Connecting Engineering and Architecture Through Structural Topology Optimization

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Research Objectives

- To apply topology optimization to the field of structural engineering through high-rise building design
- Utilize manufacturing and layout constraints to make results more meaningful
- Address the importance of achieving a balance between engineering and architecture for efficient, sustainable design

Introduction: Engineering and Architecture

- Historical examples of structures by architects with strong and innovative engineering concepts

Antonio Gaudi[1]

Buckminster Fuller[2]

Felix Candela[3]

[1-3] Multiple websites

  - Gaudi used physical models to calculate sophisticated structures (Sagradia Familia Cathedral, Barcelona, Spain - still under construction)
  - Fuller's philosophical ideas about holistic design, synergetics, and geometry led to innovative structures (Montreal Biosphere, Montreal, Canada, 1967)
  - Candela created thin-shell concrete structures, which are efficient and beautiful (Los manantiales, Xochimilco, Mexico, 1958)
- Goal: overcome dichotomy between architectural aesthetics and engineering efficiency using topology optimization

Basic Topology Optimization Framework

- Minimum compliance criteria

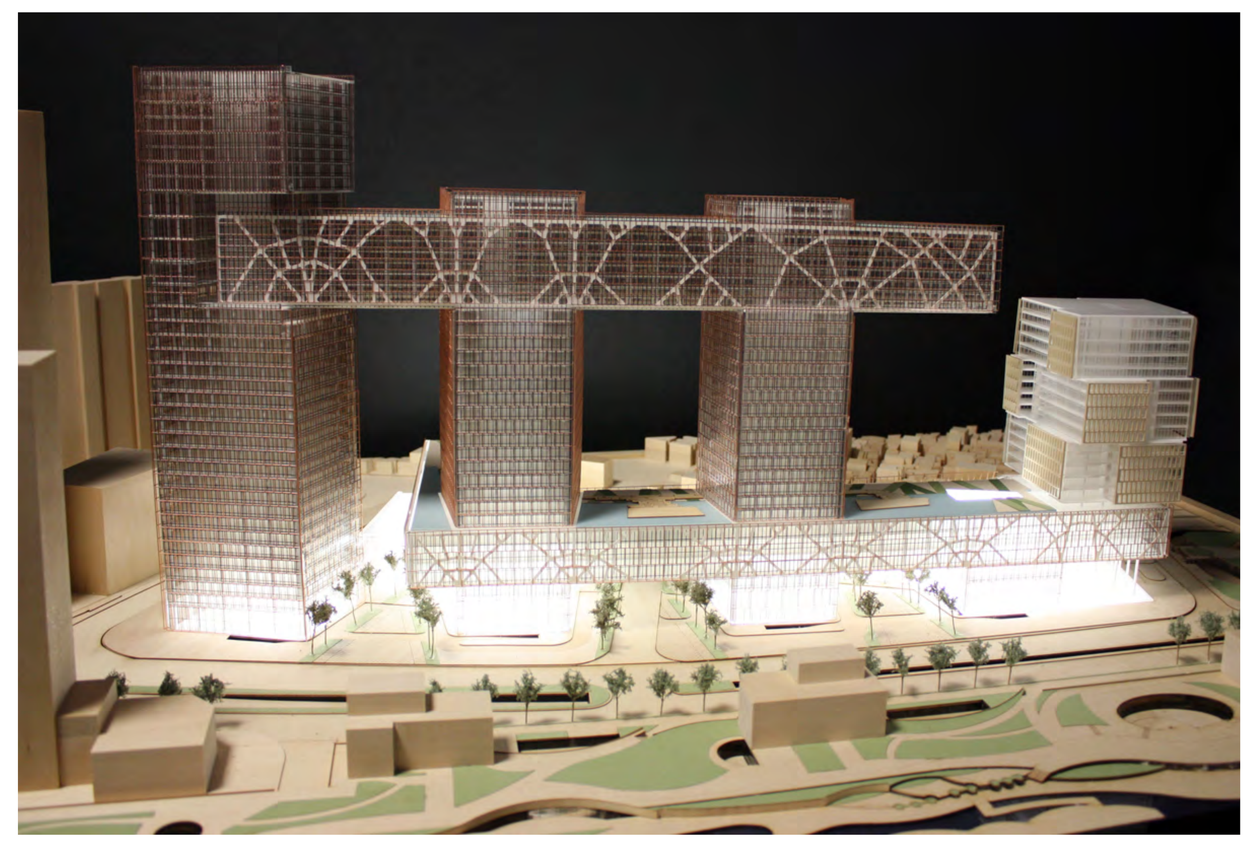
$$\begin{aligned} \min_{\rho,\mathbf{u}} \quad & c(\rho,\mathbf{u}) \\ s.t. \quad & \mathbf{K}(\rho)\mathbf{u} = \mathbf{f} \\ & \int_{\Omega} \rho \, dV \leq V_s \\ & \rho(\mathbf{x}) \in [0,1] \, \forall \mathbf{x} \in \Omega \end{aligned}$$

- Other criteria
  - Deflection (P-Δ)
  - Buckling load
  - Natural frequency

Motivation for Layout/Manufacturing Constraints

- Minimum/maximum member sizes according to AISC available shapes
- Minimum/maximum hole size to run a pipe through a beam
- Pattern repetition to eliminate custom cut glass shapes, reuse formwork, increase speed and quality control
- Pattern gradation to transition column sizes from large at base to small at top, bracing angle around 65° at base (overturning moment) to 45° at top (shear)

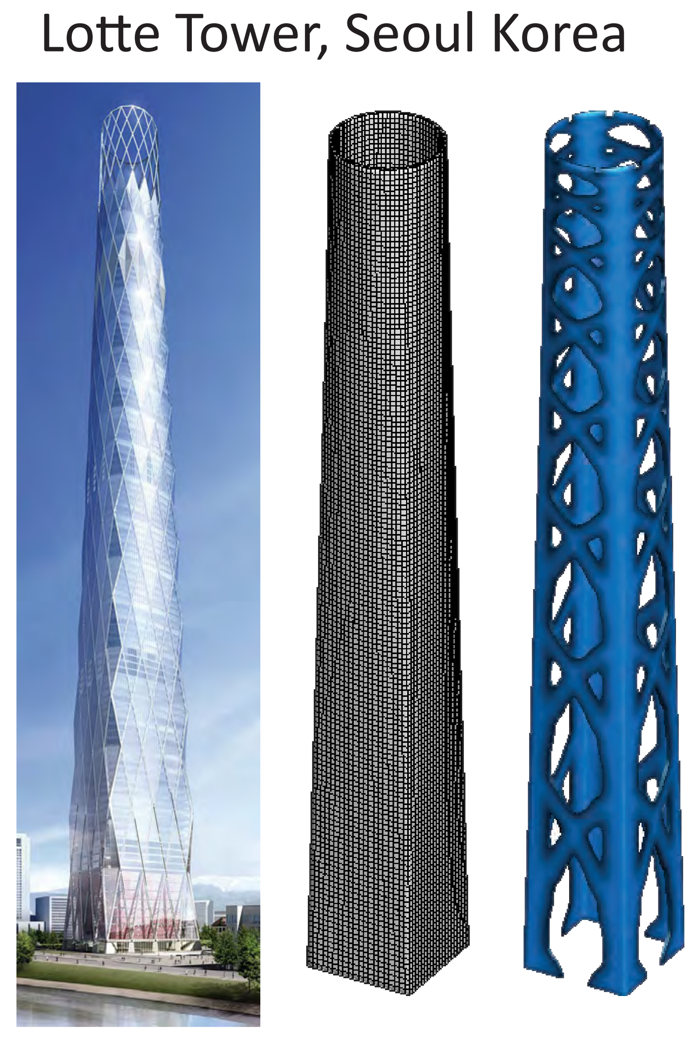
Zendai Competition (China)



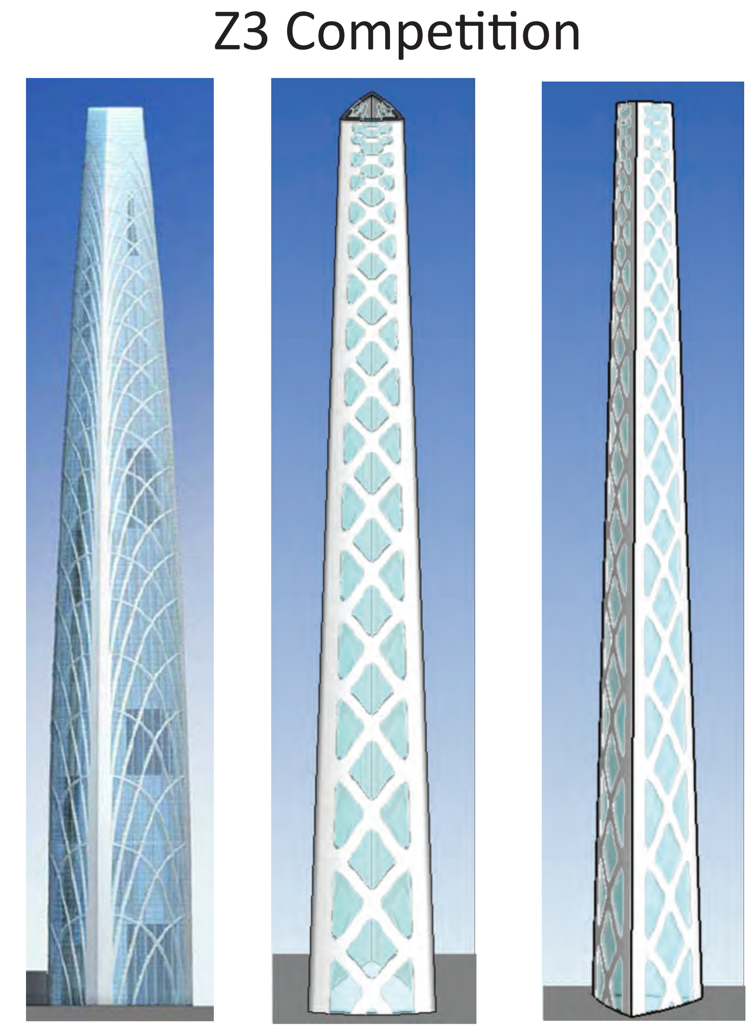
Rendering of final design and picture of physical model using topology optimization results (courtesy of SOM)

Application of Pattern Gradation to Buildings

Lotte Tower, Seoul Korea



Z3 Competition



Conclusions

Topology optimization can be a valuable tool to bridge the gap between engineering and architecture in the construction design industry. Moreover, resulting designs will be more efficient and sustainable, by optimizing the material consumption.

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