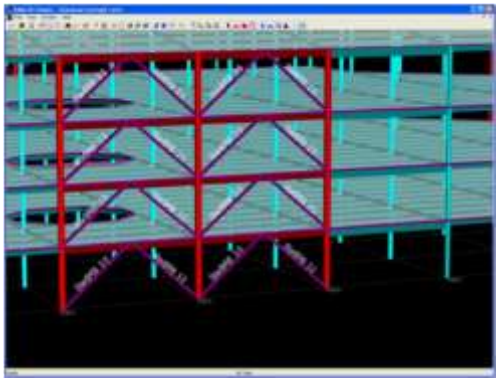


The Diagrid System



BRB Based Systems





BRB Based Building -Manila

- Located in Makati City, Philippines
- 50-story + 3½ - story below grade parking
- Total height of 166.8 m above ground level

Innovative Building

Doha Tower, Qatar
CTBUH Best Tall Building Award 2012

KfW Westarkade, Frankfurt
CTBUH Best Tall Building Award 2011

Burj Khalifa, Dubai
CTBUH best Tall Building Award 2010

Innovative Buildings

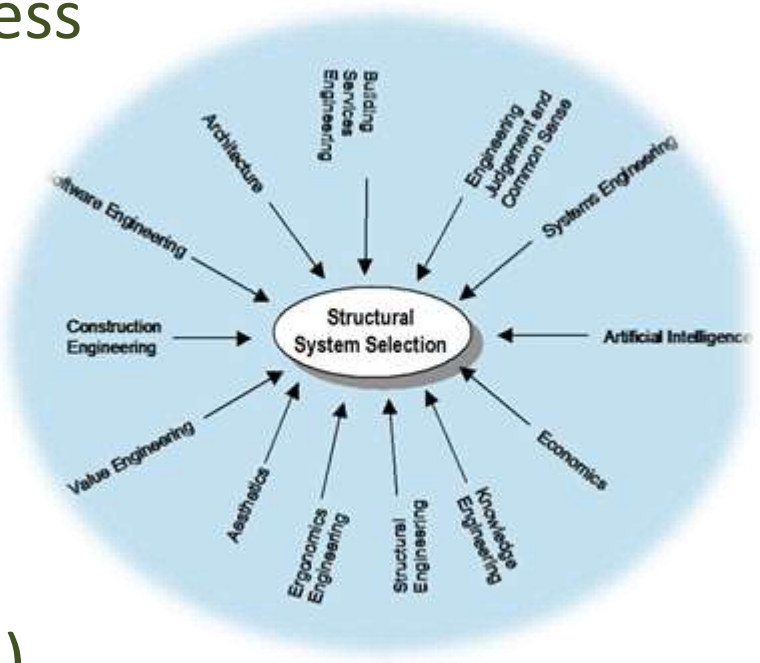
Linked Hybrid, Beijing
CTBUH best Tall Building Award 2009

Shanghai World Financial Center, China
CTBUH best Tall Building Award 2008

The Beetham Hilton Tower, Manchester, UK
CTBUH best Tall Building Award 2007

Structural System Selection

- Multi and Interdisciplinary process
- Fuzzy Logic
- Expert Systems (ES)
- Value Engineering
- Blackboard Approach
- Rich Pictures
- Analytic Hierarchy Process (AHP)



AHP

- The Analytical Hierarchy Process (AHP)
  - A weighted importance and suitability value analysis to determine the comparative value of a system or option

Value of an Option

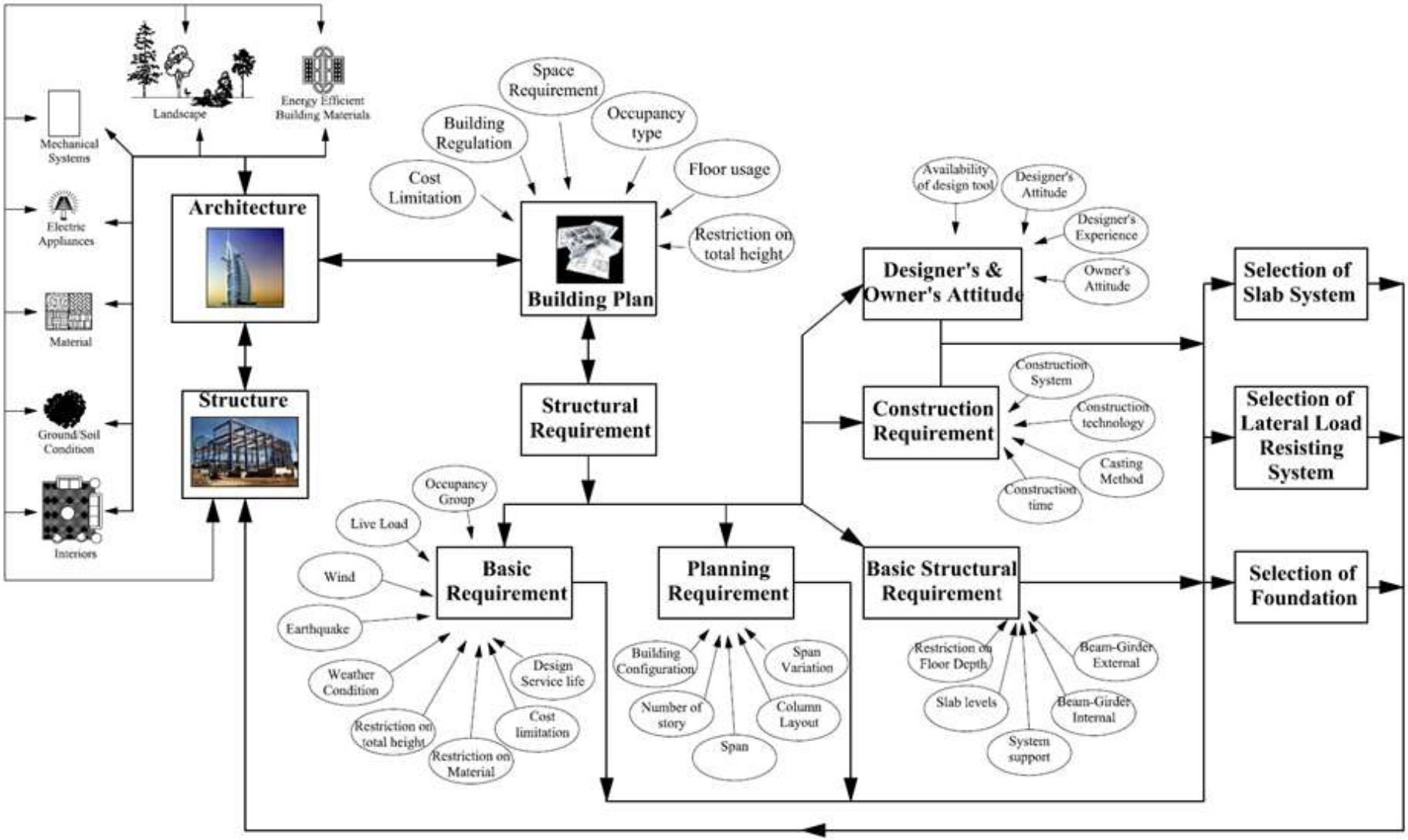
$$V_l = \sum_{i=1}^{m} A_i S_i \left(\sum_{j=1}^{n} B_{ij} S_{ij} \left(\sum_{k=1}^{p} C_{ijkl} S_{ijk} \right) \right)$$

Global Importance Weights and Scores

Sub Importance Weights and Scores

Suitability Value and Score

Rich Picture Diagram Building System



Cost and Performance

The Cost Issues

- What is Project Cost ?
- How are Project Cost and Design Related?
- What Factors effect the Cost?
- How to Reduce the Cost?
- How Performance and Cost are inter-related?

What is the Cost of a Project?

- Cost may include
  - Financial Cost (loan, interest, etc)
  - Planning and Design Cost
  - Direct Construction Cost
  - Maintenance Cost
  - Incidental Cost
  - Liquidated Cost (lost profit etc)
  - Opportunistic Cost
  - Environmental Cost
  - Emotional Cost
  - Non-determinist Resources

Cost may be:
"Consumption of Particular Resources, at Particular Time"

Sustainability may be:
<Consumption of all resources, and their impacts through throughout the life cycle>

Built to Last - A challenge

Sustainable buildings need sustainable design, sustainable certification and sustainable regulation

Sustainable buildings are quality buildings with low energy requirements

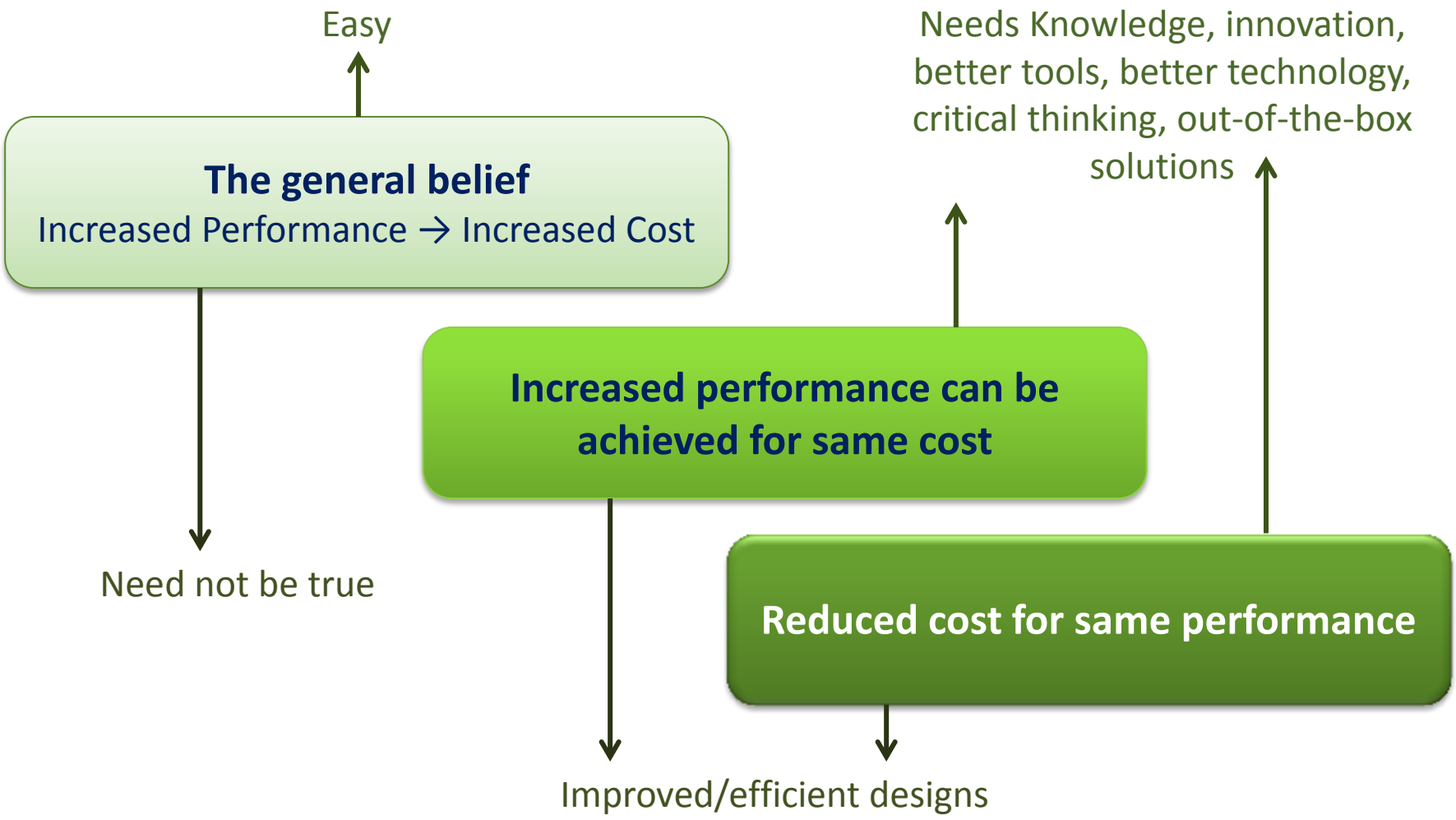
Sustainable buildings are healthy buildings, avoiding toxic materials and offering control to their occupants

Sustainable buildings are built to last - with the next generation in mind

SESSION 3: What Makes Buildings Green and Sustainable?

Dr. Brahmanand Mohanty

Cost and Performance

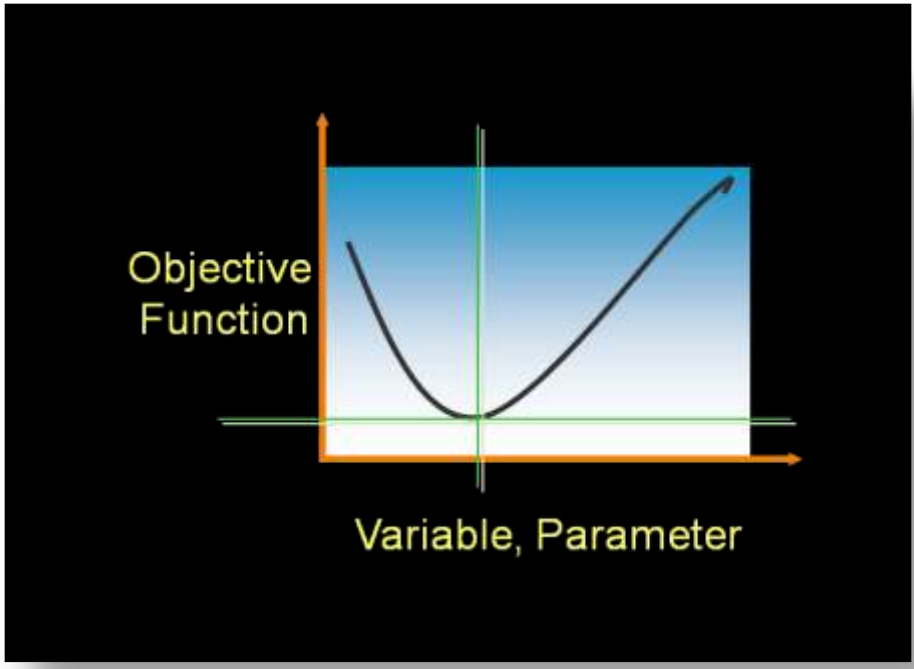


Cost and Performance

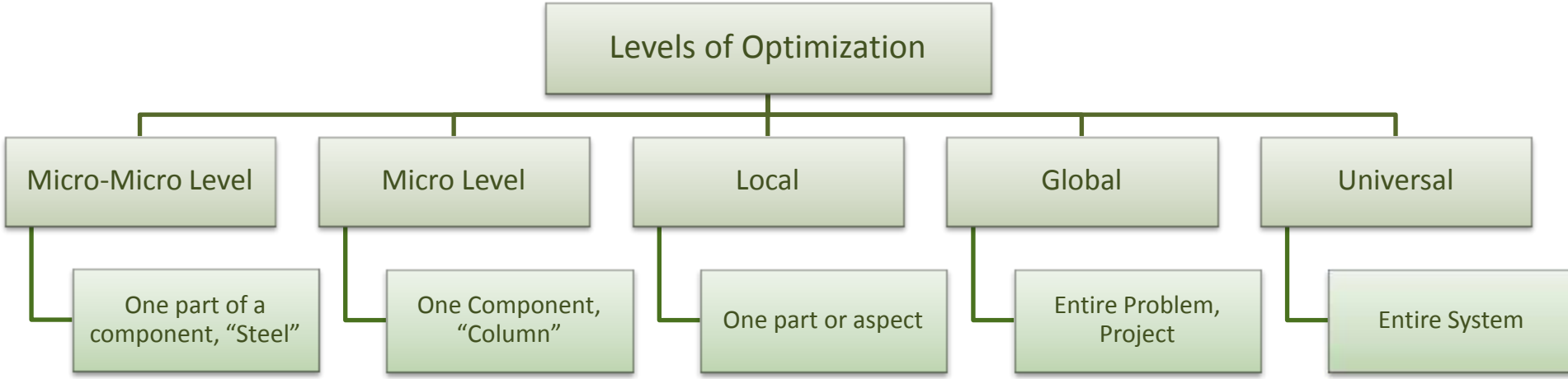
- **Enhancement of Performance**
  - Dynamic response parameters
  - Lateral load response
  - Vertical load response
  - Demand and capacity ratios
  - Response irregularity, discontinuity
  - Explicit Performance Evaluation at Service, DBE and MCE
- **Cost Effectiveness**
  - Capacity utilization ratio
  - Reinforcement ratios
  - Reinforcement volume ratios
  - Concrete strength and quantity
  - Rebar quantity
  - Constructability, time and accommodation of other constraints

Optimization

- Need to define What to optimize? And what are the parameters that can be changes?
- Optimizing one or two items may “un-optimize” others
- Optimizing everything is a “Holy Grail”
  - …. and “Holy Grail” doesn't exist
- Tools
  - Genetic Algorithms (GA)
  - Artificial Neural Networks (ANN)
  - Linear and Nonlinear programing

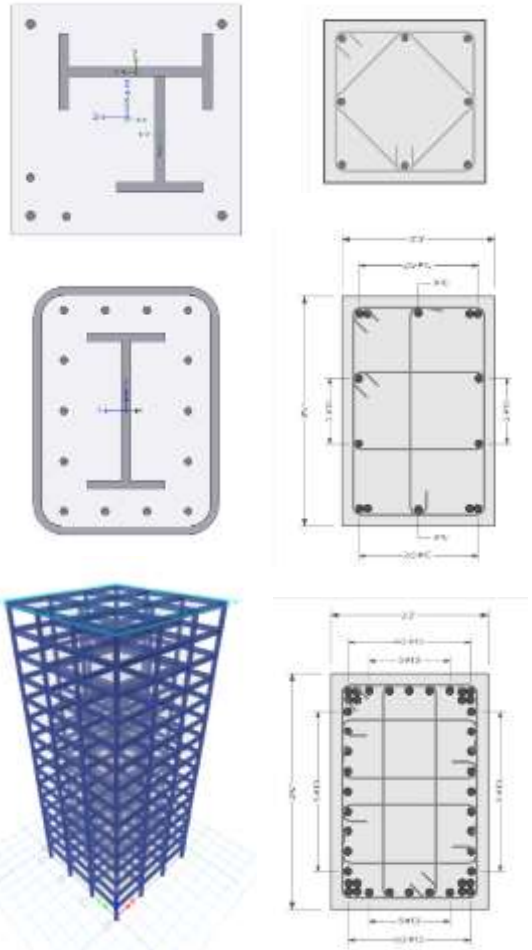


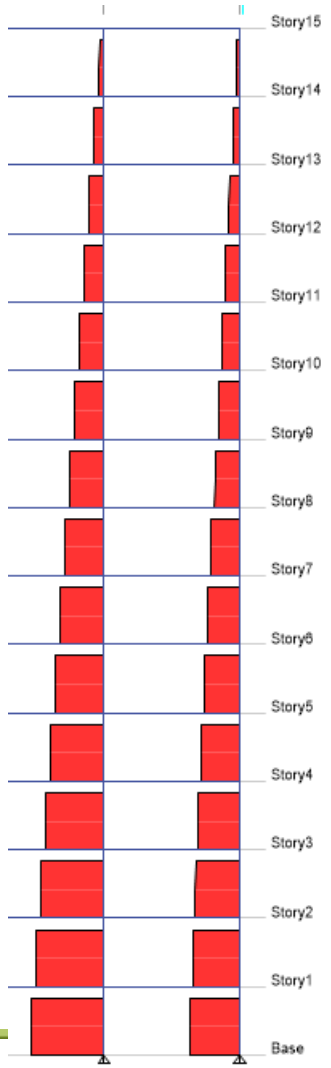
Levels of Optimization



Local Vs Global Optimization

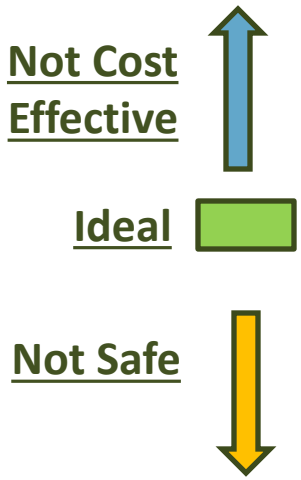
- **Simple Example of a Column Stack – What and how can we optimize ?**
  - Concrete Strength
  - Steel Strength
  - Column Size
  - Rebar Amount
  - Composite Section
- **Material Cost, Labor Cost, Formwork Cost, Management and operations Cost, Time ??**





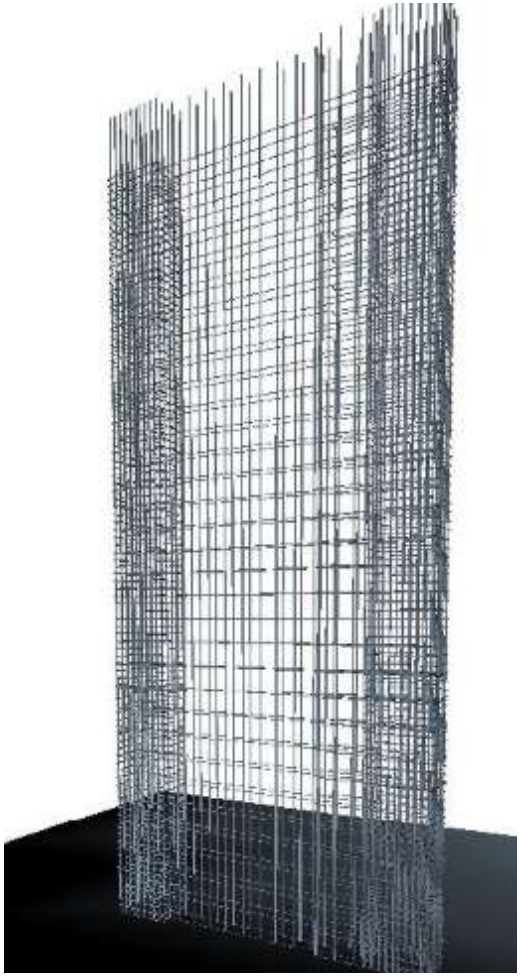
Cost Effectiveness > Utilization Ratio

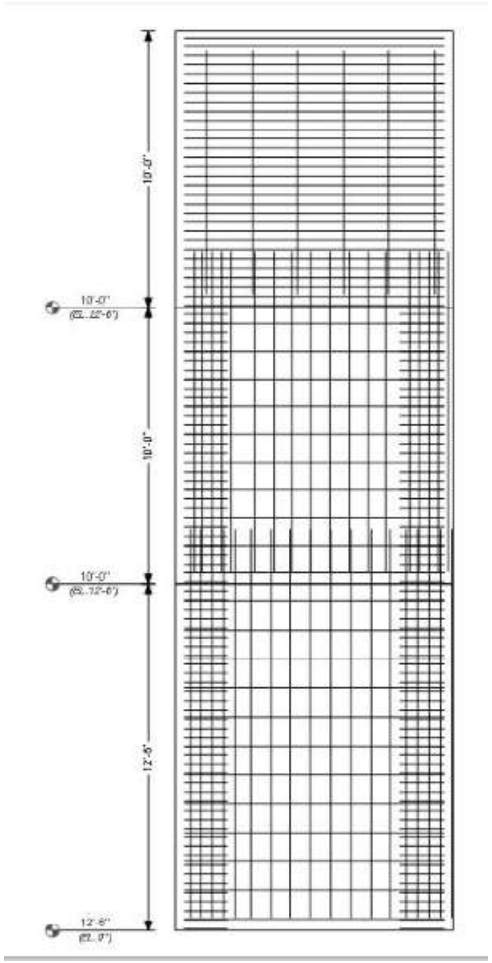
- **Utilization Ratio**
  - Compare, What is Needed against What is Required
- **One measure**
  - The Demand/ Capacity Ratio (D/C)

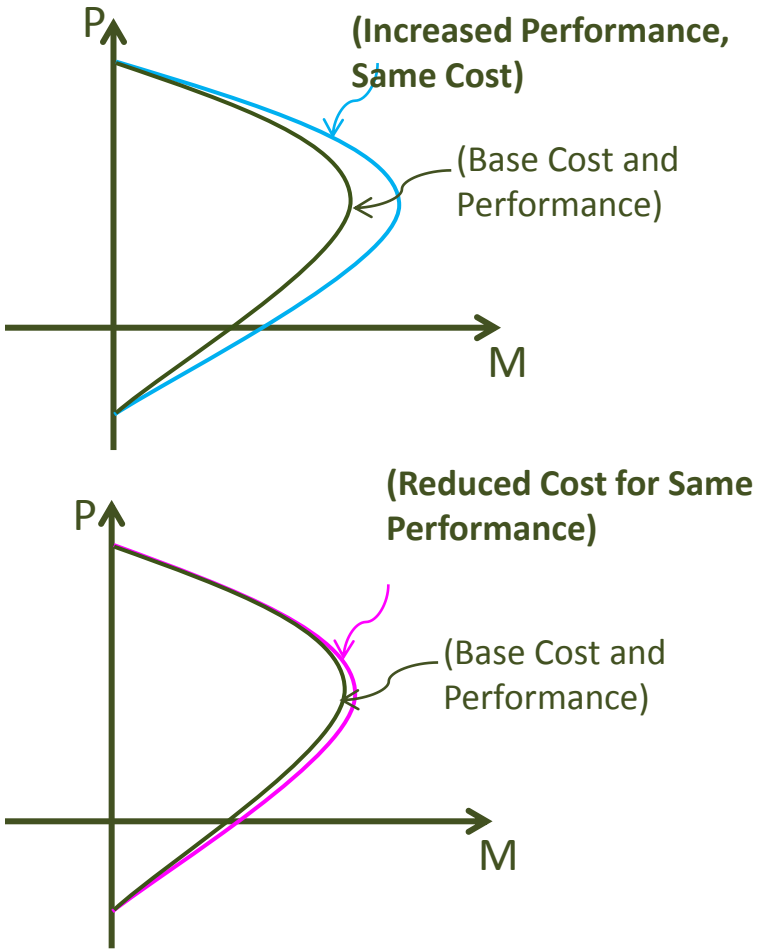


Demand/ Capacity	Columns	
	No.	%
D/C<0.5	178	16%
0.5<D/C<0.7	534	49%
0.7<D/C<1	346	31%
1<D/C<1.5	30	3%
1.5<D/C<2.5	12	1%
D/C>2.5	0	0%
Total	1100	100.00%

Cost and Performance



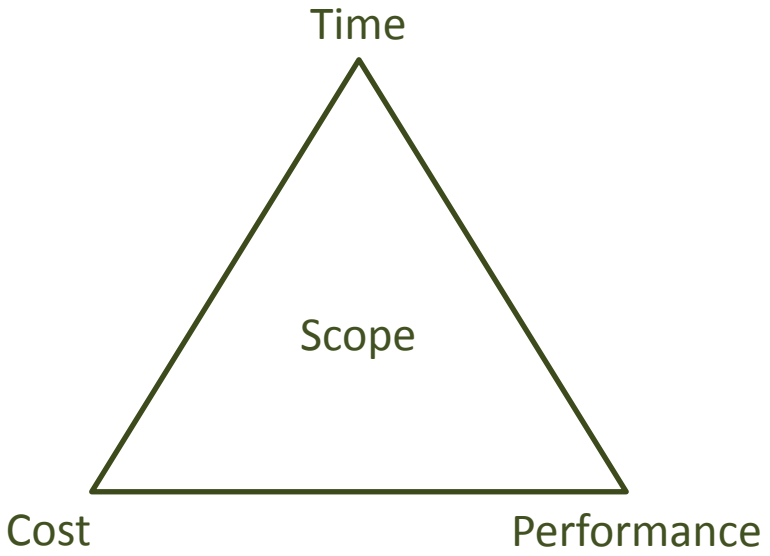




Cost and Time

- Time, Cost and Performance need to be balanced
- Time can be “Cost”

- How to reduce construction time
  - Automation
  - Reducing no. of components
  - Prefabrication
  - Innovative structural systems
  - Innovative construction process and management



Design Methodologies and Technologies

Technology

- **Technology is a broad term and may include**
  - Data, Information and Knowledge
  - Understanding of Knowledge
  - Application of Knowledge
  - Techniques for application of knowledge
  - Tools for applications
  - Ability to use the right tools for the right application
  - Finding Innovative, out of the box solutions

Technology

- **Knowledge**
  - Academic knowledge
  - Research outcome
  - Design Codes and Guidelines
- **Techniques and Tools**
  - System Development, Selection
  - Modeling, Analysis, Design
  - Lab Tests, Simulations, Software

The Responsibility

- Client/Owner
- Architect
- Structural Designer
- Geotech Consultants
- Peer Reviewer
- Builder/Contractor

- General Building Codes
- Structural Design Codes
- Law Makers
- Building Officials
- Legal and Justice System

Public/ Users/ Occupants

The First Code - Hammurabi's Code (1772 BC)

Clause 229: If a builder builds a house for someone, and does not construct it properly, and the house which he built falls in and kills its owner, then that builder shall be put to death.

Consequence

Explicit Performance

Implicit Specifications

History of Building Codes - Law of Moses (1300 BC)

"In case you build a new house, you must also make a parapet for your roof, that you may not place bloodguilt upon your house because someone falling might fall from it".

- The Bible, Book of Deuteronomy, Chapter 22, Verse 8

Life Safety

… Ultimately….. Performance is what is desired…

Prescriptive Codes
Implicit Performance

7.2.3 — Inside diameter of bend in welded wire reinforcement for stirrups and ties shall not be less than $4d_b$ for deformed wire larger than MD40 and $2d_b$ for all other wires. Bends with inside diameter of less than $8d_b$ shall not be less than $4d_b$ from nearest welded intersection.

(ACI 318 – 11)

Do this …

Your structure is OK

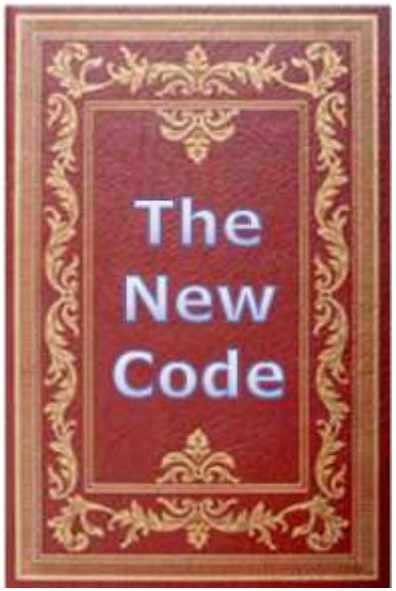
Shortcomings of the Prescriptive Codes For Tall Buildings

- **Traditional codes govern design of general, normal buildings**
  - Over 95% buildings are covered, which are less than about 50 m
- **Not specifically developed for tall buildings > 50 m tall**
- **Prescriptive in nature, no explicit check on outcome**
- **Permit a limited number of structural systems**
- **Do not include framing systems appropriate for high rise**
- **Based on elastic methods of analysis**
- **Enforce uniform detailing rules on all members**
- **Enforce unreasonable demand distribution rules**
- **Do not take advantage of recent computing tools**

Performance-based Engineering

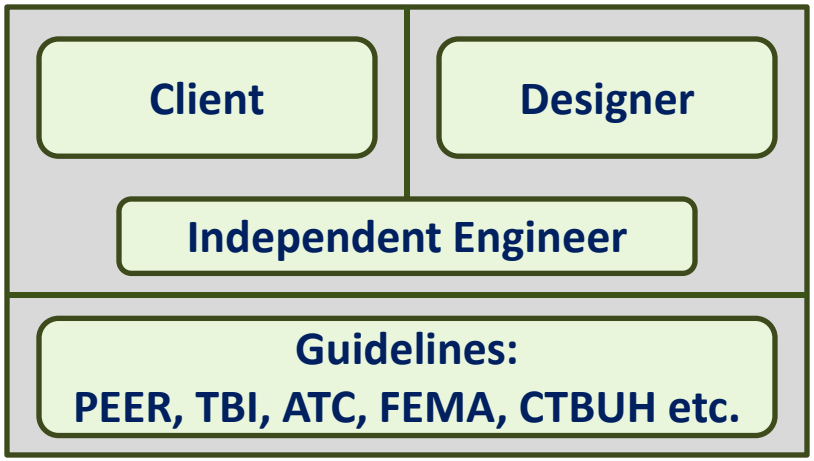
Design for the achievement of specified results rather than adherence to particular technologies or prescribed means.

- Peter May, 2004



… Now, instead of worrying about mix proportions of concrete, you can directly ask contractor for a 60 MPa concrete → Courtesy: Performance based approach

Performance-based Design Approach

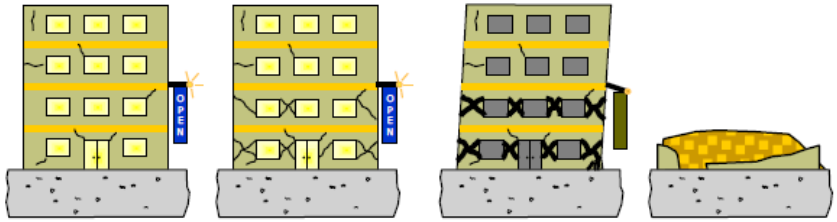


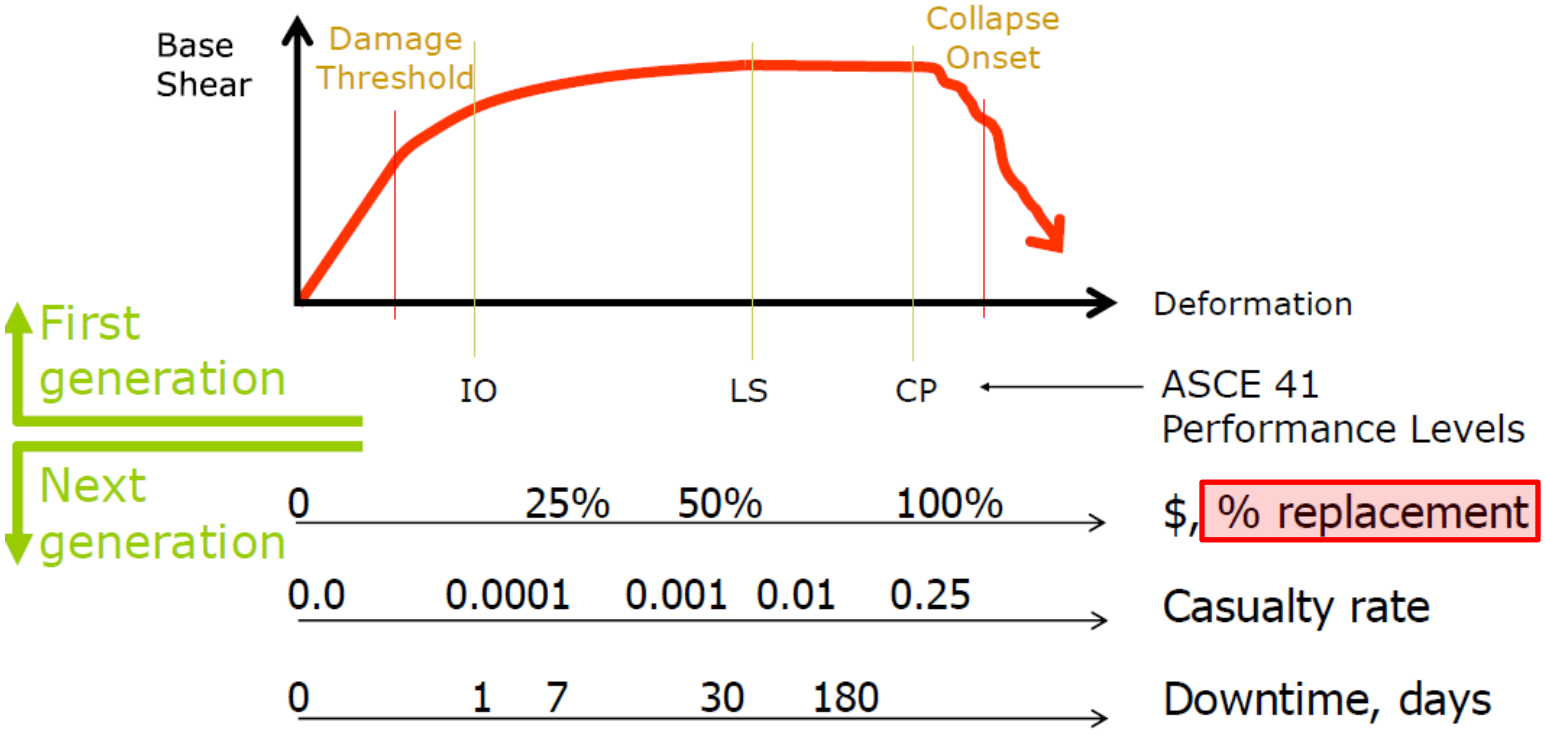
What to expect?

How to achieve?

Knowledge – Skills – Tools

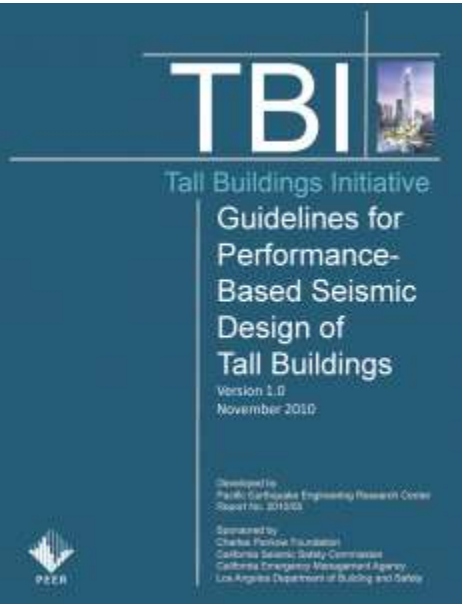
Building Performance Objectives





Jack Moehle 2011, PEER, SEAOSC

Current Guidelines



Tall Buildings Initiative Guidelines
A Project of Pacific Earthquake Engineering Research Center (PEER)

http://peer.berkeley.edu/tbi/

Council of Tall Buildings and Urban Habitat (CTBUH)

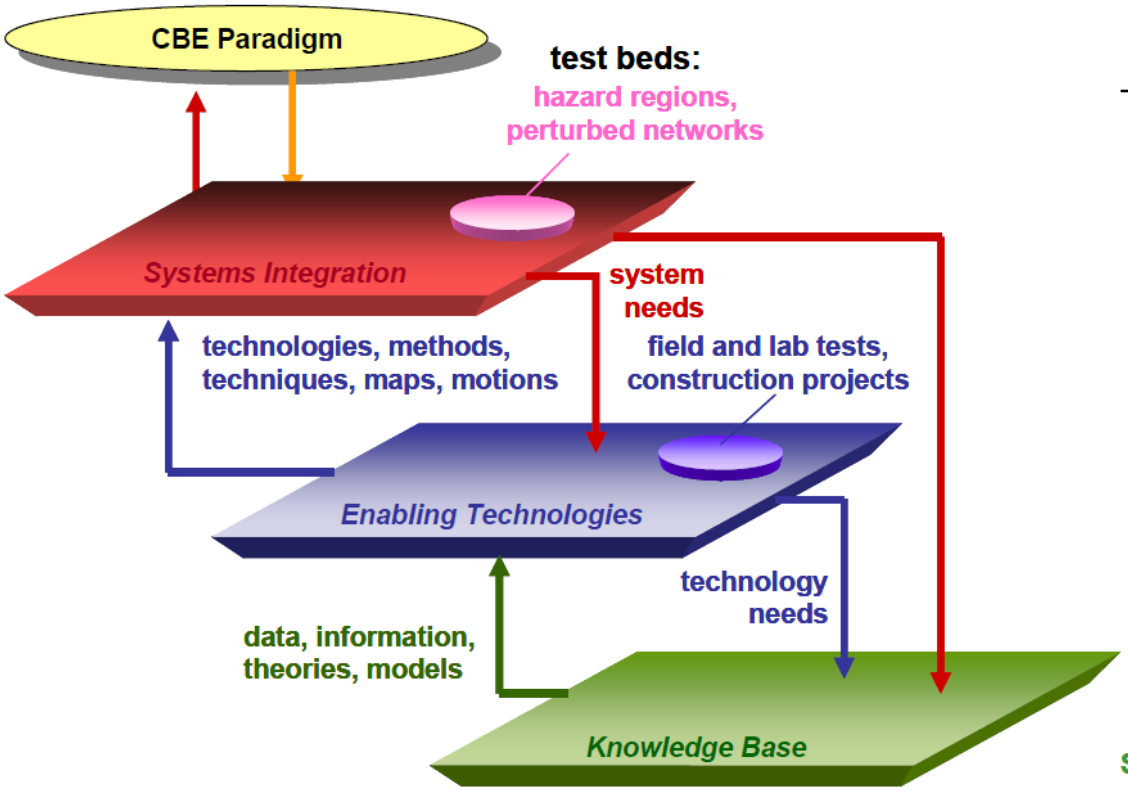
http://www.ctbuh.org/

National Earthquake Hazards Reduction Program

http://www.nehrp.gov/

Consequence-based Engineering

A New Engineering Paradigm



Research

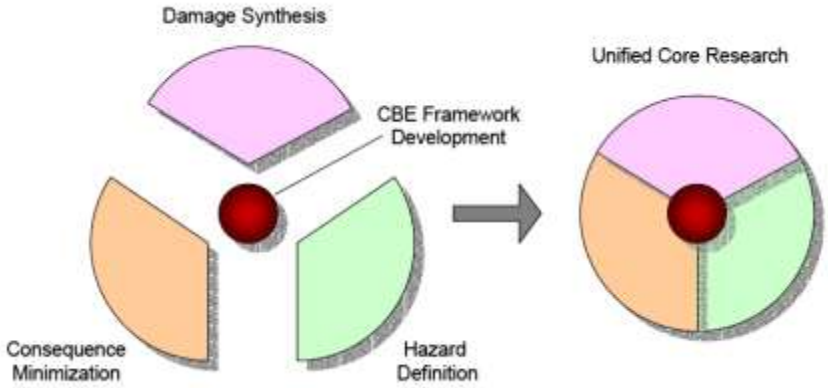
CBE Framework
Uncertainty Modeling
Network Vulnerability
Regional Damage Synthesis
Loss Visualization

Inventory Technologies
Computational Methods
Damage-Probability Models
Design/Rehab. Techniques
Synthetic Earthquake Hazards

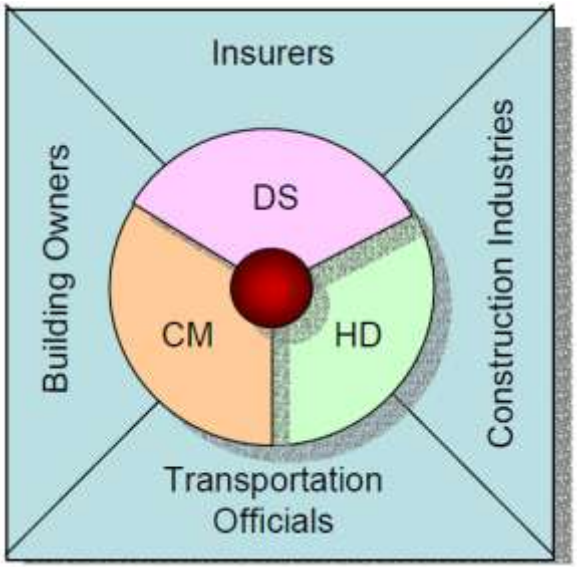
Economic Flows
Decision Making
Structural Response
Component Vulnerability
Source/Path/Site Characterization
Ground Deformation

(Abrams D.P, 2002)

Core Research Thrust Areas



Stakeholder Thrust Areas



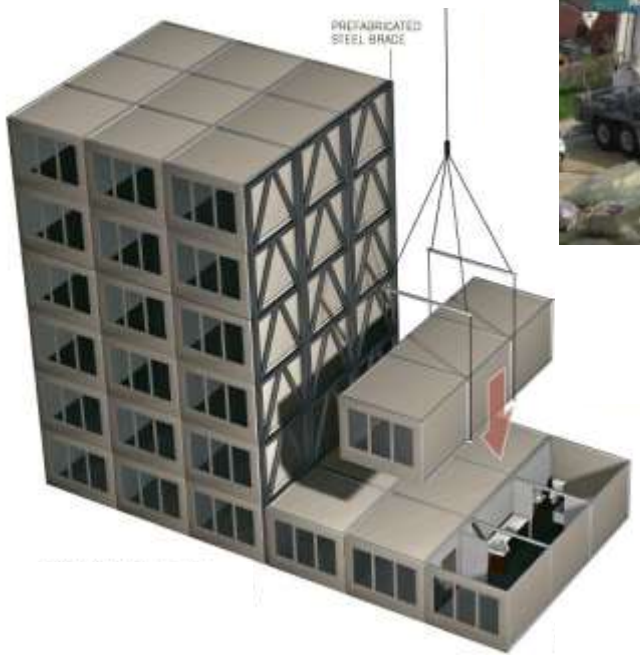
(Abrams D.P, 2002)

Construction Innovations

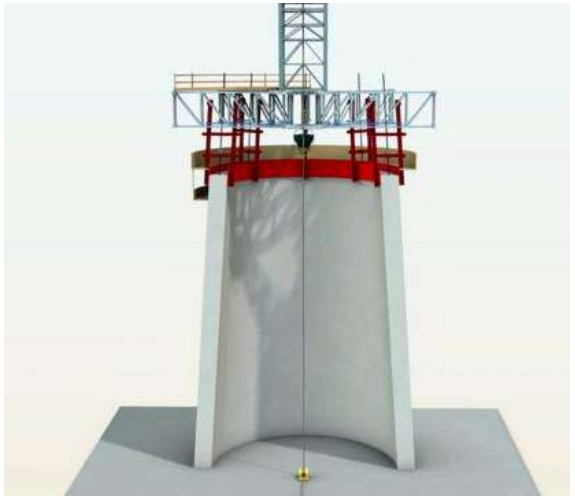
Construction Technology

- **Pre-Fabrications**
  - Single parts
  - Larger components and units
  - Fully assembled systems
  - Modular Construction
- **Rapid Construction**
  - Slip forming, flying forms, pre-assembled cages
  - Rapid hardening concretes, newer material,
  - Top-down and bottom up construction
- **Improved Management**
- **Technologies in development**
  - Printed Buildings

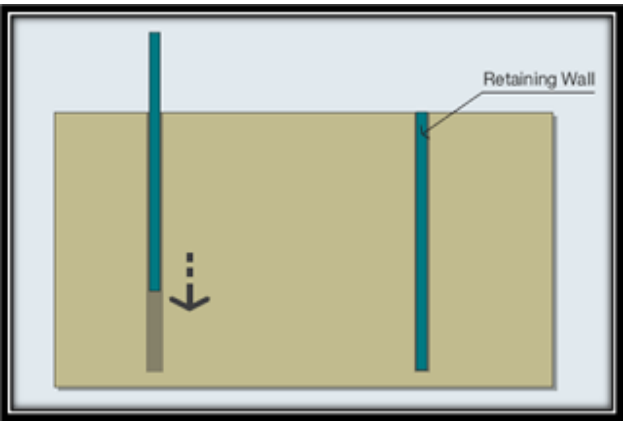
Pre Fabrication

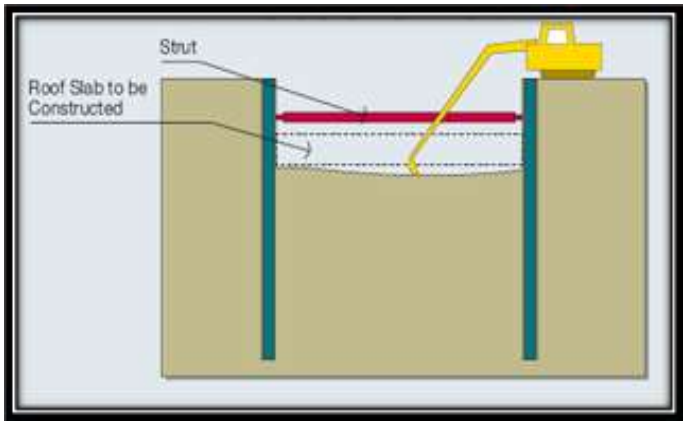


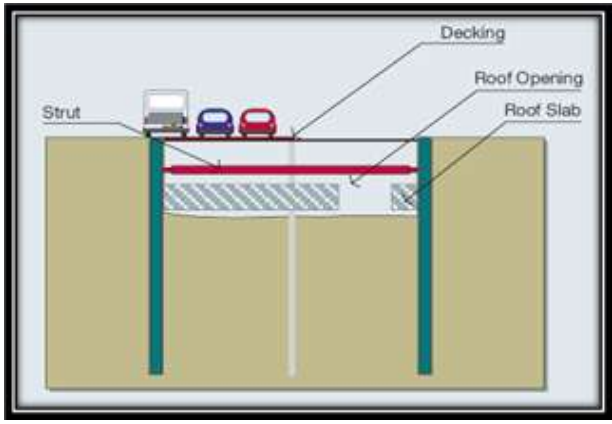
Slip Forming

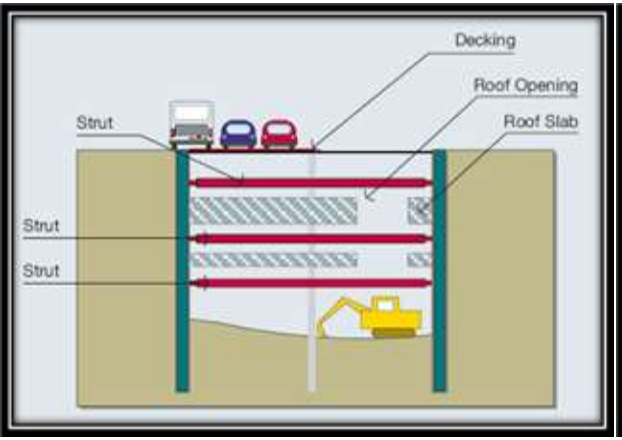


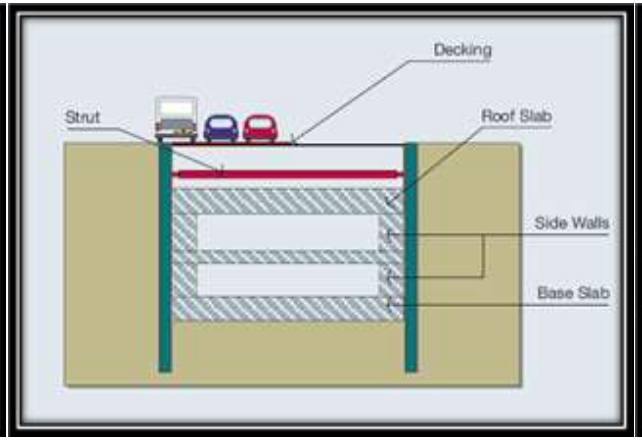
Top Down Construction

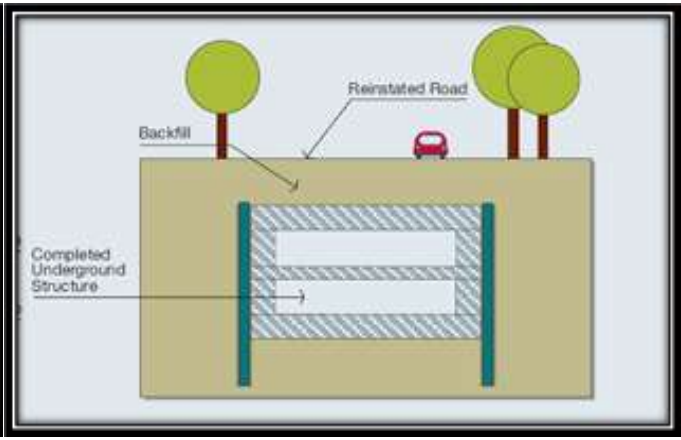








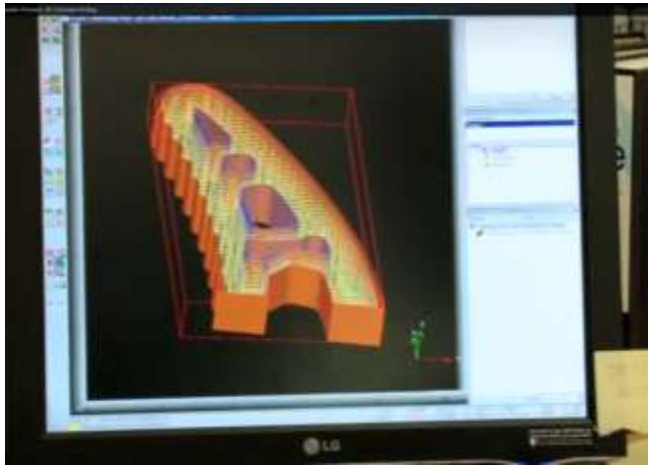


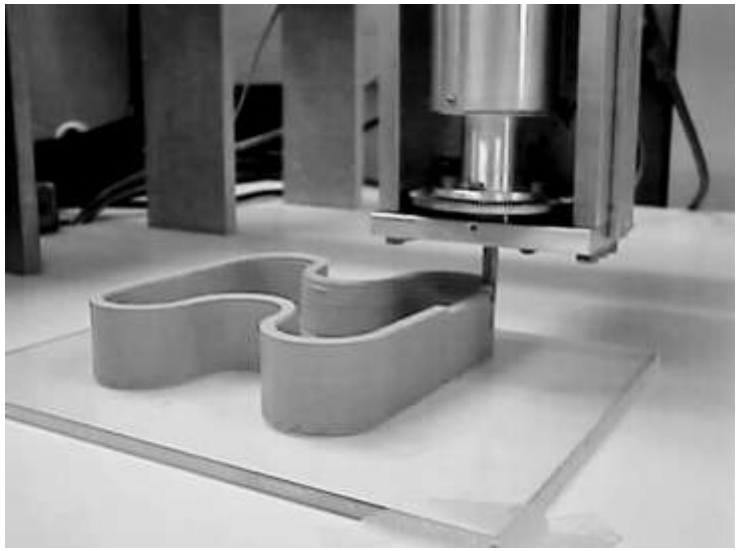


Modular Construction

30 story in 15 days - China

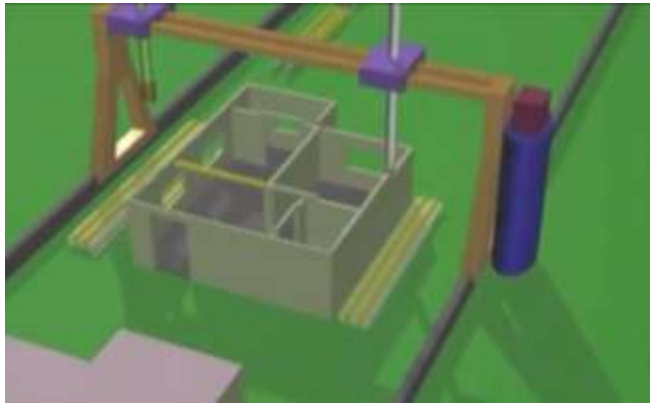
Concrete Printing





Contour Crafting

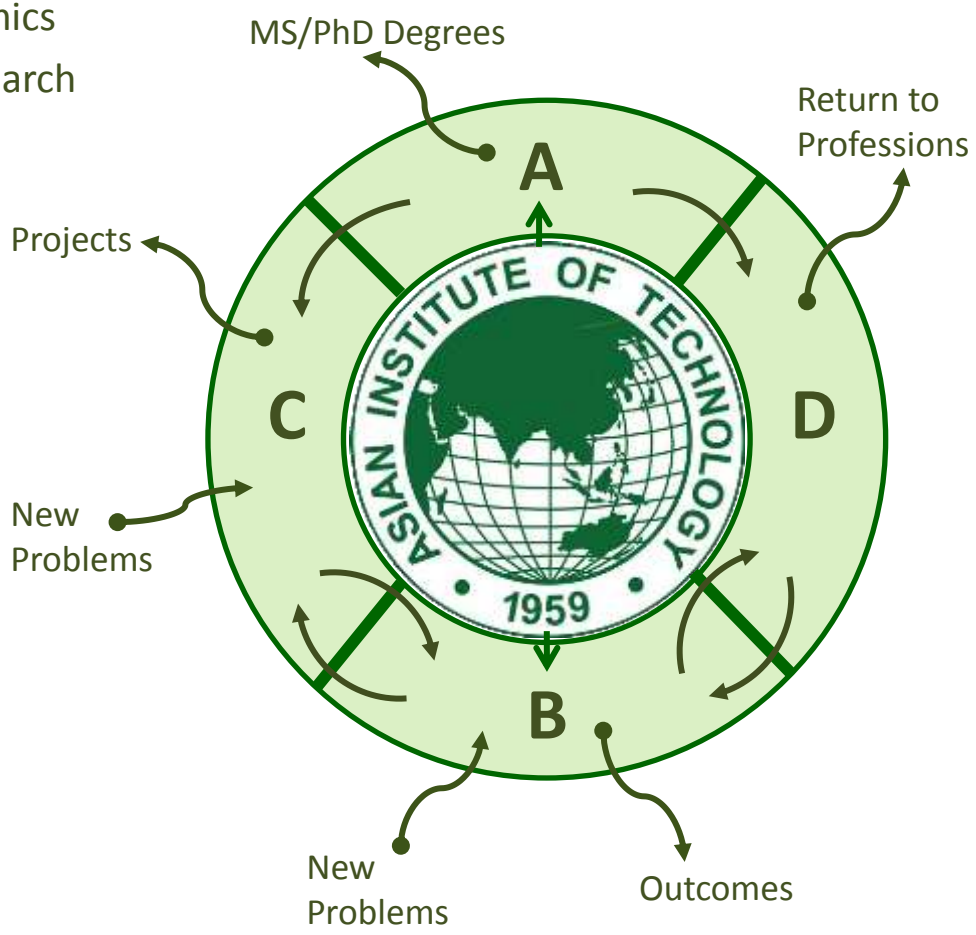


AIT and Tall Buildings

AIT Integrated Knowledge Development and Application

- Present AIT's Model/role
  - A. Existing Knowledge → Teaching/Academics
  - B. New Problems/New Knowledge → Research
  - C. Apply Knowledge → Consulting
  - D. Develop Skills → Executive Education



Advanced Tools for Tall Buildings

CSiBRIDGE®
Integrated 3D Bridge Design Software

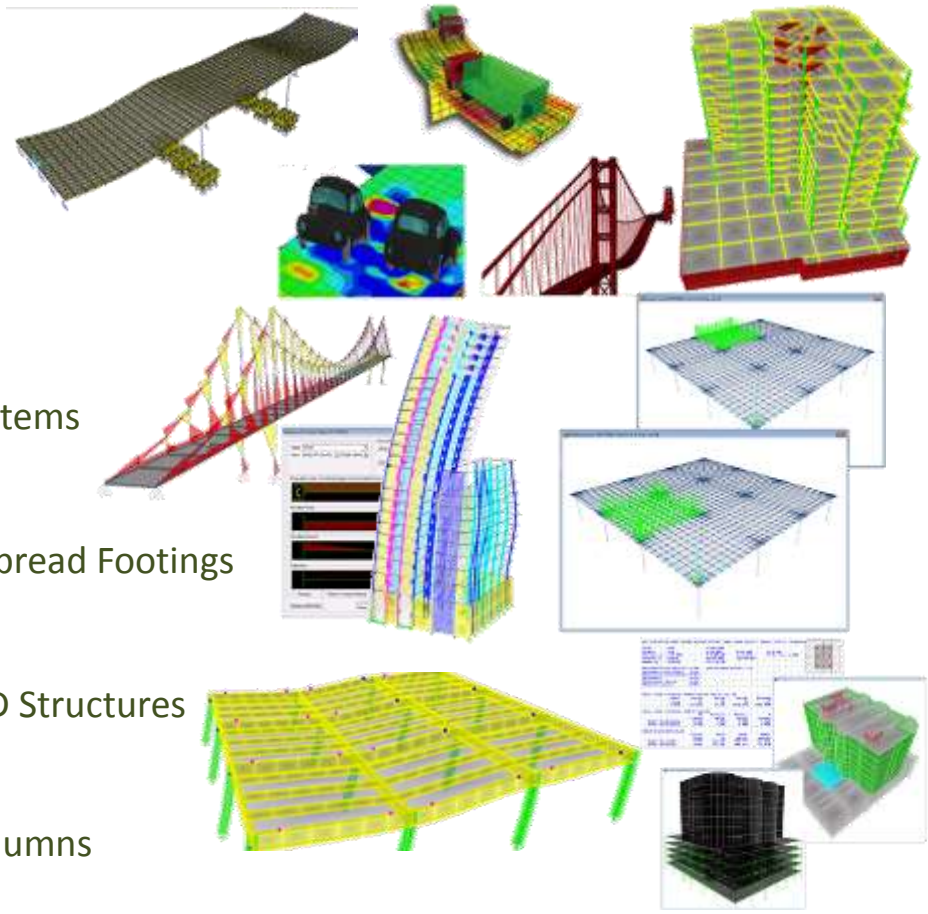
SAP2000®
Integrated Software for Structural Analysis and Design

ETABS®
Integrated Analysis, Design and Drafting of Building Systems

SAFE®
Integrated Design of Flat Slabs, Foundation Mats and Spread Footings

PERFORM®3D
Nonlinear Analysis and Performance Assessment for 3D Structures

CSiCOL
Design of Simple and Complex Reinforced Concrete Columns



Thank You

AIT
Asian Institute of Technology

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