



Sustainability at the Structural Scale

Advanced
Cementitious
Materials

Prof. David Ruggiero
ENAC-CONSTRUCT

4 December, 2024



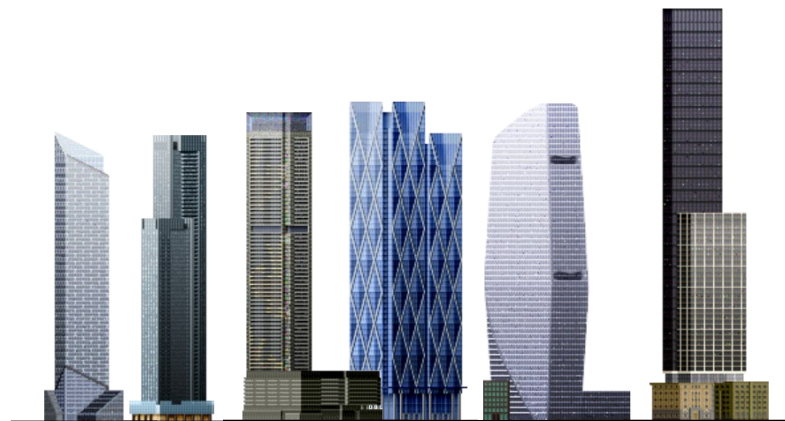
Introduction

Case studies

Problems

Solutions

- Ph.D. from University of Toronto: “The Behaviour of Reinforced Concrete Subjected to Reversed Cyclic Shear”
- Postdoctoral studies in seismic engineering at the Institute for Advanced Studies of Pavia, Italy
- 5 years as structural engineer at Read Jones Christoffersen (RJC) Toronto
- Associate Member of Canadian Standards Association CSA A23.3 Technical Committee on Design of Concrete Structures
- Chair of Joint Committee on the GLOBE Consensus



SkyscraperPage contributor Koops65

Concrete Behaviour and Structural Design Laboratory – ENAC-CONSTRUCT

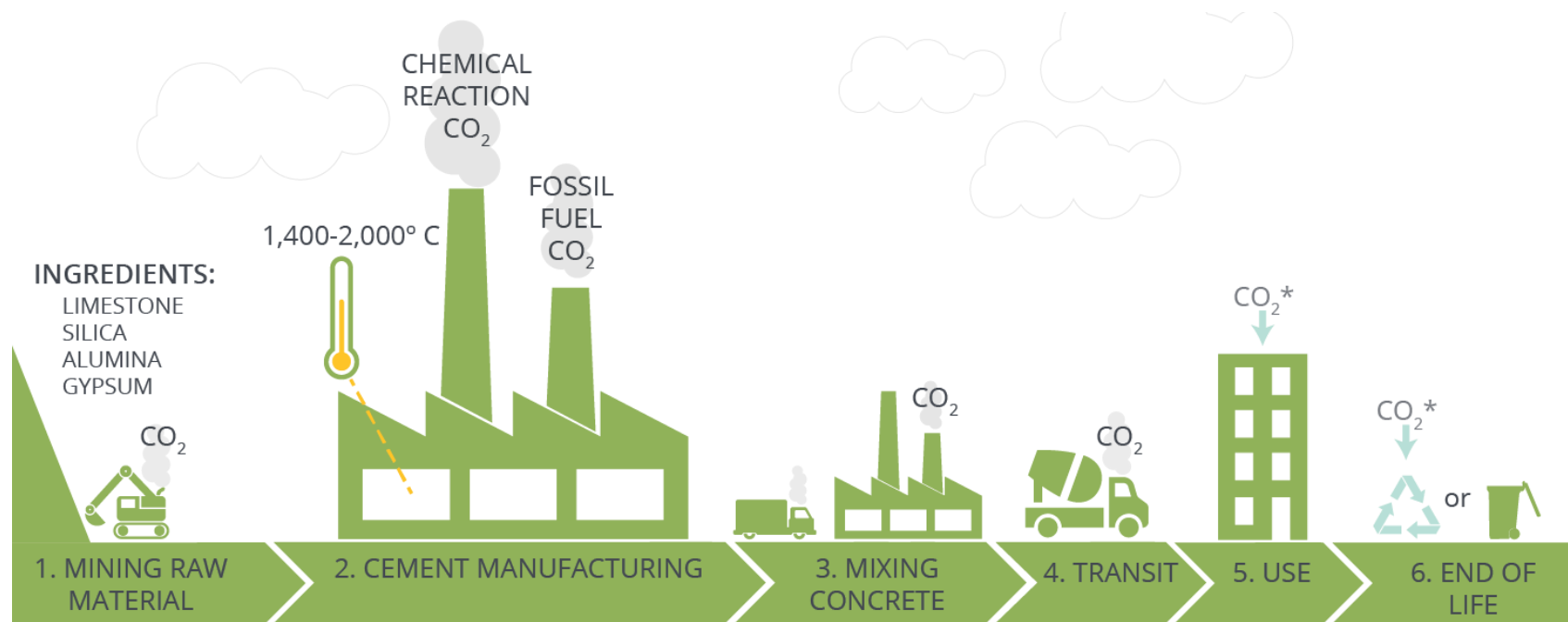
**Lower-carbon
alternatives**

**Design for reuse
and longevity**

**Better mechanical
modelling and
optimization**



Carbon impacts of concrete



Architecture 2030

Estimated Global CO₂ Emissions by Sector (2020)



Visualizing the Scale of Anthropogenic Mass

Anthropogenic mass, or human-made mass, refers to the materials embedded within inanimate solid objects that are made by humans.

In 2020, the amount of anthropogenic mass exceeded the weight of all global living biomass.

As humans continue to dominate Earth, questions surrounding our material output are increasing. We break down the composition of all human-made materials and the rate of their production.

1120 Gt

Global Biomass

The dry weight of all life on Earth is comprised of plants, animals, bacteria, fungi, protists, archaea, and viruses, too.

This study converted carbon weight of all life on Earth to dry weight by a factor of 2.25

All humans make up **~0.01%** of global living biomass.

1154 Gt

Anthropogenic Mass

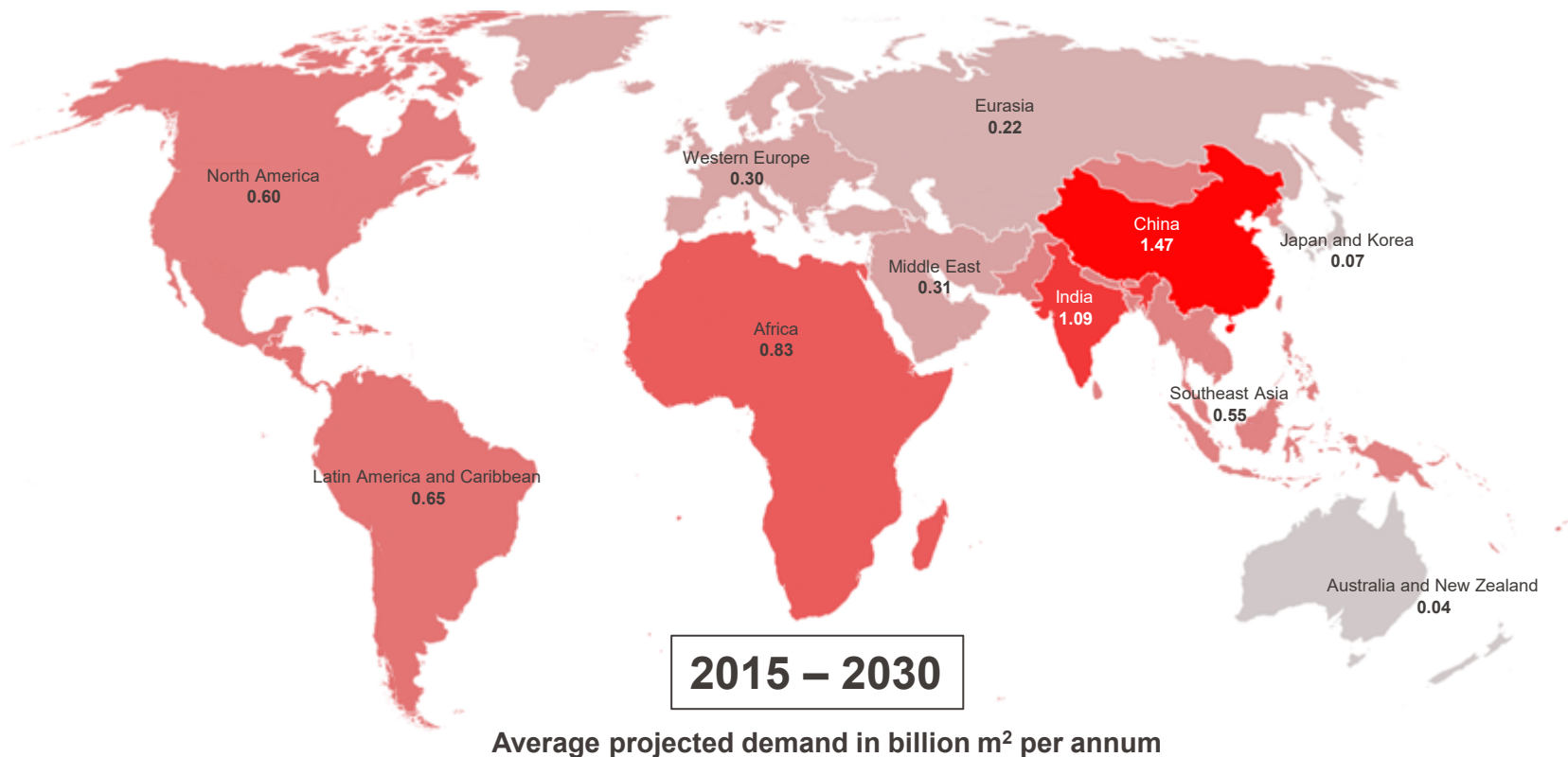
Here is everything the human population has created since **1900 to 2020**.

Humans

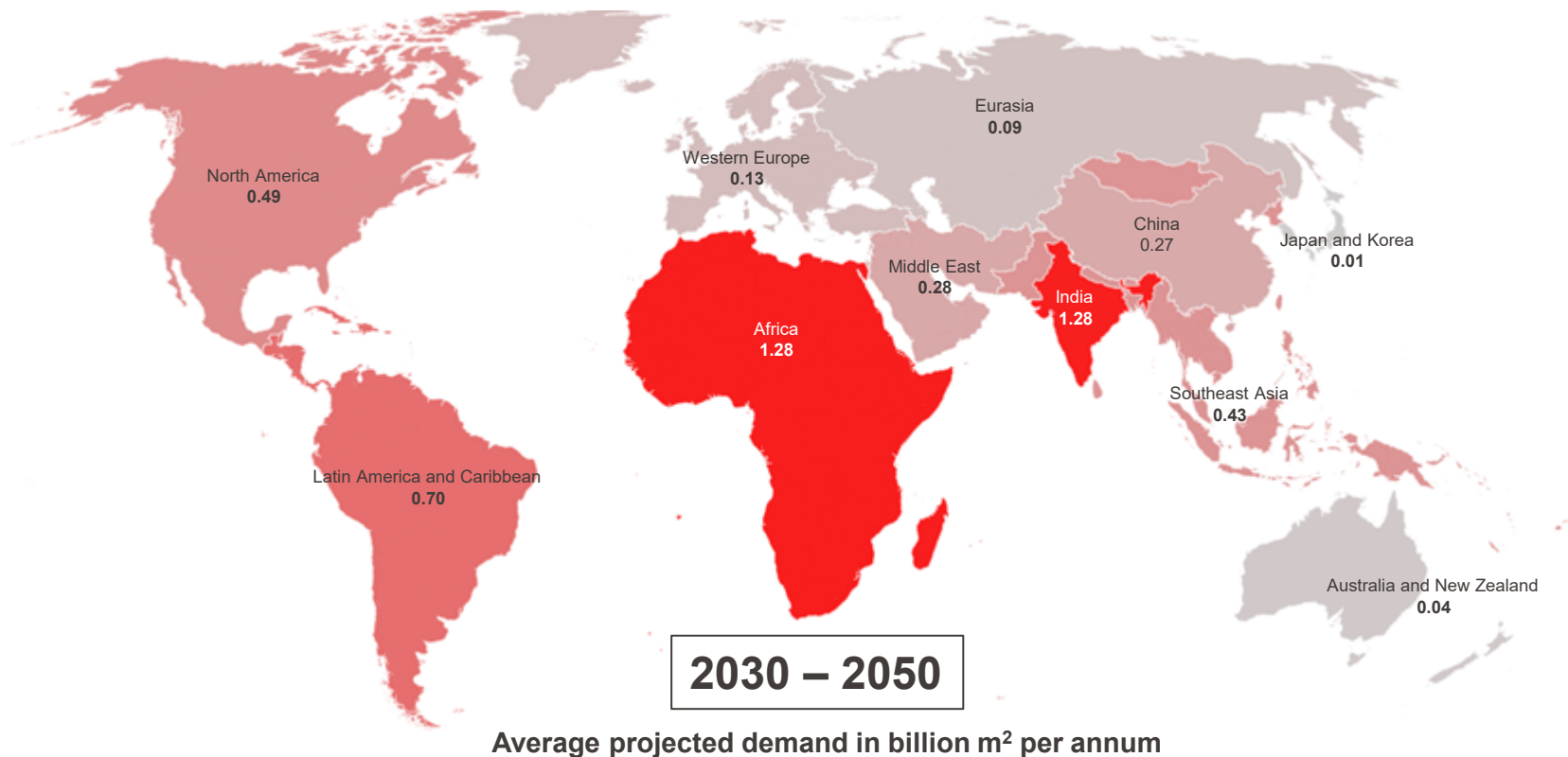
1 Gigaton, Gt (1 thousand million metric tons)



Global demand for net increase in floor area



Global demand for net increase in floor area



UNEP, 2016, United Nations Environment Programme, *Towards zero-emission efficient and resilient buildings*, *Global Status Report 2016*

”

By one estimate, the world will add 2 trillion square feet of buildings by 2060—the equivalent of putting up **another New York City every month** for the next 40 years.

Bill Gates



City of Toronto Archives, Fonds 1526, File 46, Item 20

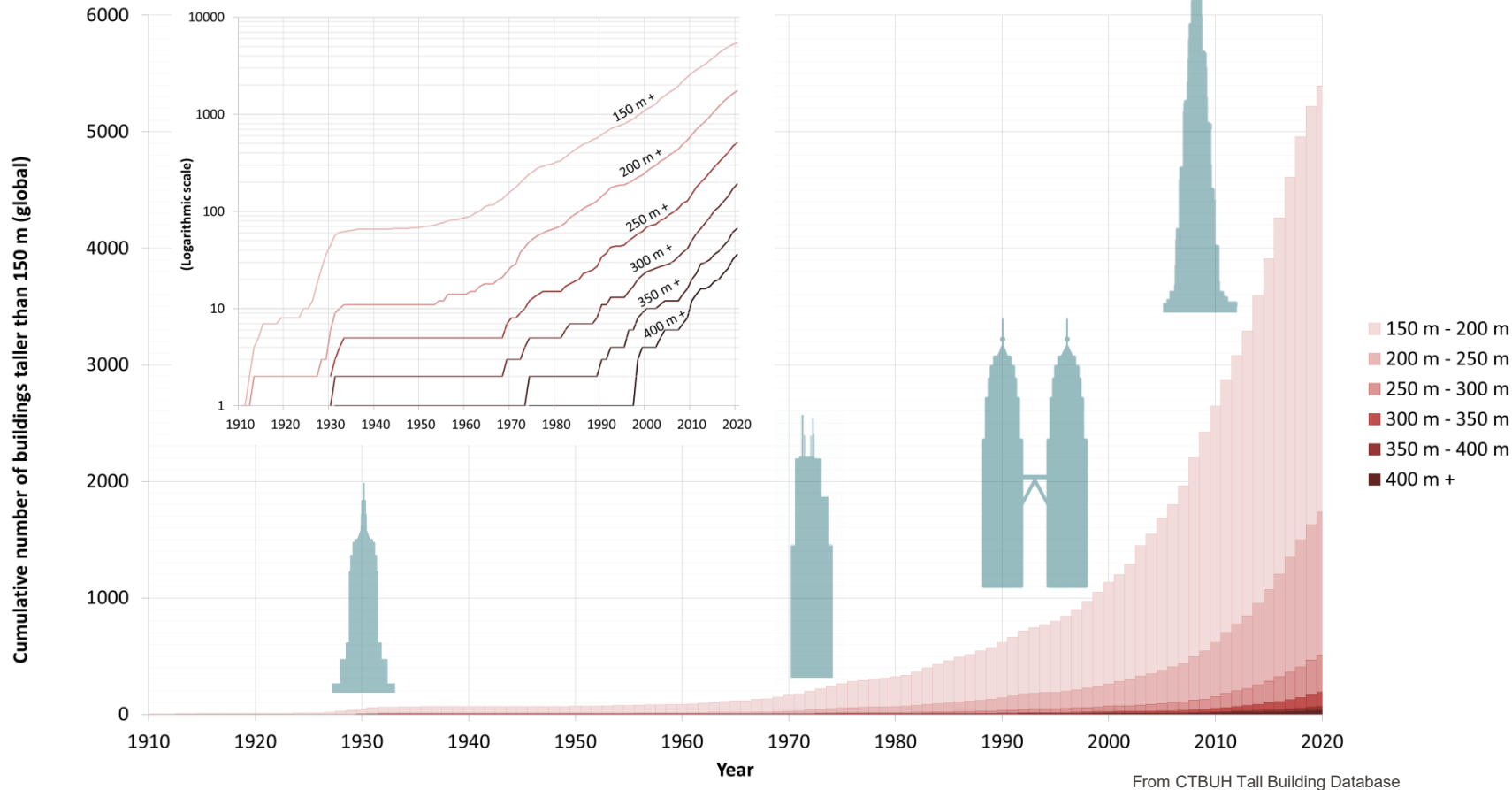


Toronto, Canada – 2030?

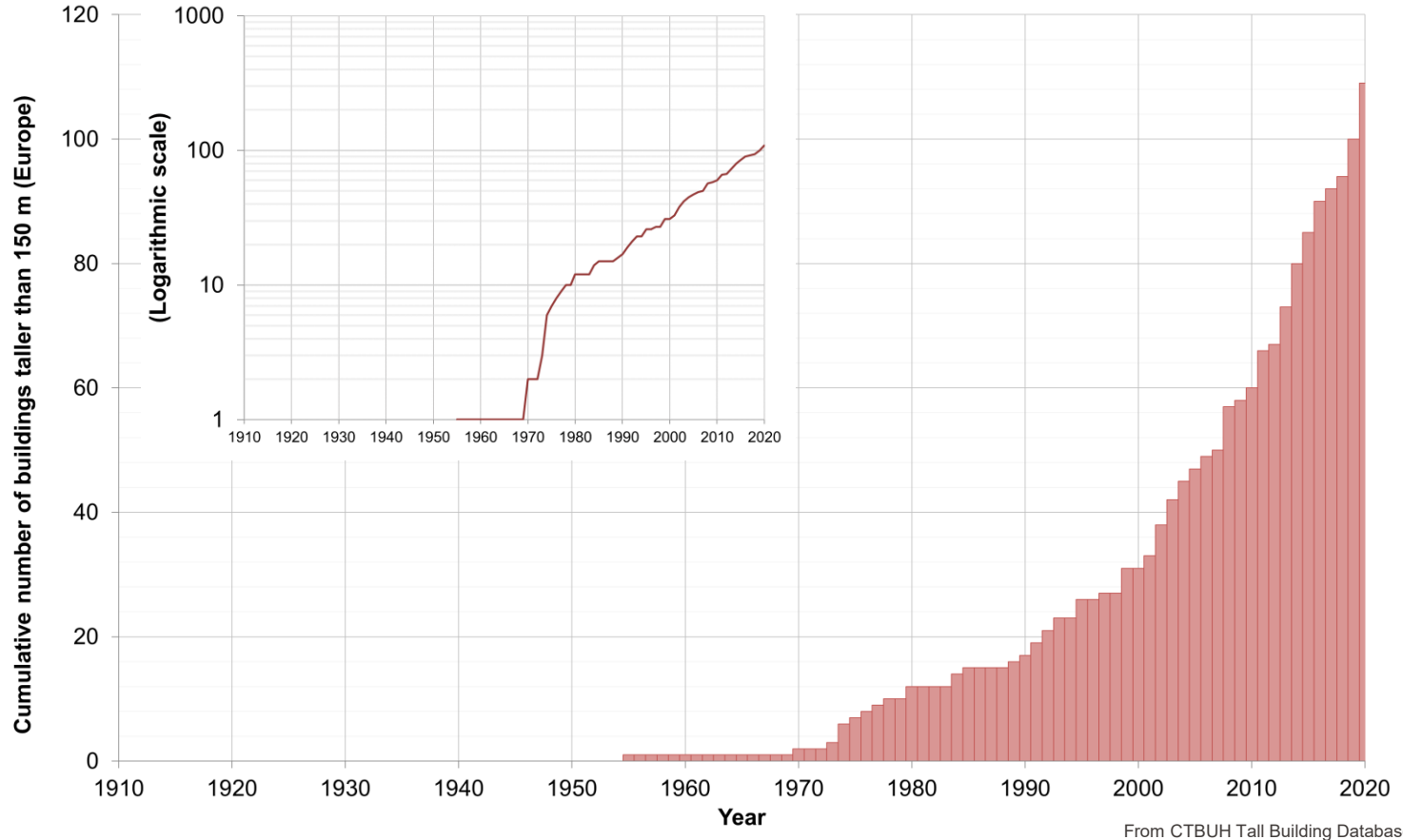


Future Model Toronto

Skyscraper proliferation



Skyscrapers in Europe



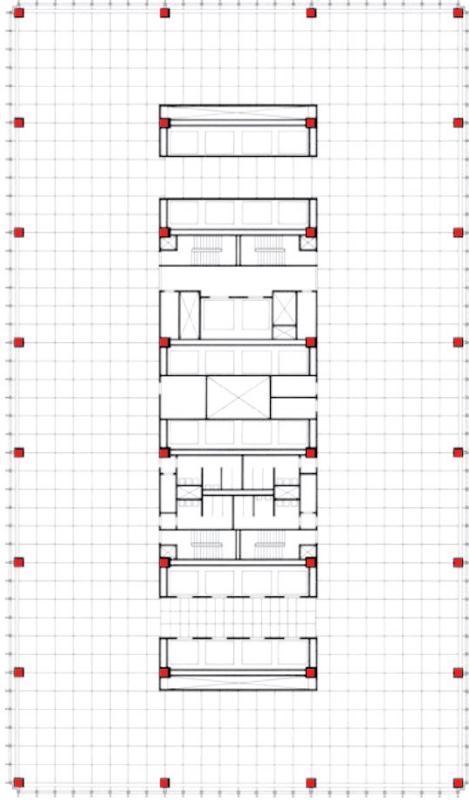
Then ...



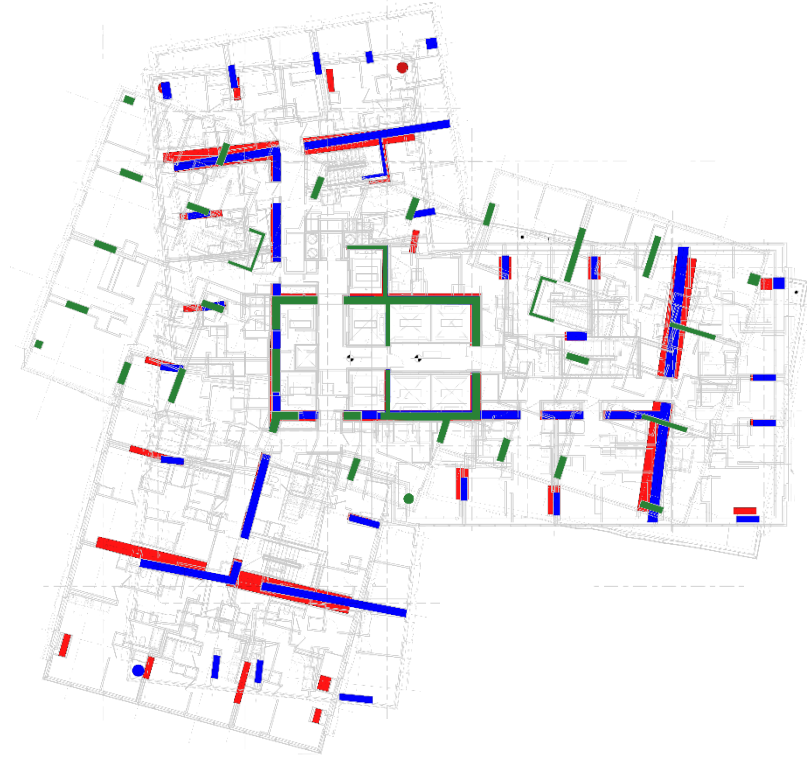
... and now



Then ...



... and now



CIBC Square, Toronto

■ SUSTAINABILITY AT THE STRUCTURAL SCALE

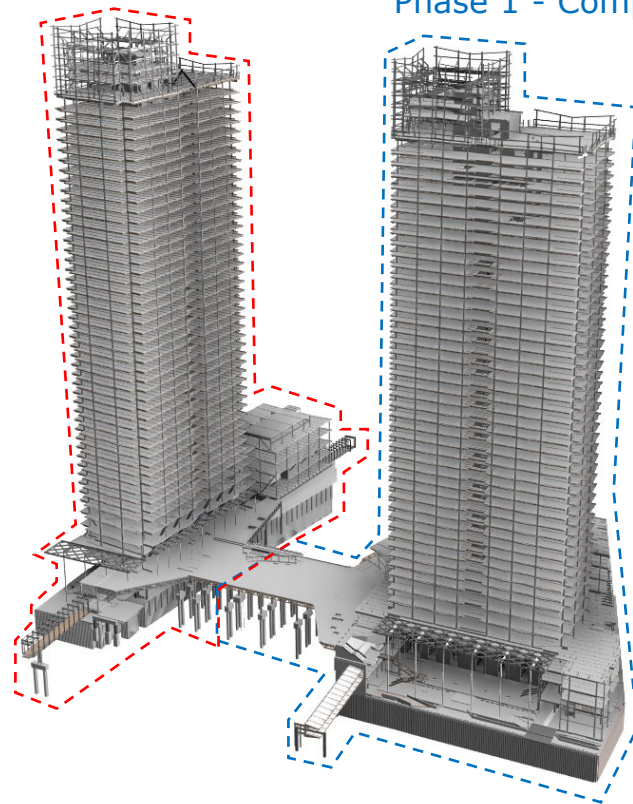
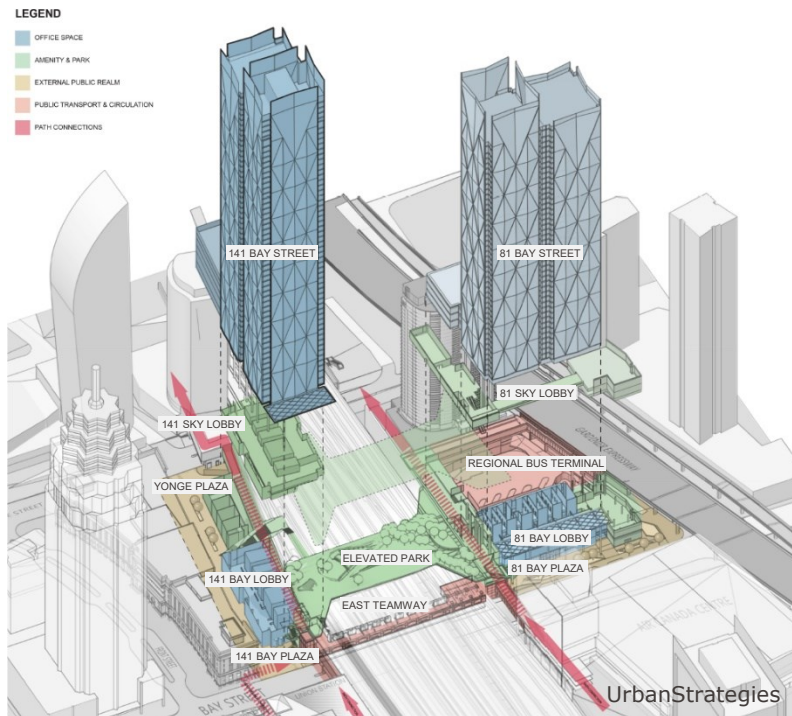


DBOX, WilkinsonEyre

Complex program, constrained site

Phase 2 – Under Construction

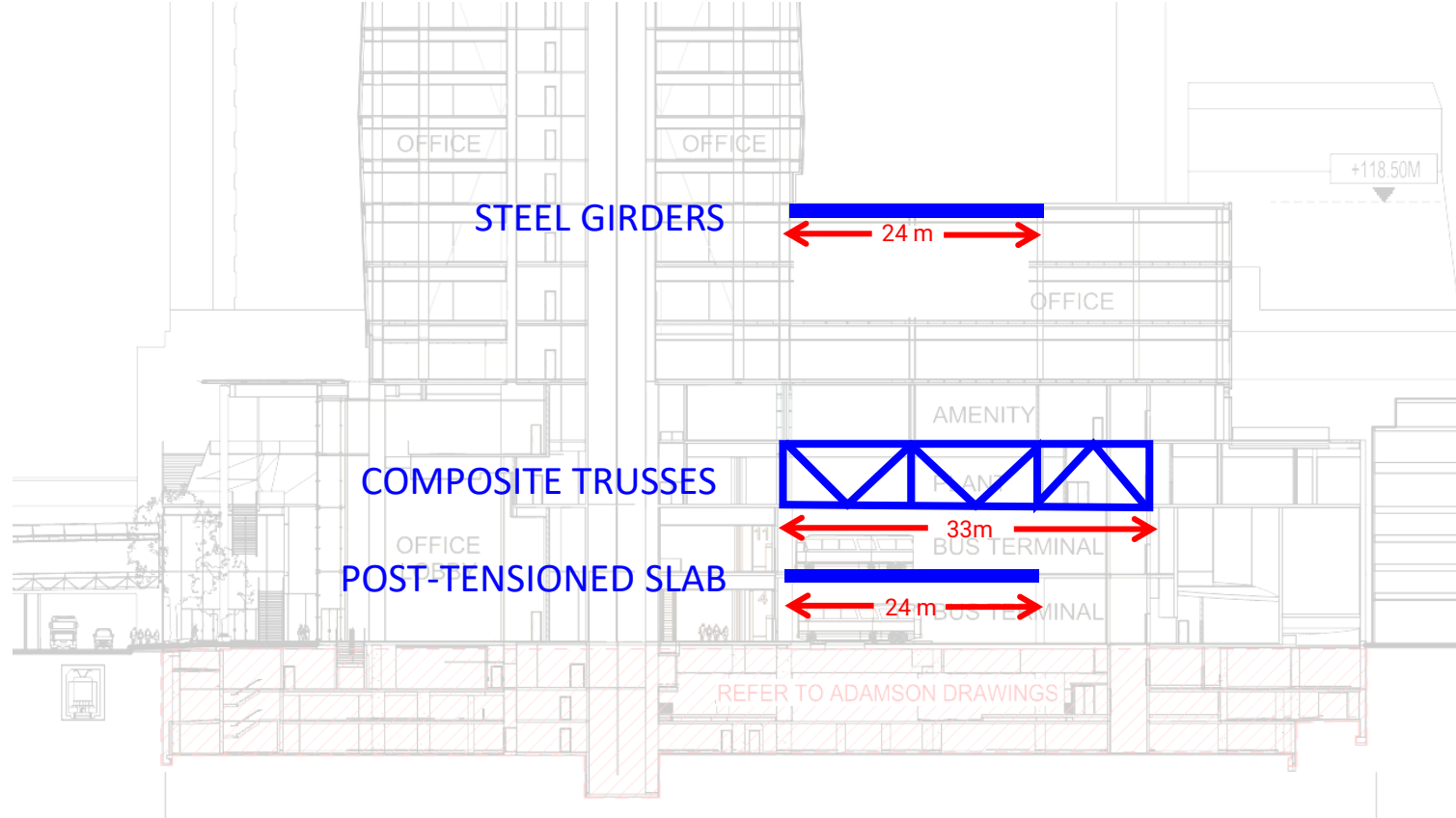
Phase 1 - Complete

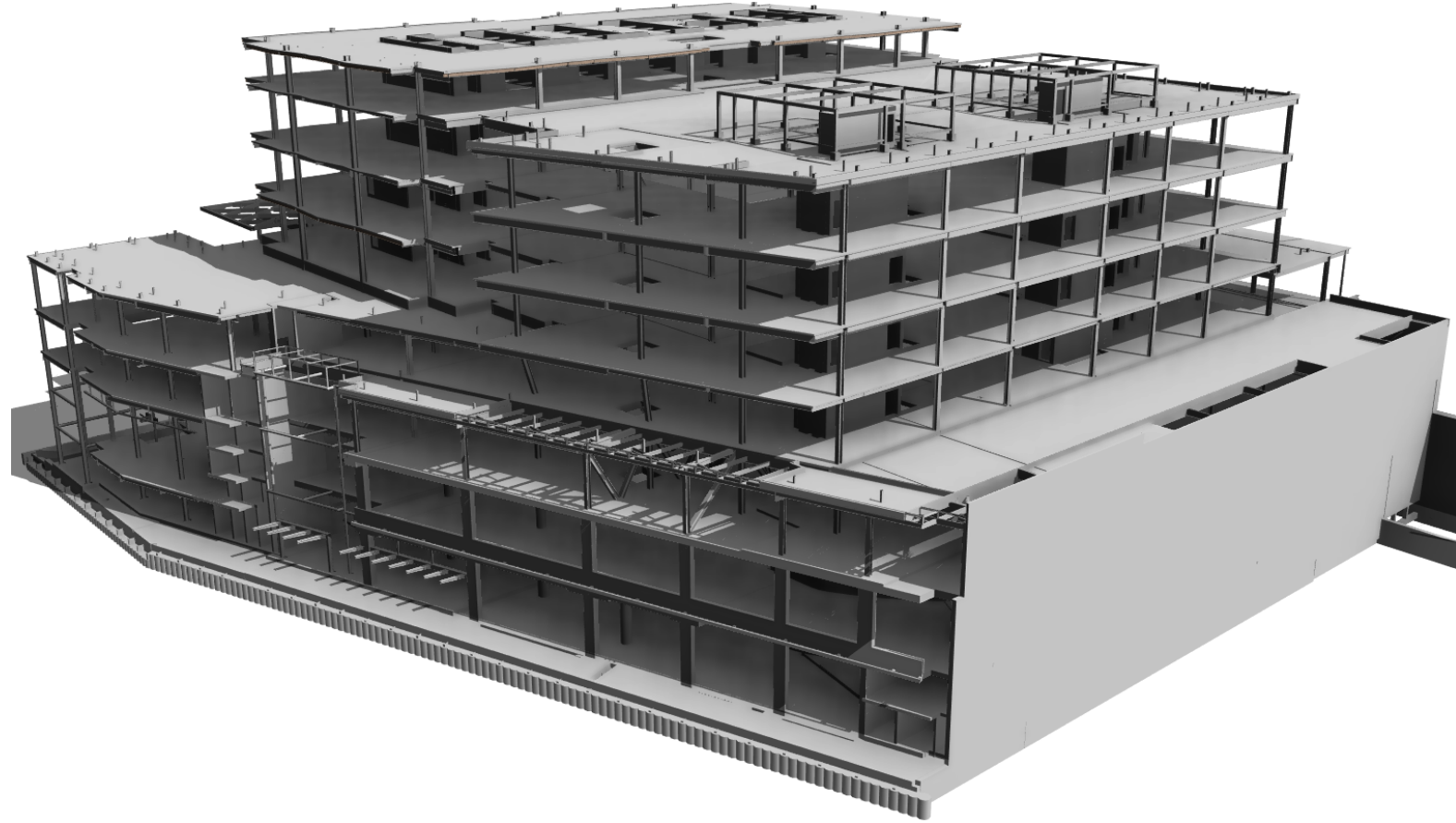




Tower columns









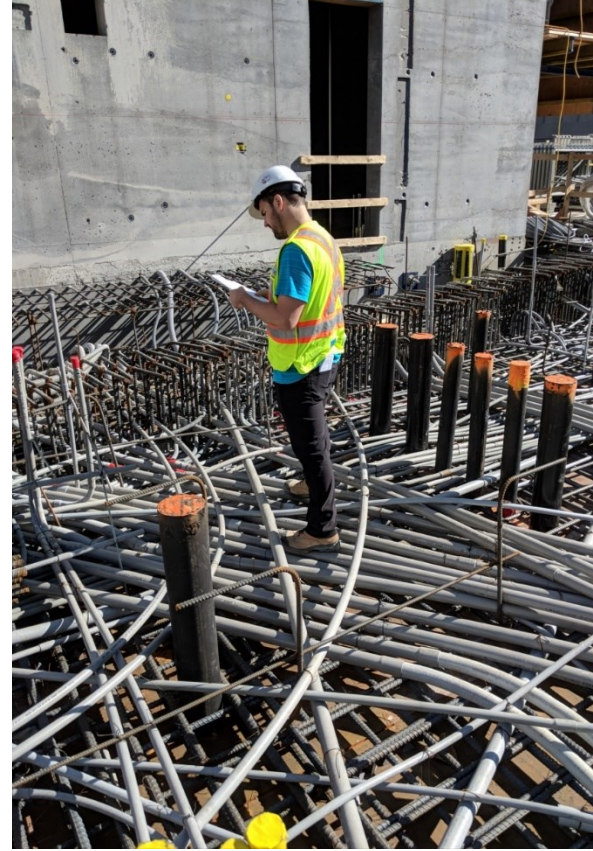








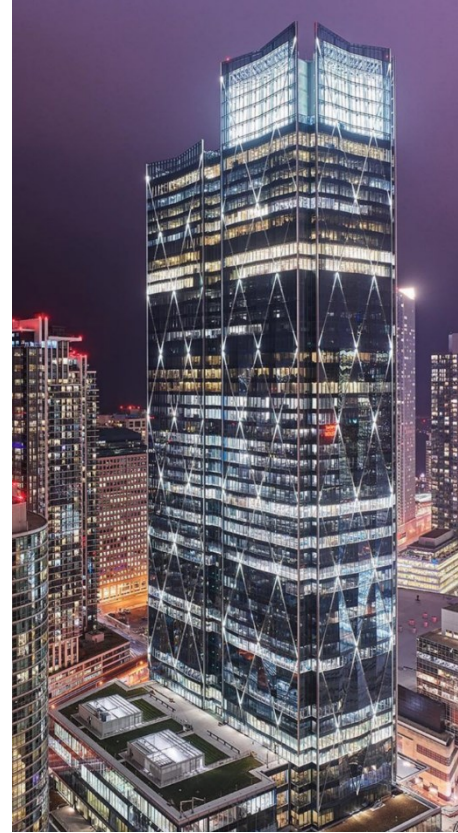
Electrical conduit

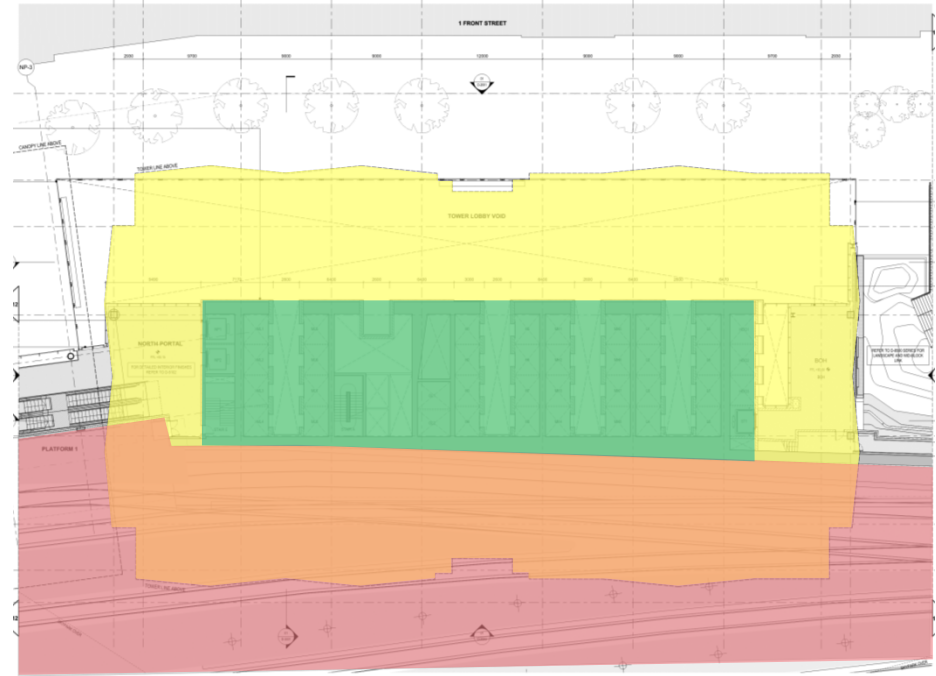
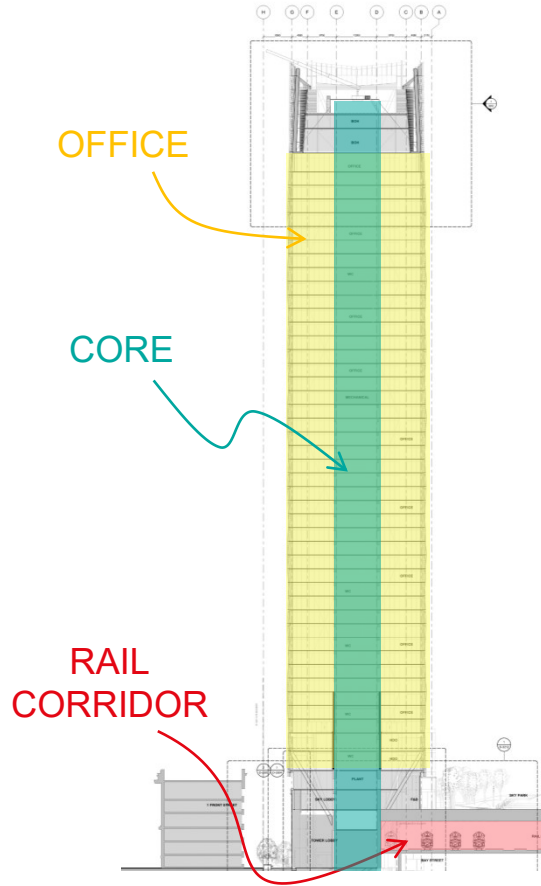


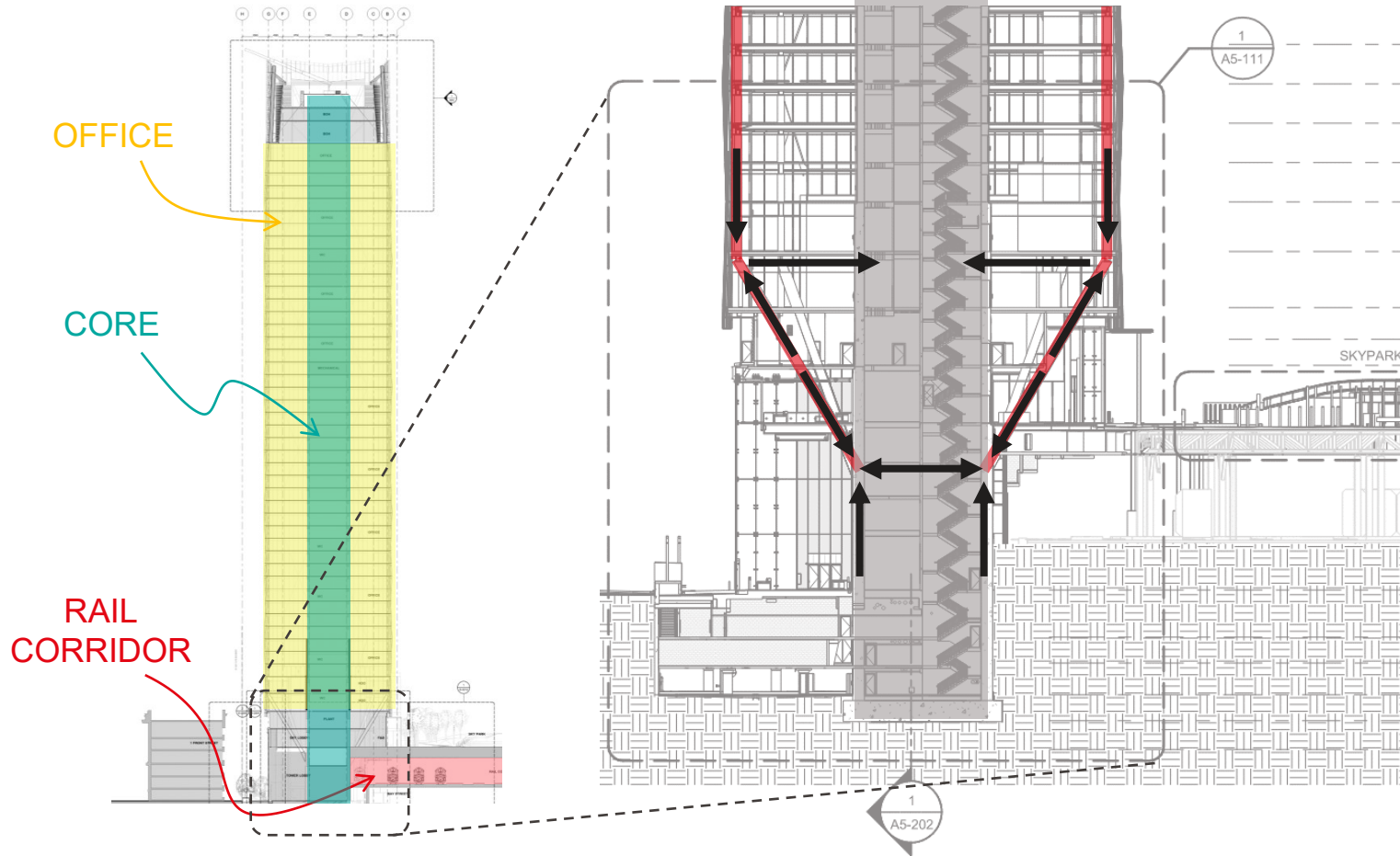
Phase I complete



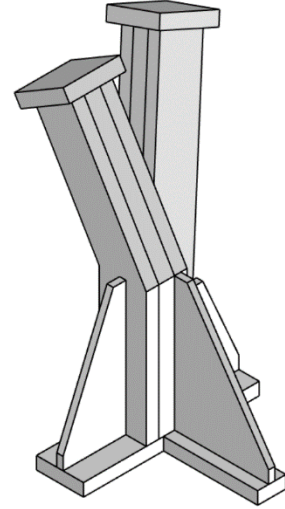
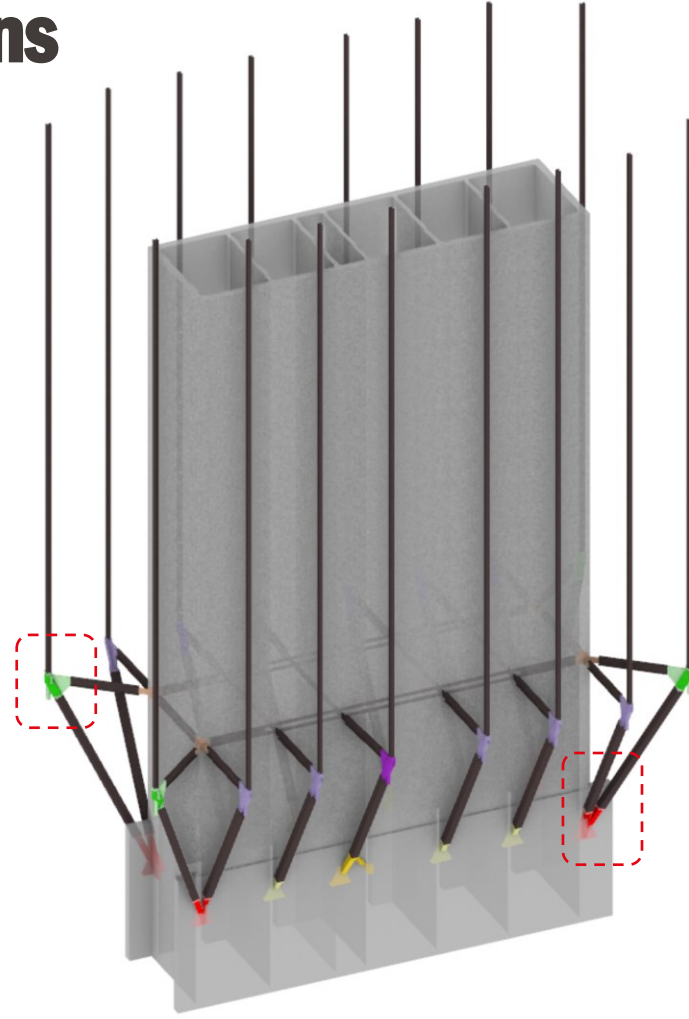
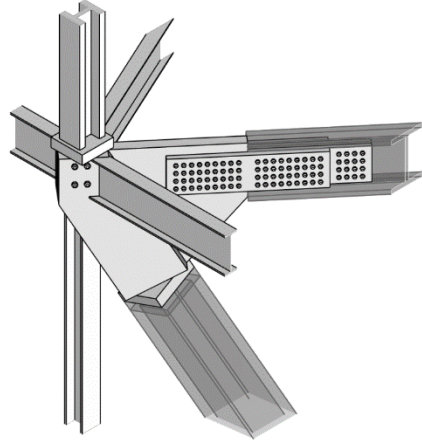
DBOX, WilkinsonEyre, RJC



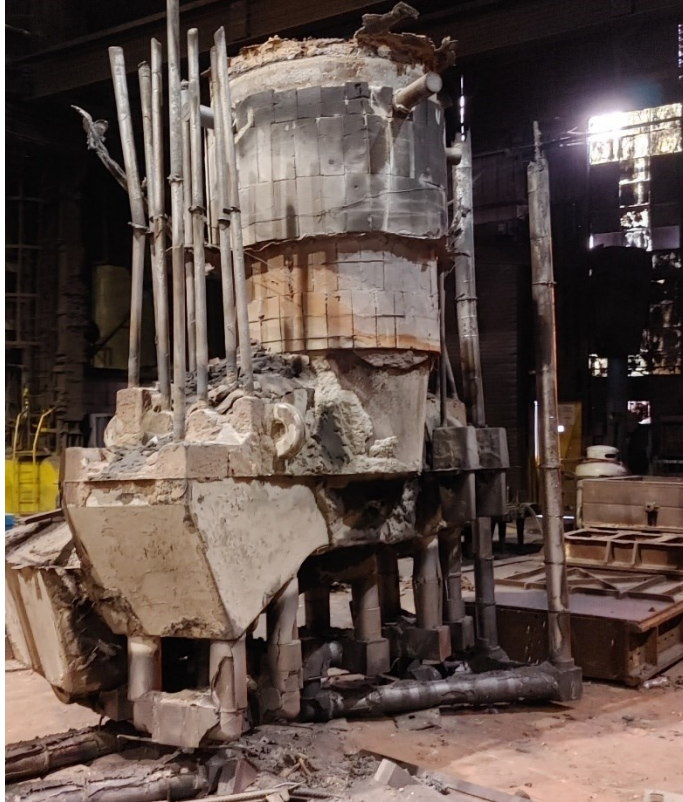




Sloping columns

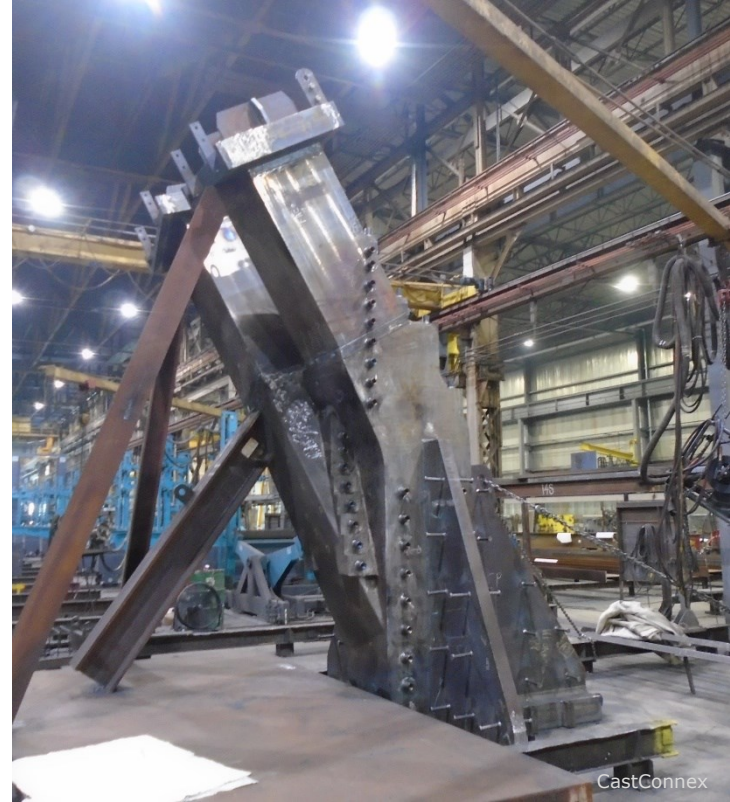


Cast steel nodes



CastConnex

Cast steel nodes



CastConnex

Cast steel nodes



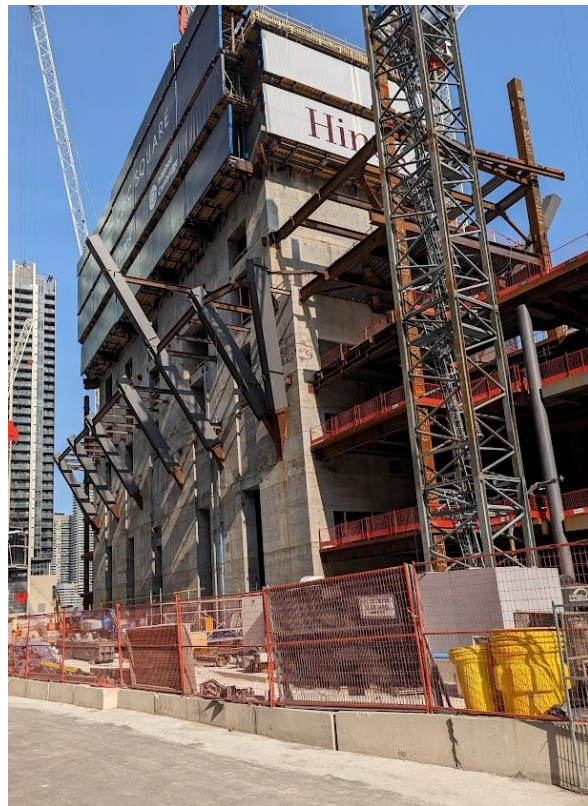
Cast steel nodes



Sloping columns

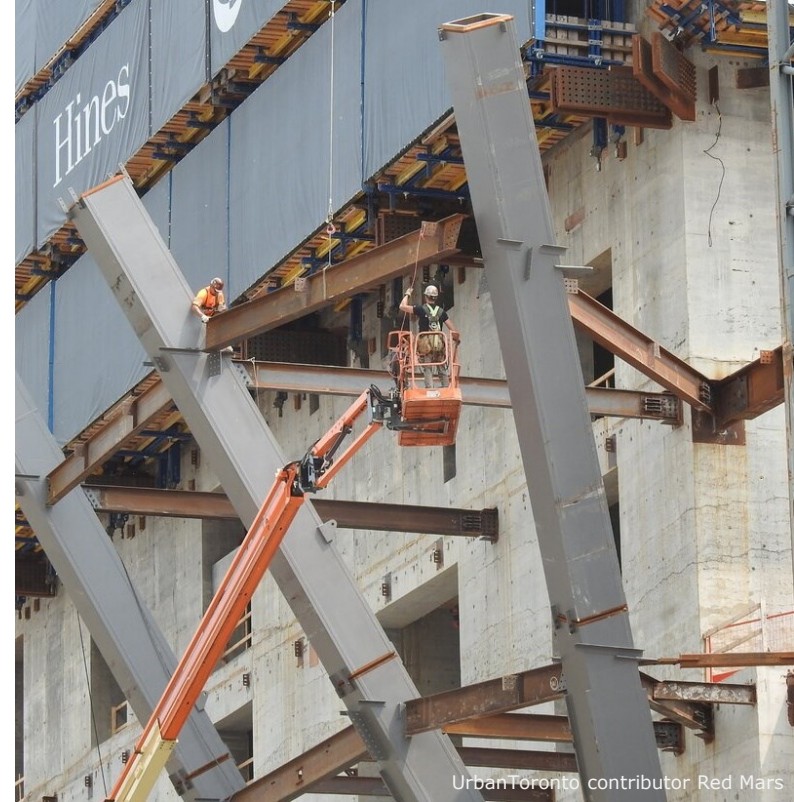


Sloping columns



Hines/Ivanhoé Cambridge

Sloping columns



UrbanToronto contributor Red Mars

Sloping columns



Construction progress



Construction progress



Construction progress



Construction progress



Construction progress



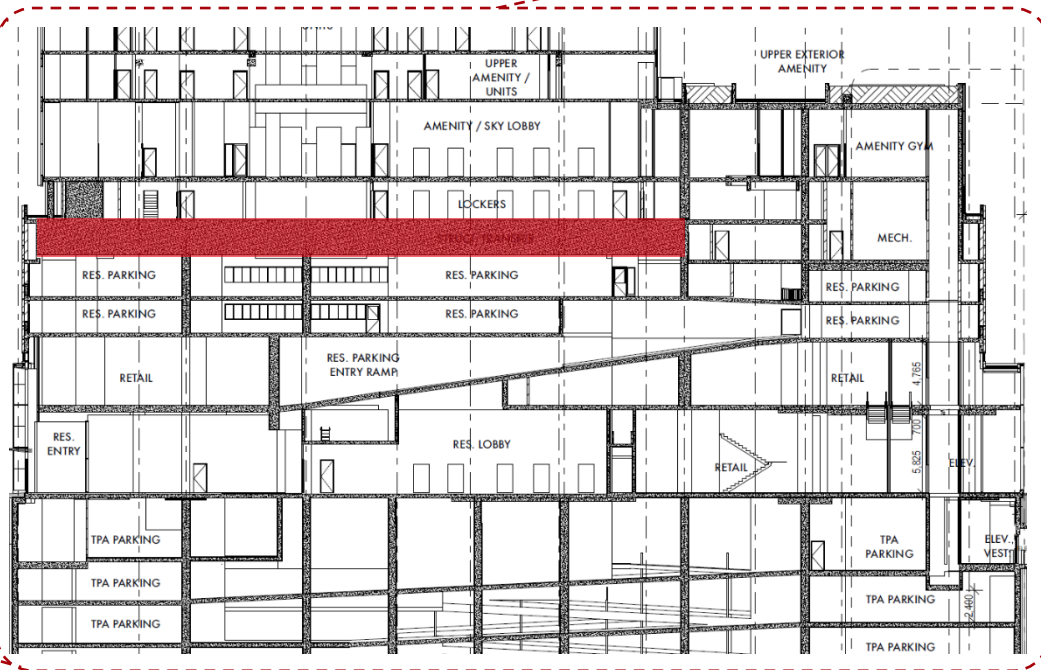
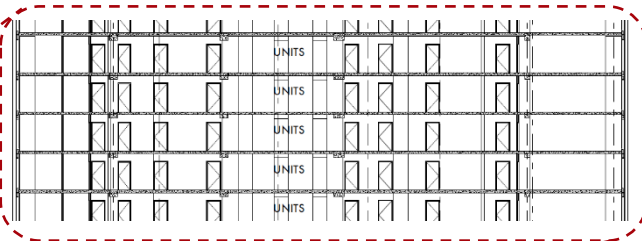
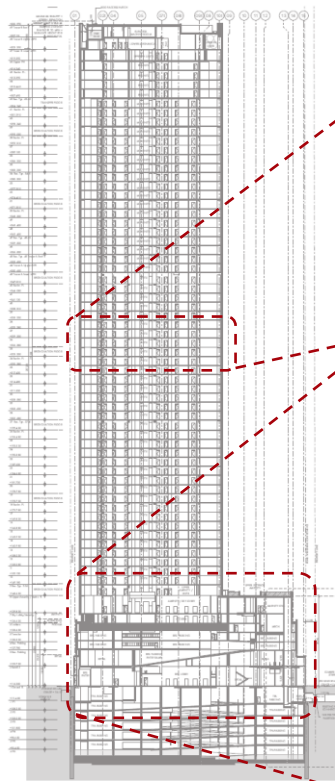
Phil Quach

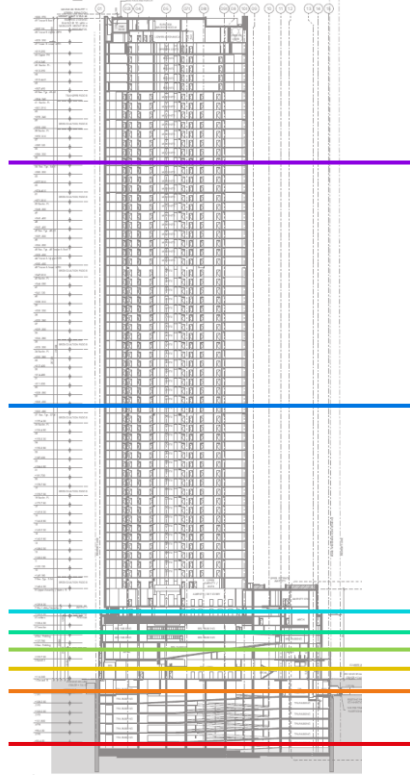


68-storey residential

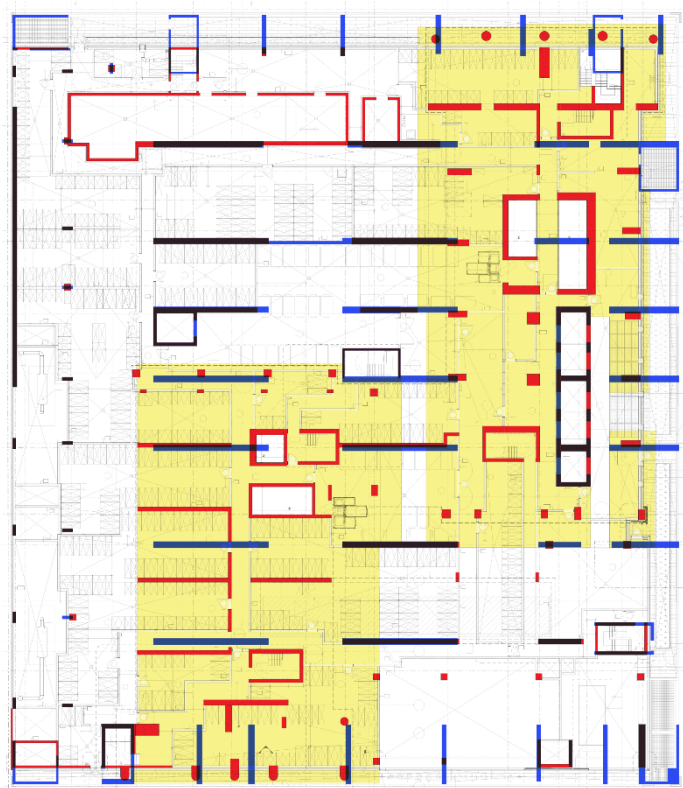


Cross-section

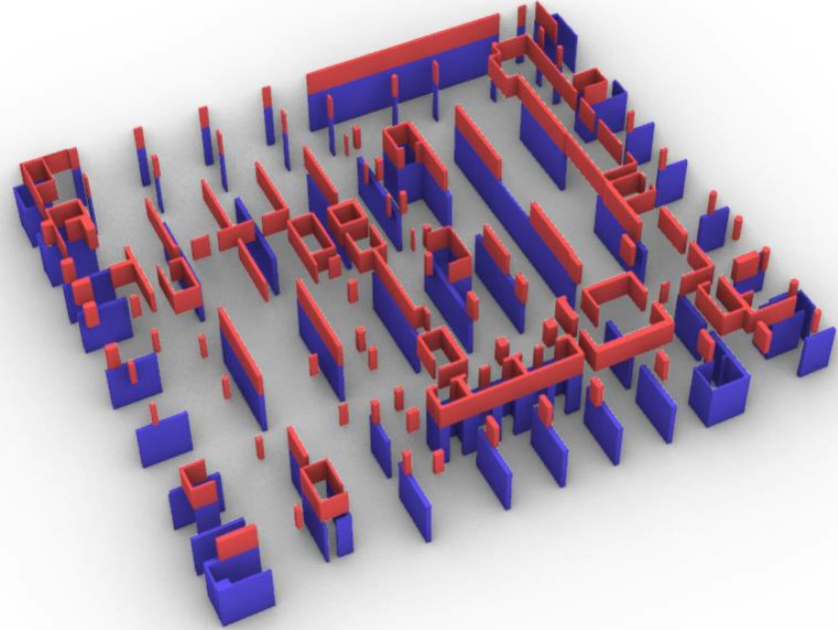




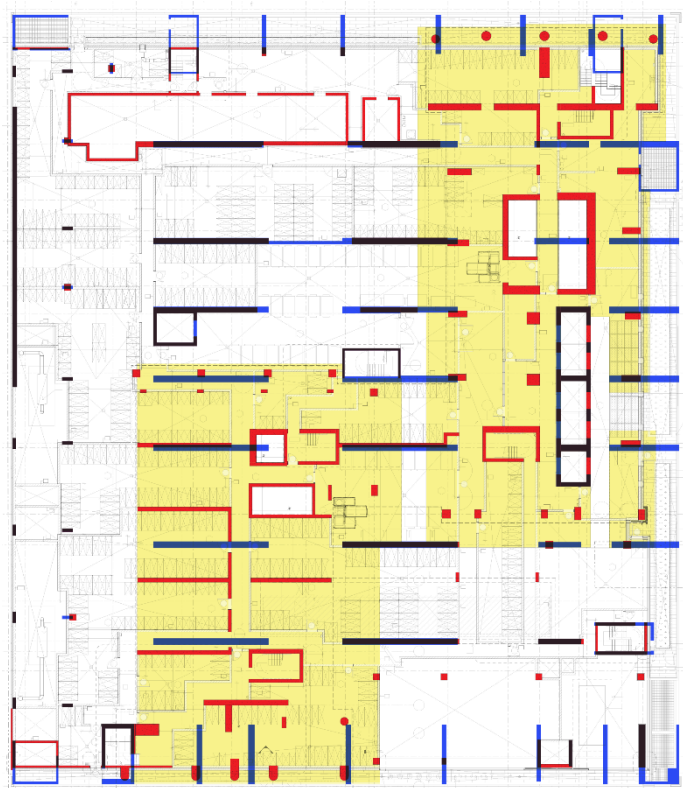
Transfer slabs



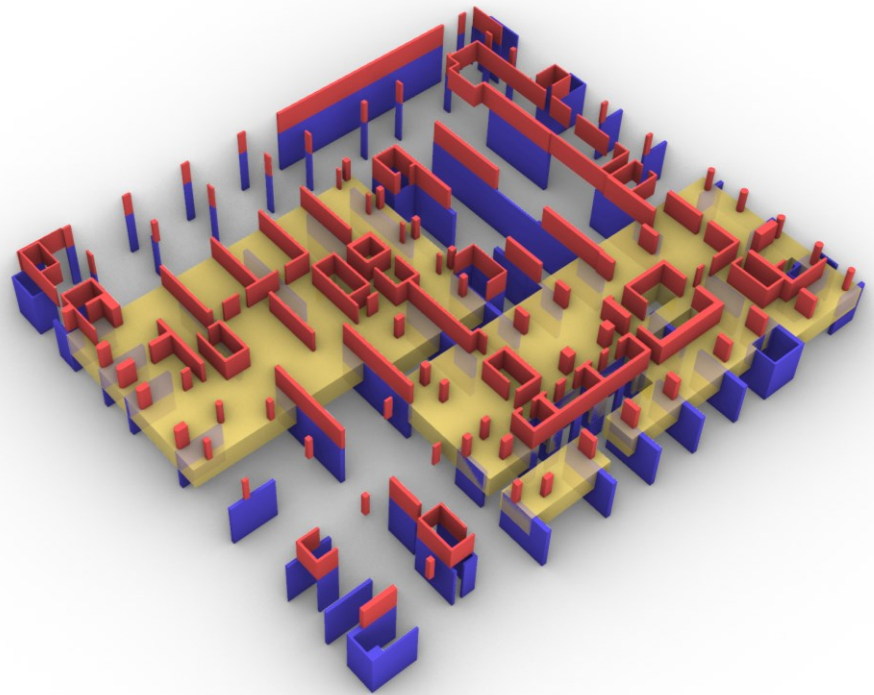
■ Above ■ Below ■ Transfer slab



Transfer slabs



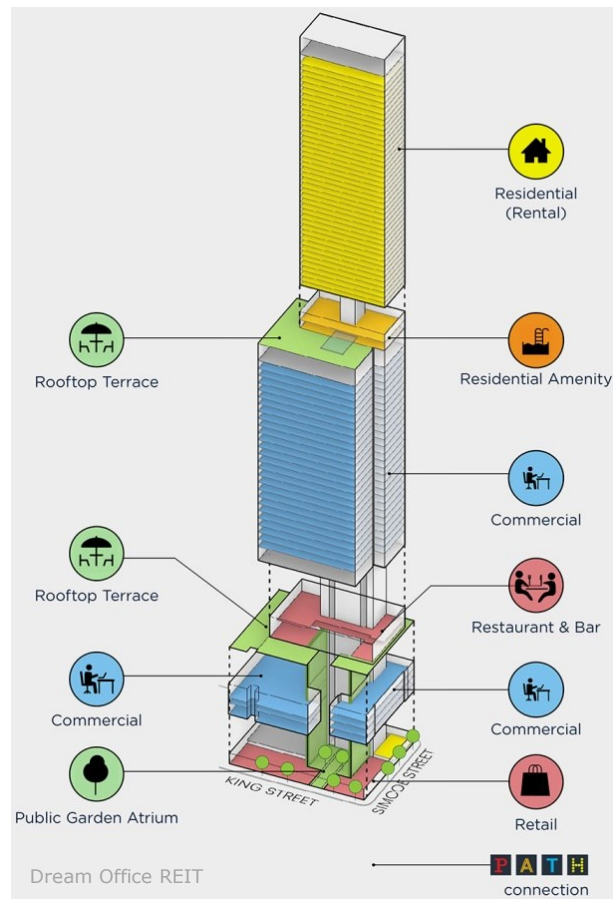
■ Above ■ Below ■ Transfer slab



Transfer slabs

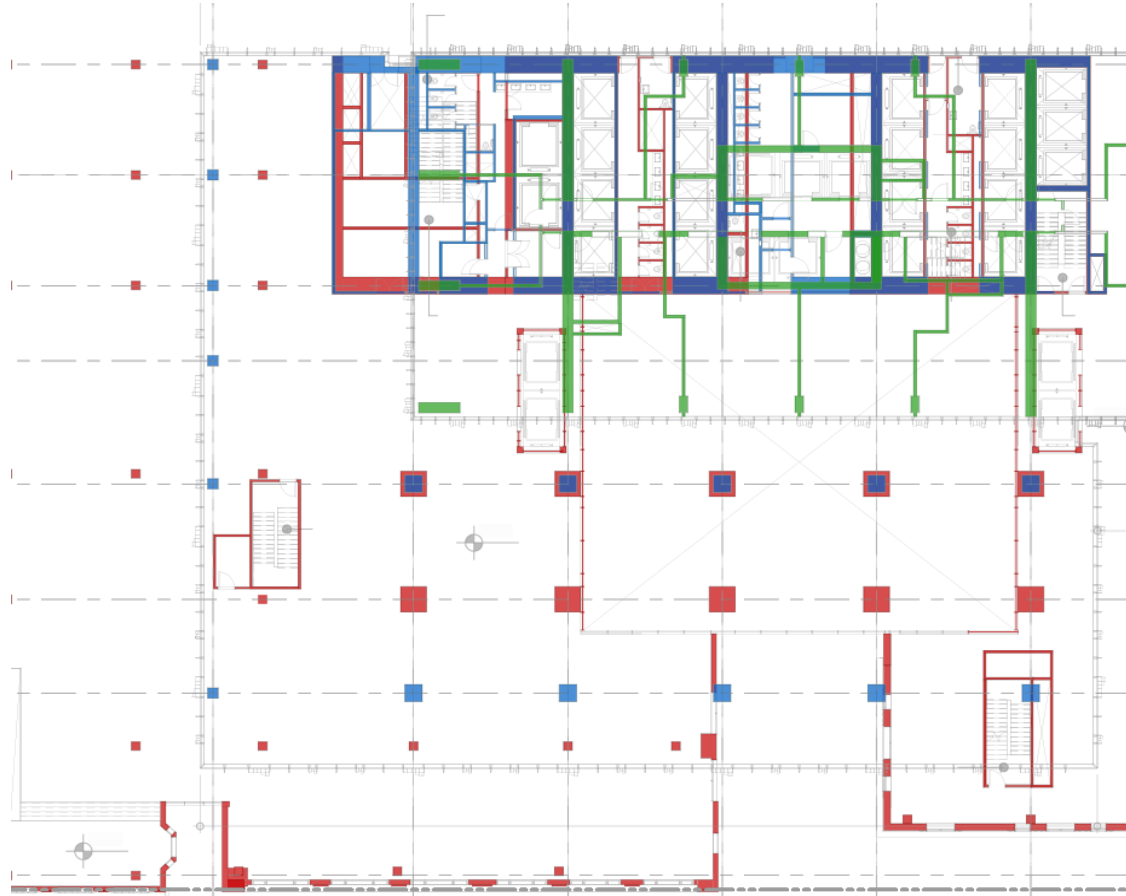


80-storey mixed use

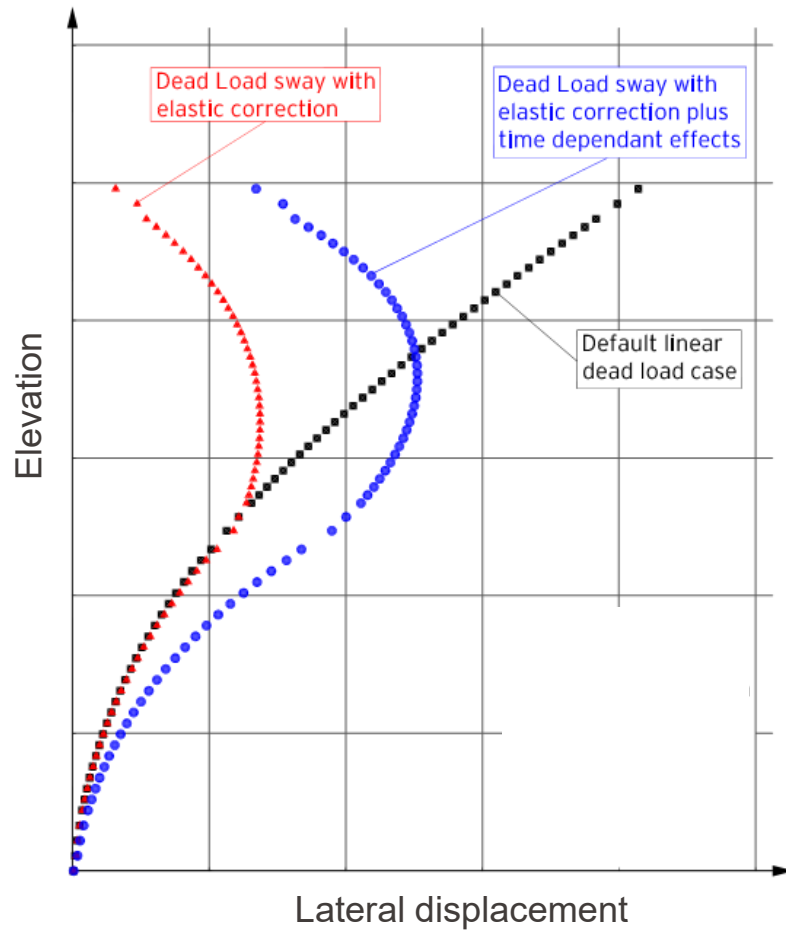
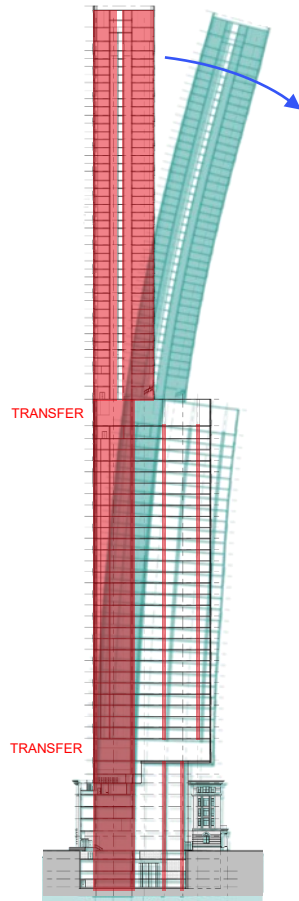


80-storey mixed use

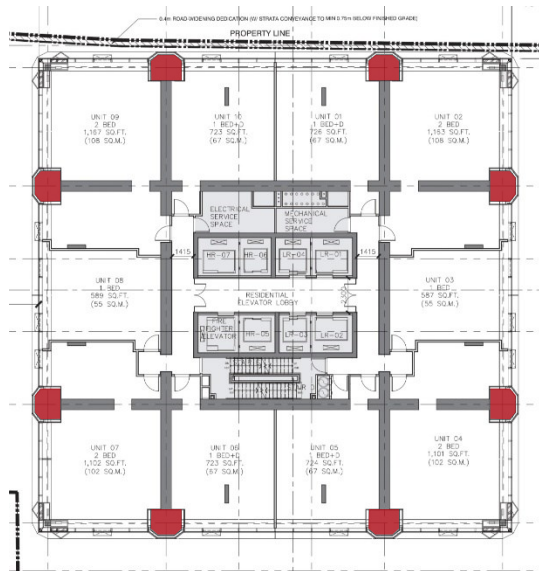




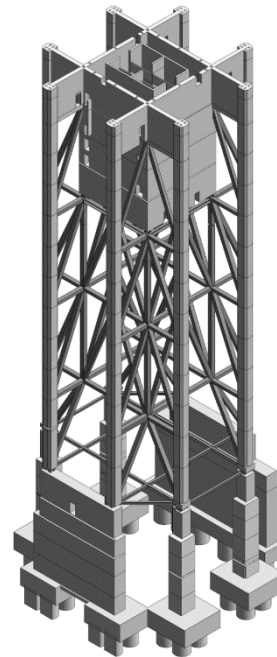
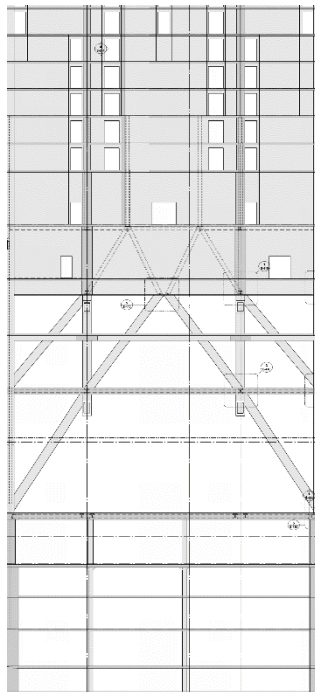
PODIUM
OFFICE
RESIDENTIAL







MEGACOLUMNS



RJC Engineers

1 Bloor St W



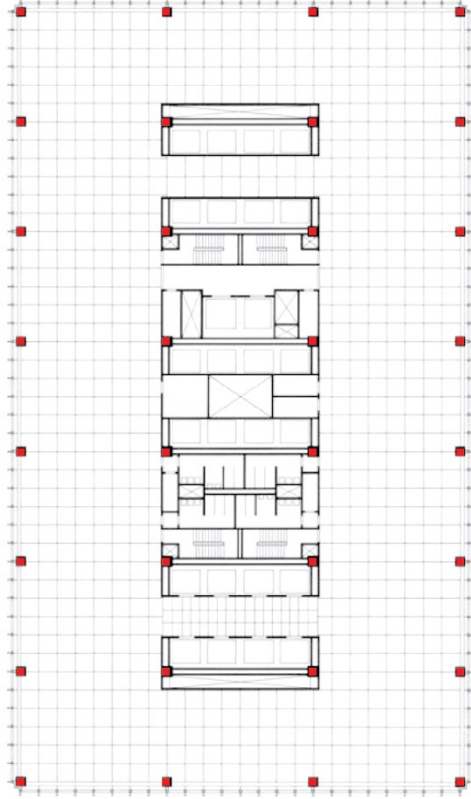
1 Bloor St W



1 Bloor St W



Increasing complexity



Increasing complexity



Increasing complexity



Increasing complexity



Increasing complexity



Increasing complexity



Urban Toronto contributor wmedia

Increasing complexity



Urban Toronto contributor Red Mars

Increasing complexity



Increasing complexity



Increasing complexity



Increasing complexity



Phil Quach

Increasing complexity



Increasing complexity



UrbanToronto contributor Jeff Morgan

Increasing complexity

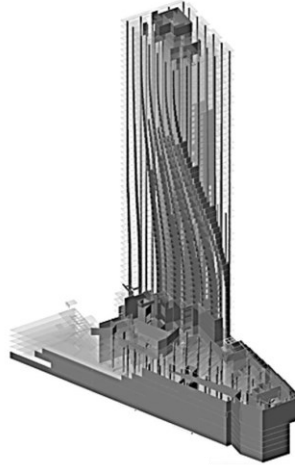
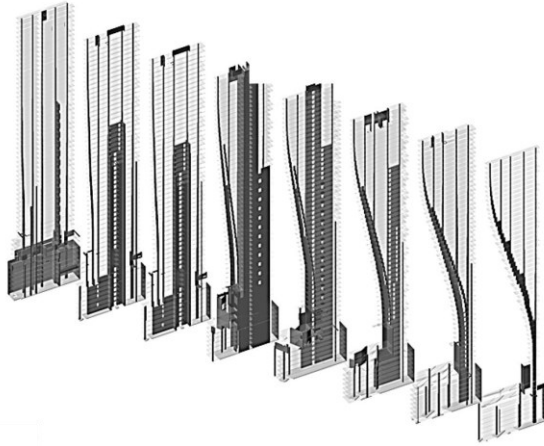


Tim MacDonald

Increasing complexity



Increasing complexity

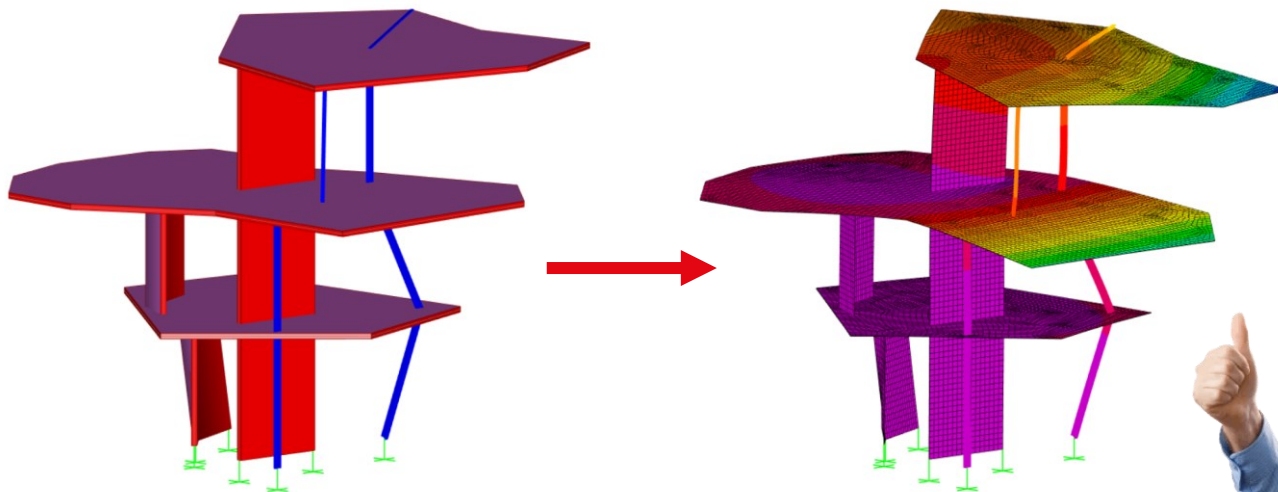


STRUCTURE Magazine



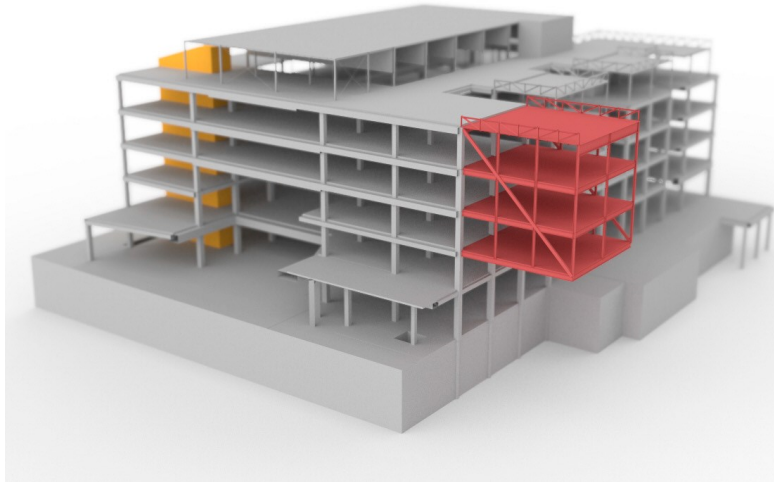
Increasing complexity



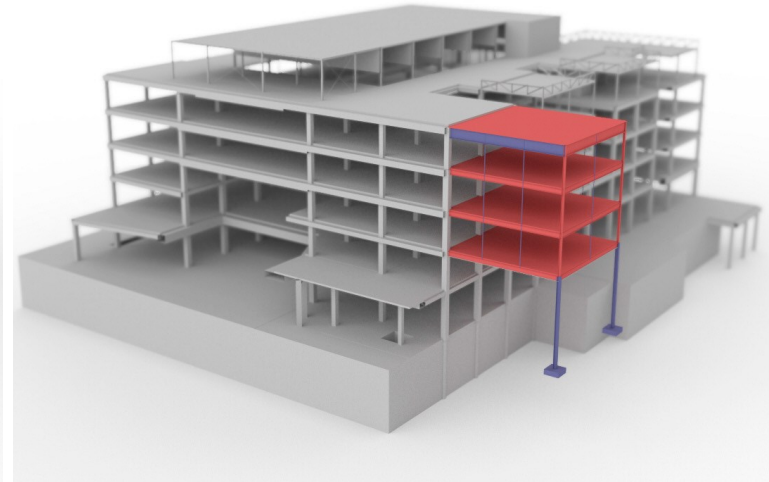


Garbage in ...

... Garbage out

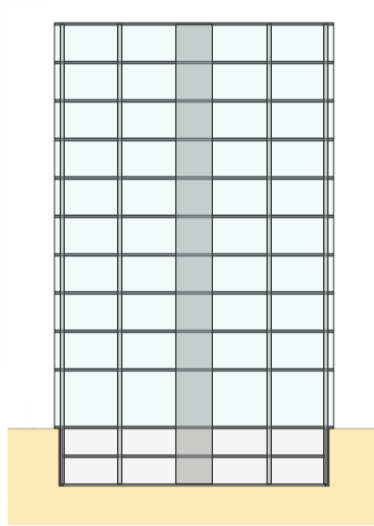


Helal, J.; Trabucco, D.; Ruggiero, D.; Miglietta, P.; Perrucci, G.
Embodied Carbon Premium for Cantilevers. *Buildings* **2024**, *14*, 871.
<https://doi.org/10.3390/buildings14040871>



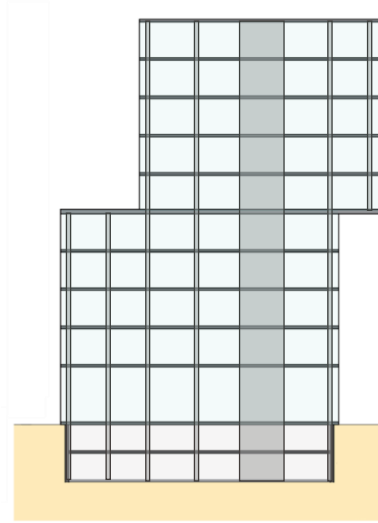
~50% higher embodied carbon
associated with cantilever floor area

Carbon cost of irregularity



~138 kgCO₂e/m²

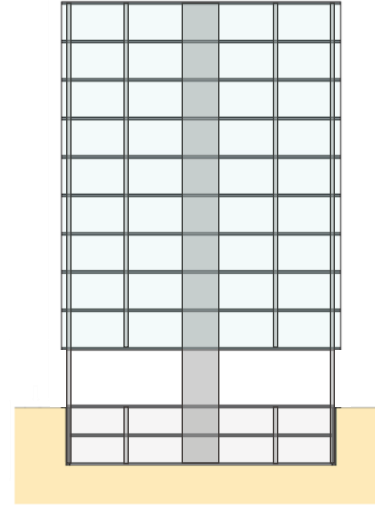
(8 designs)



~154 kgCO₂e/m²

(4 designs)

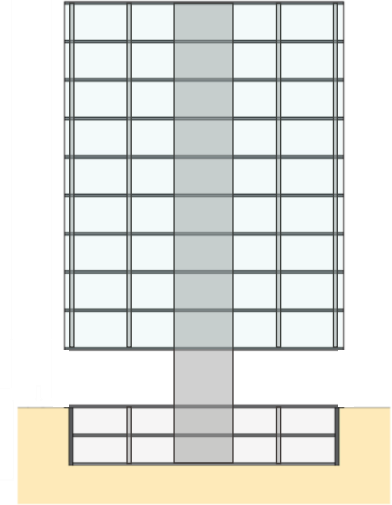
+11%



~189 kgCO₂e/m²

(1 design)

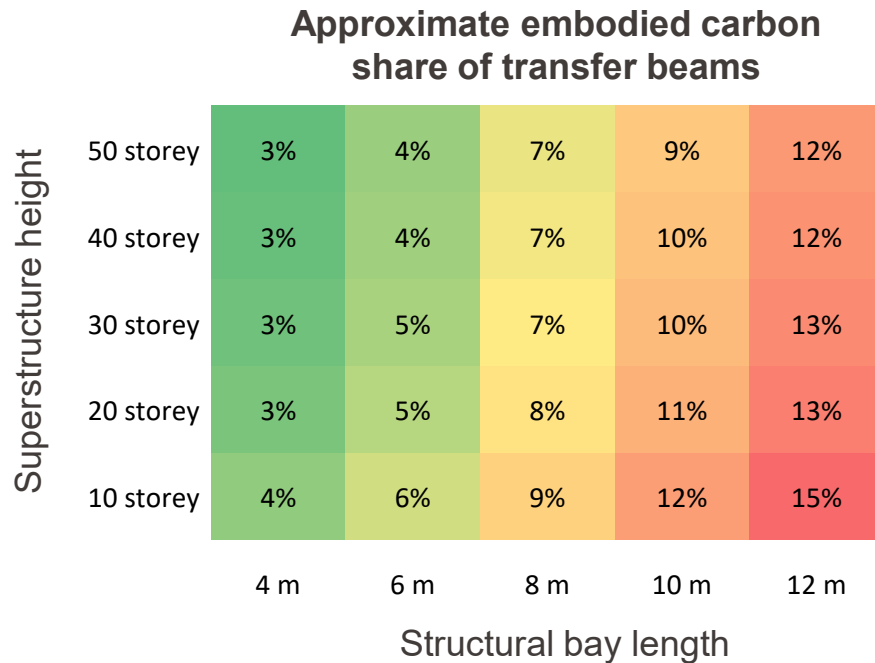
+37%



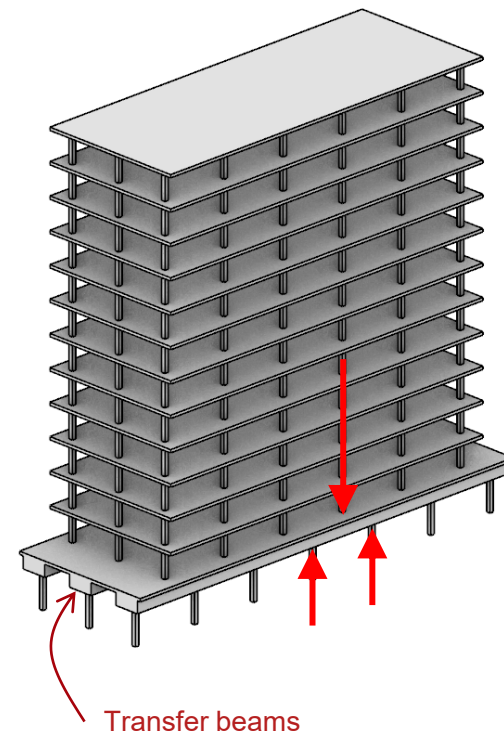
~291 kgCO₂e/m²

(1 design)

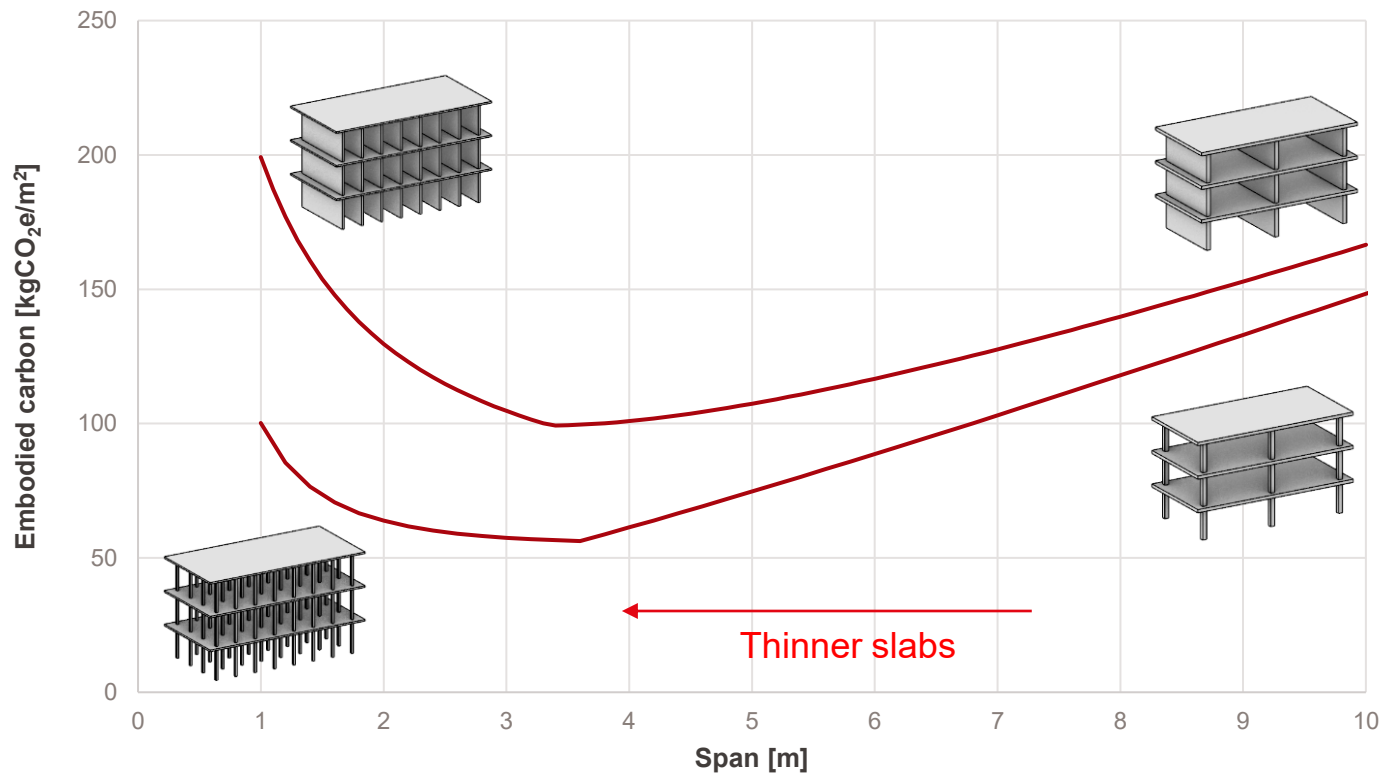
+110%



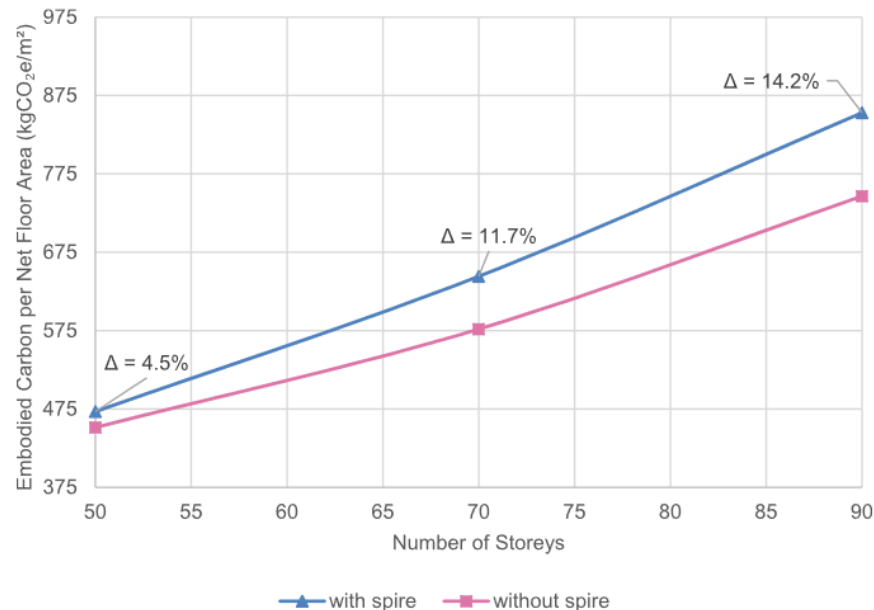
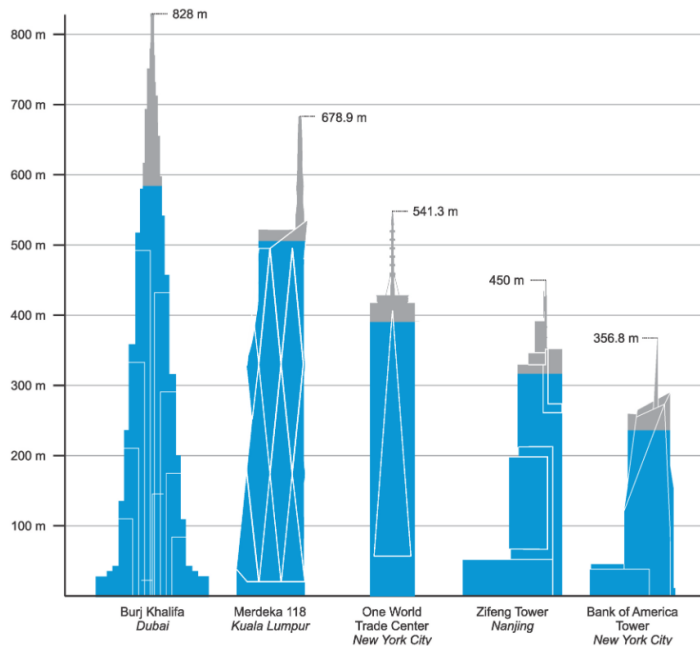
* Relative to gravity system (slabs + columns); no foundations



Carbon cost of long spans

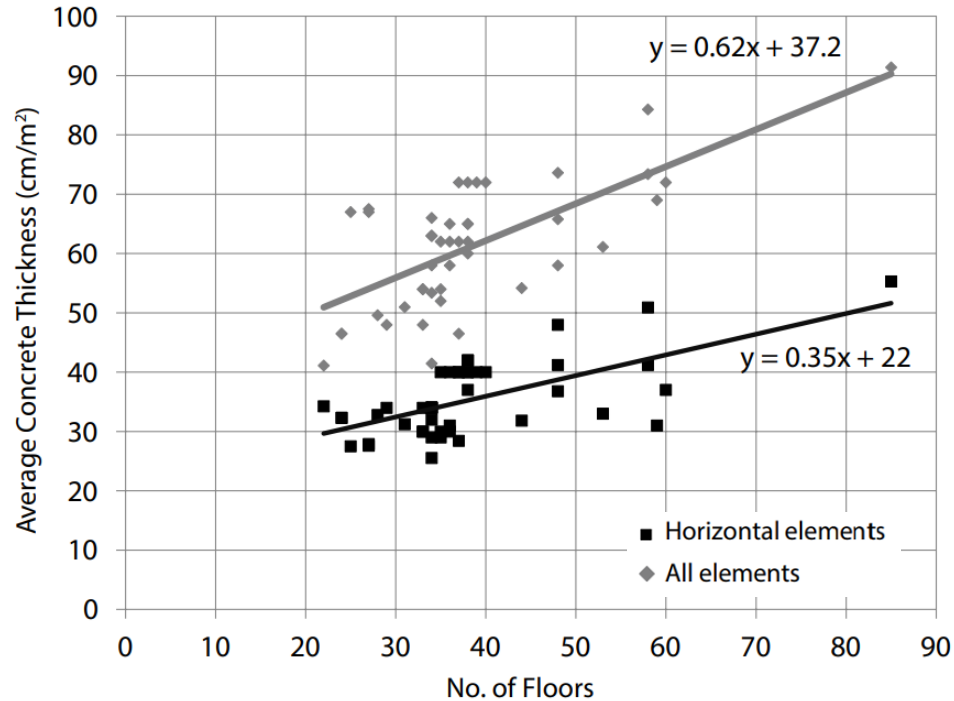


Carbon cost of vanity spires

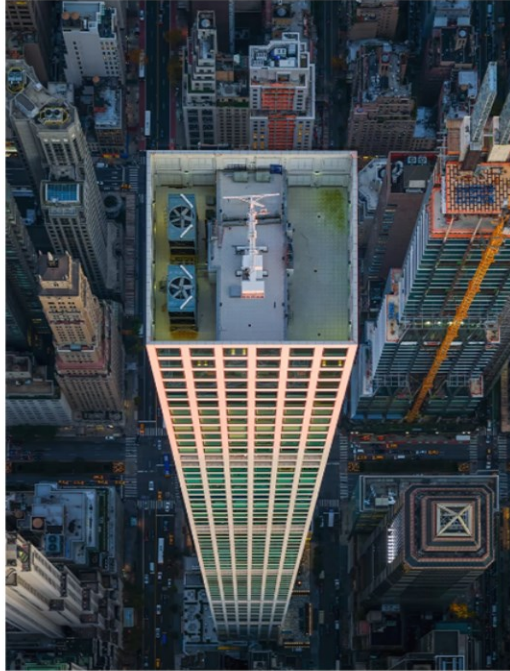


Helal, James, Dario Trabucco, and Dalibor Savovic. 2024. 'Embodied Carbon Premium for Vanity Height: A Case for the Exclusion of Decorative Spires in the Design of Tall Buildings'. *Journal of Cleaner Production* 456 (June):142334.

Carbon cost of height



Ali Sherif S. Rizk Director, Dar al-Handasah Shair and Partners (2010). "Structural Design of Reinforced Concrete Tall Buildings". In: CTBUH Journal.



TECHNOLOGY

HOW TALL IS TOO TALL?

The rise and rise and rise of the supertall skyscraper

By Bianca Bosker

Photographs By Jeffrey Milstein

The Atlantic

January/February 2023 Issue

Vanity projects – 11th century



Vanity projects – 21st century



The Guardian







Stefano Boeri



IMPACT ENVIRONNEMENTAL

INSTALLATION D'ARBRES SUR LES BALCONS

TOUR DES CÈDRES

1008 CHAVANNES-PRÈS-RENNES

« En prenant en compte les éléments analysés de la structure porteuse, l'installation d'arbres sur les balcons représente une **augmentation ... de 65.9 % l'émission de gaz à effet de serre** dues en comparaison d'une variante sans arbres. »

« En effet, les promoteurs du projet mettent en avant les vertus environnementales de l'installation de **80 arbres** et 3'000 m² d'arbustes sur le projet de la Tour des Cèdres ... [L]a compensation des émissions de CO₂ sur un horizon temporel de 60 ans nécessiterait de planter environ **20'000 arbres** au moment de la construction. »

AUTEUR JULIEN PATHÉ
VERSION / REF 9 AOUT 2023 / 22.63
CONTACT julien.pathe@2401.ch / 021 510 29 09

Société coopérative 2401 - Avenue des Alpes 50 - 1820 Montreux - contact@2401.ch - Construire durable ensemble

Julien Pathé – Société cooperative 2401

The future?



Matthew Borrett

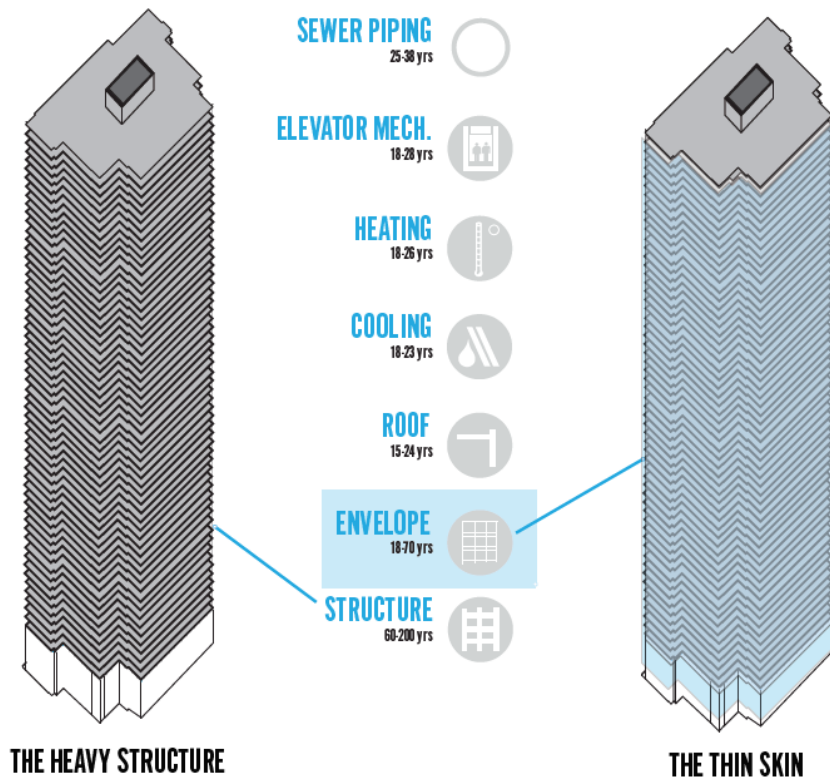
The present



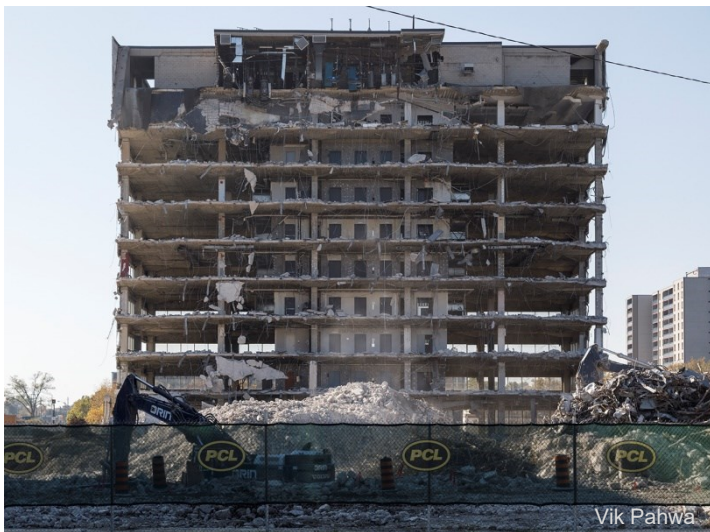
Iwan Baan



Wikipedia



Building resilience in condoland, SPACING magazine



Vik Pahwa

39 years old



1899 years old

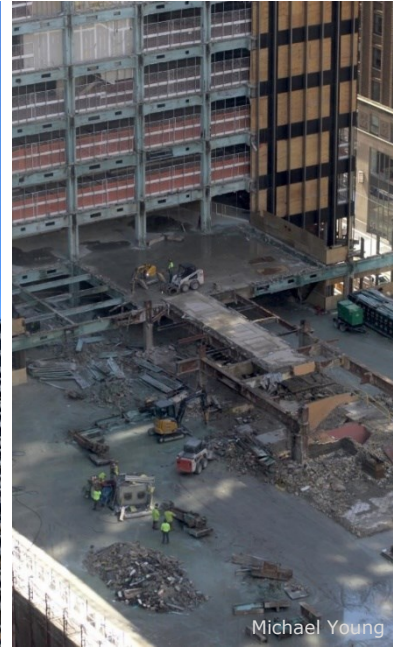
Skyscraper demolition



Google Earth



Wikimedia Commons



Michael Young

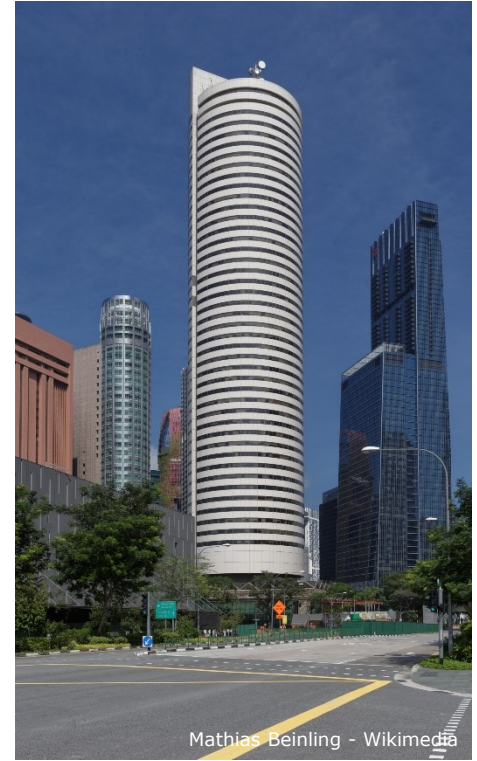


Michael Young

Skyscraper demolition



Vincent Cheang - YouTube



Mathias Beinling - Wikimedia



[Skyscrapers] need to be designed to be **never taken down**, such that their life cycle is as **close to forever** as you can get... No-one's talking about when the **pyramids** are going to come down.

Antony Wood, Executive Director of the Council on Tall Buildings and Urban Habitat (CTBUH)

Complexity

Inefficient structures

Materials

High cement content

Decommissioning

No plan for demolition

Obsolescence

Lack of adaptability

Polymakers

- Specify baseline requirements for life cycle assessments
- Review building setback requirements
- Establish maximum parking ratios
- Focus on number of units rather than height limits
- Review maximum floor plate sizes
- Prioritize projects which incorporate adaptive reuse

Developers

- Design beyond code minimums to allow for longer life span
- Incorporate longer cure times in concrete elements
- Lay out suites to reduce horizontal span distances
- Reinvent the lobby/retail space to avoid double height, open lobbies

Designers

- Quantify embodied carbon
- Advocate for responsible building practices as professionals
- Refine and optimize the scheme to minimize transfers
- Employ adaptive reuse rather than reconstruction



- Estimating embodied carbon from bottom-up quantities



- Statistically predicting embodied carbon



- Exploring or optimizing the parametric design space



- Comparing design concepts, case studies, and benchmarks



- Using less material



- Using low-carbon and carbon-sequestering materials



- Designing for reuse and reusing structural elements



- Adaptively reusing whole structures and designing for longevity



- Reducing construction and demolition waste



- Reducing load demands



- Exploiting standardization and/or customization



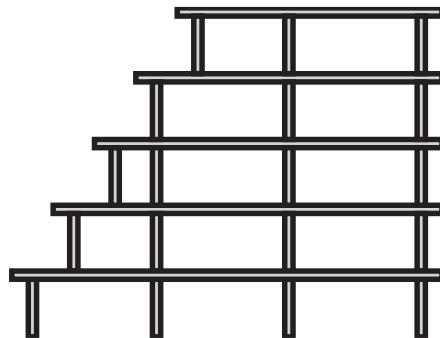
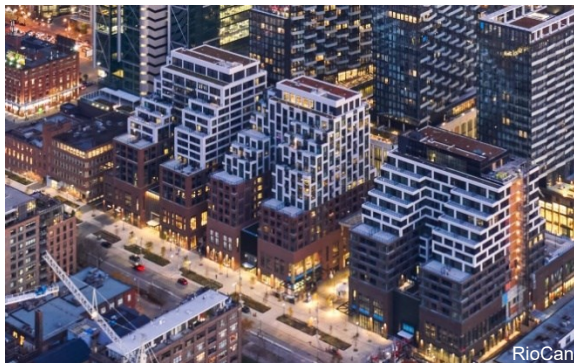
- Implementing active structures



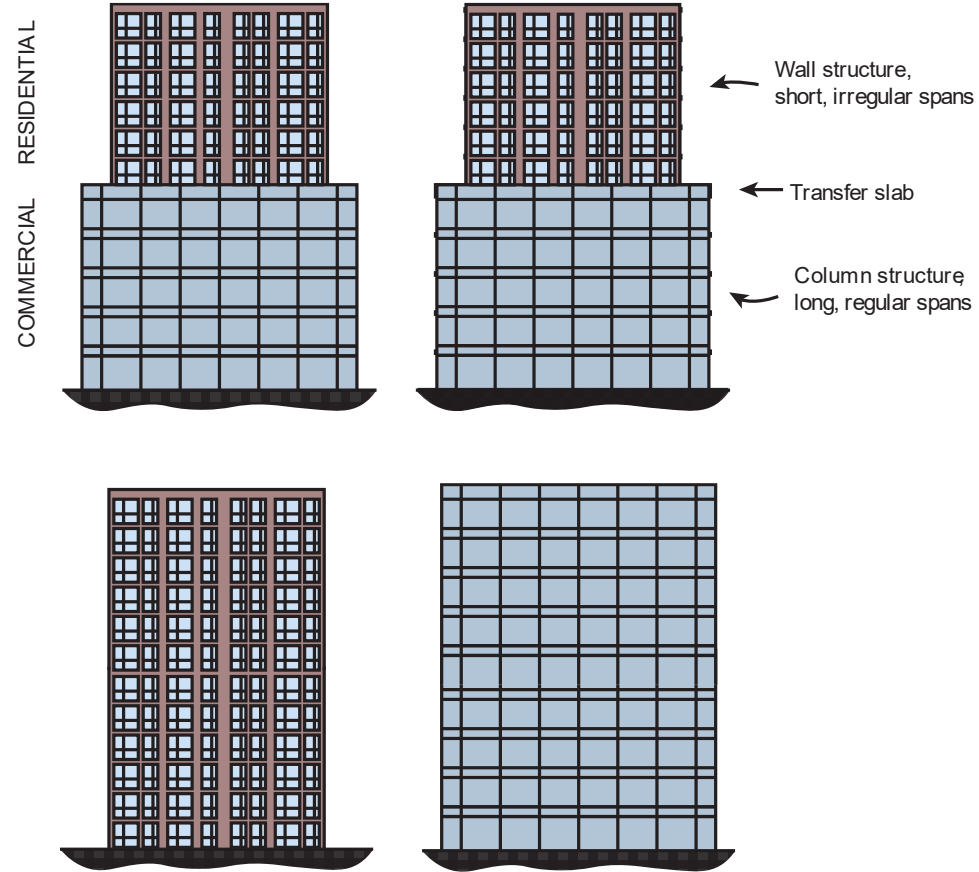
- Integrating systems

from Fang et al., *Reducing embodied carbon in structural systems: A review of early-stage design strategies*. Journal of Building Engineering, 2023.

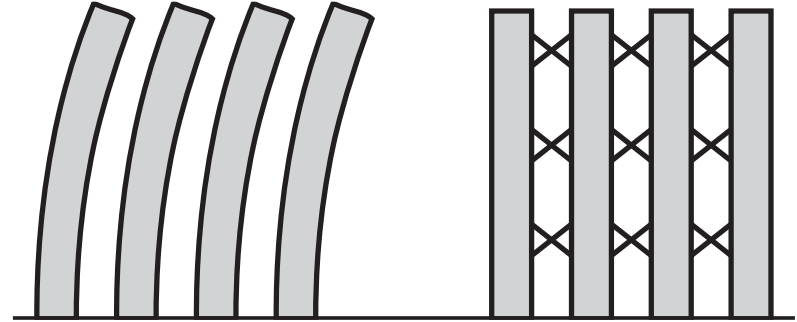
Minimize transfers



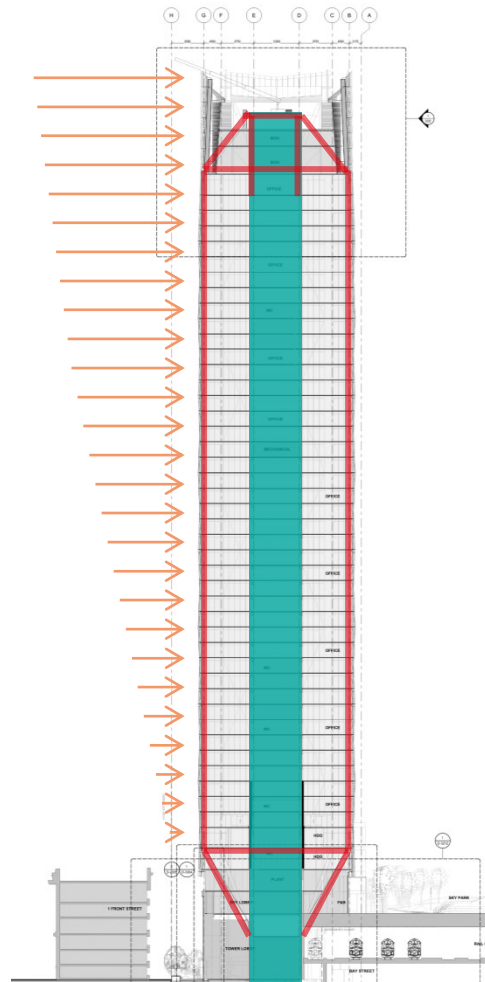
Minimize transfers



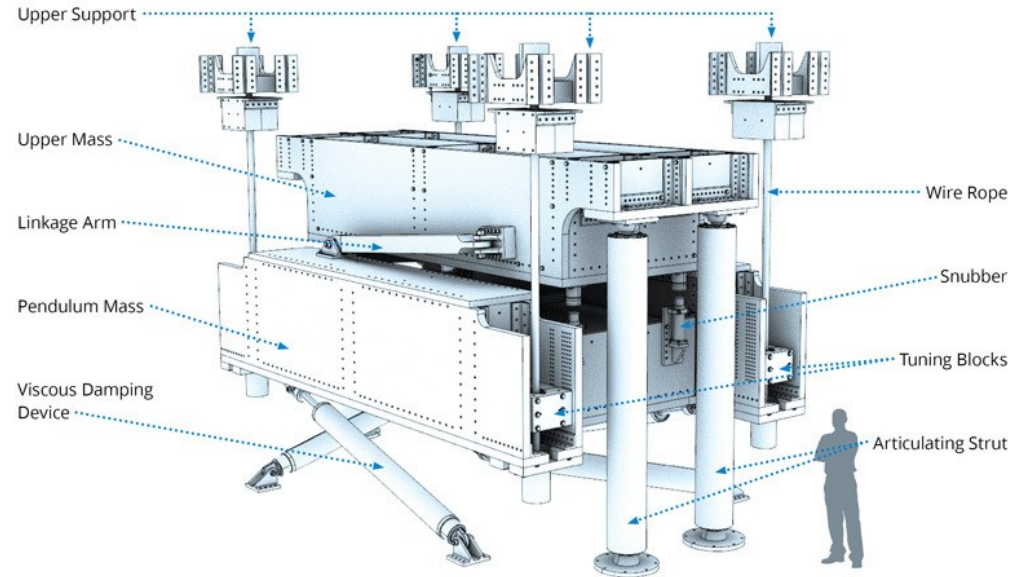
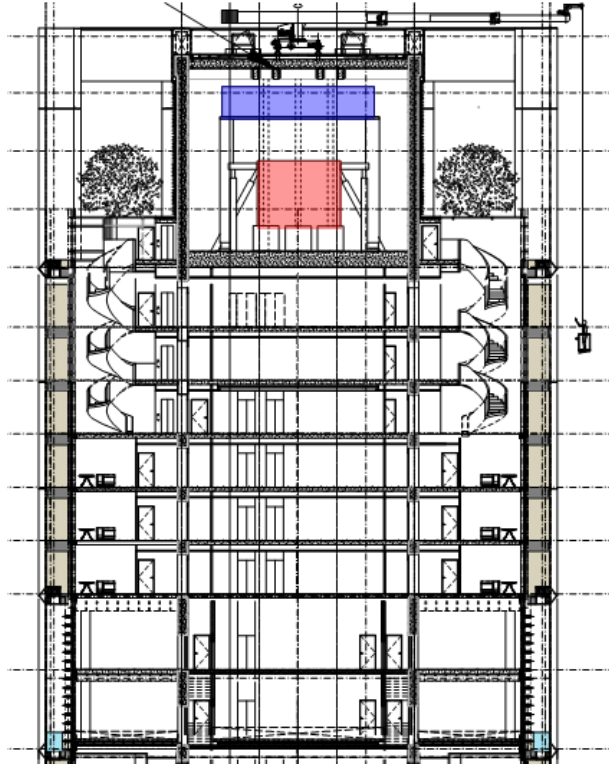
Largescale structural efficiency



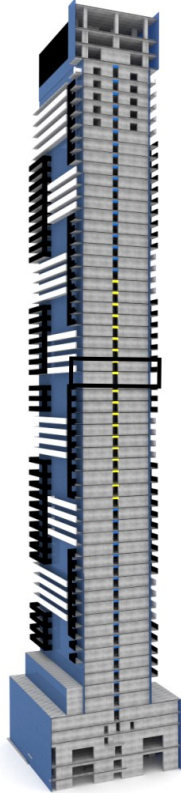
Outriggers



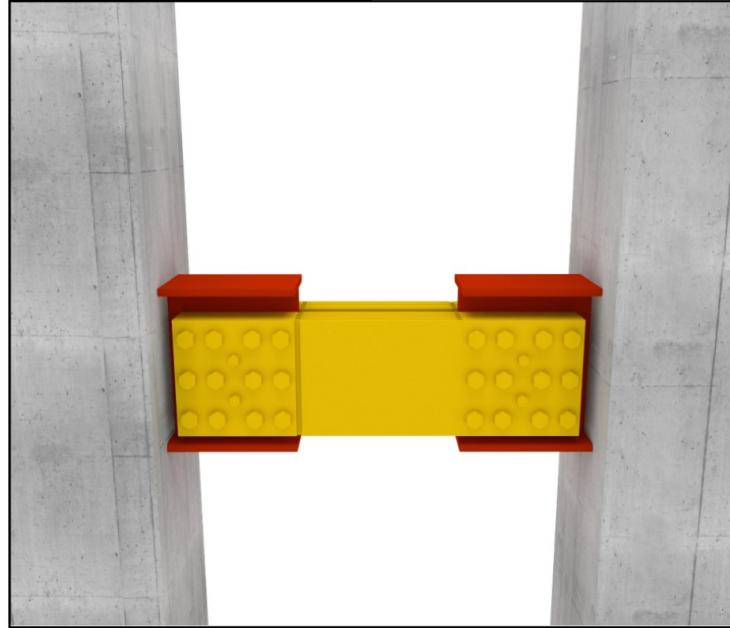
Tuned mass dampers

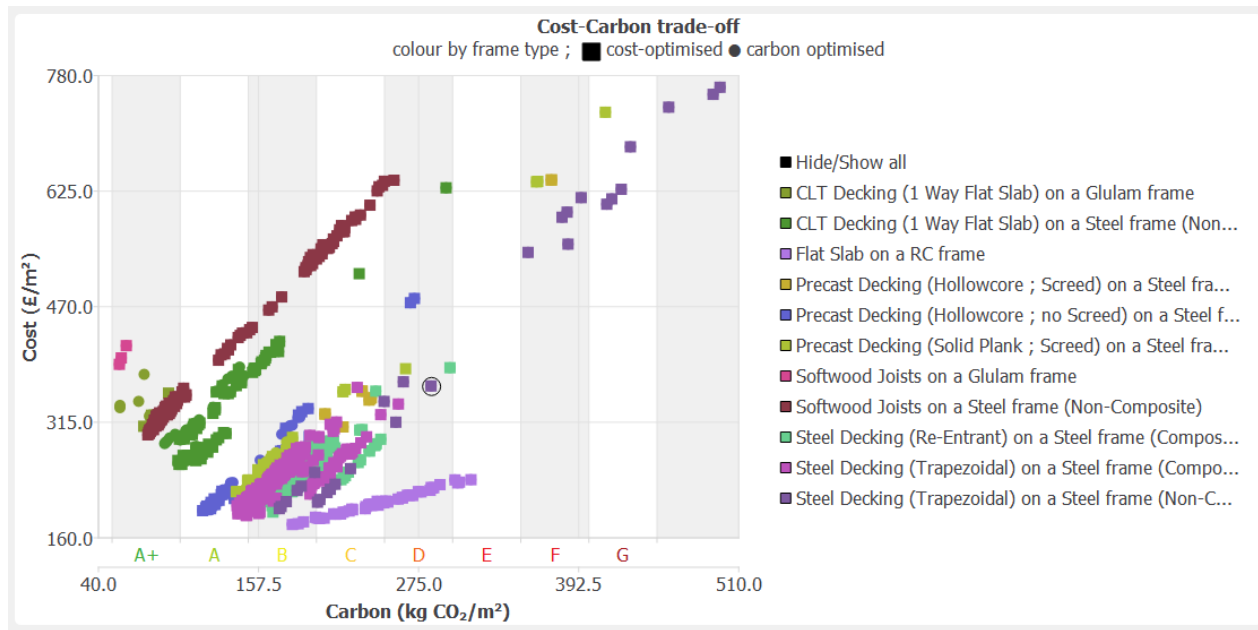


Viscoelastic coupling dampers



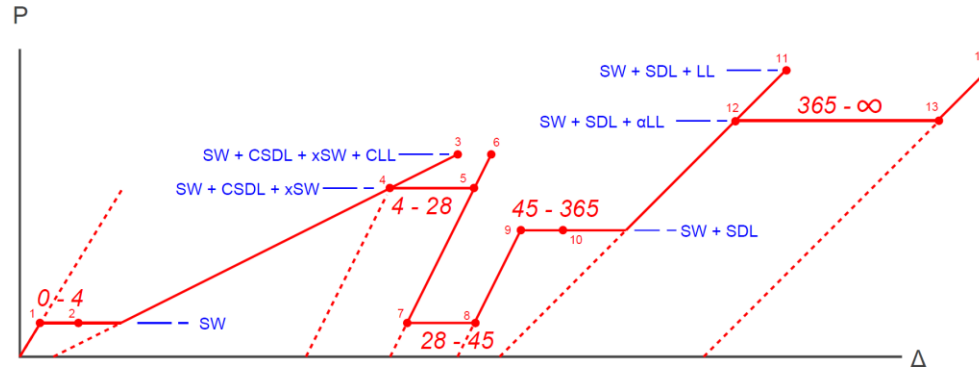
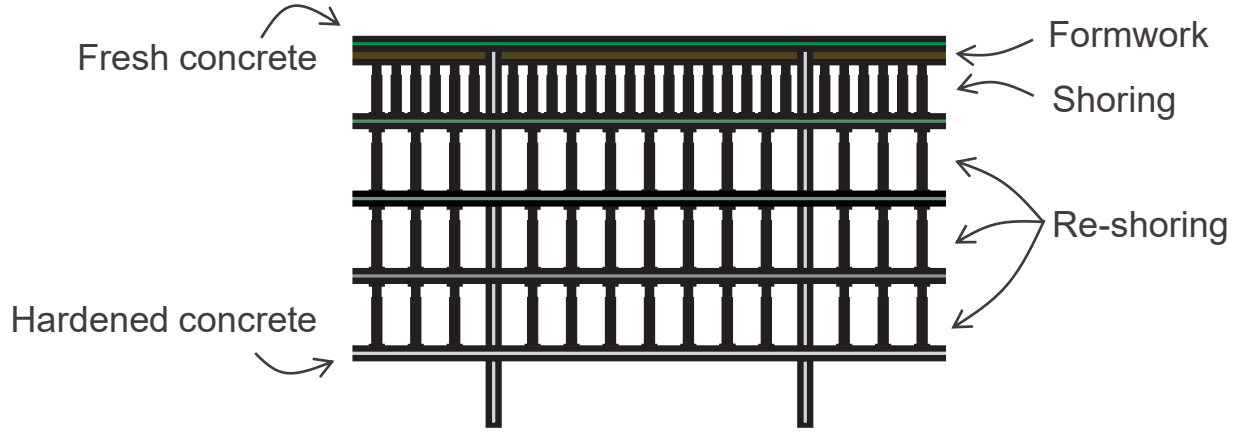
Coupling Damper close-up



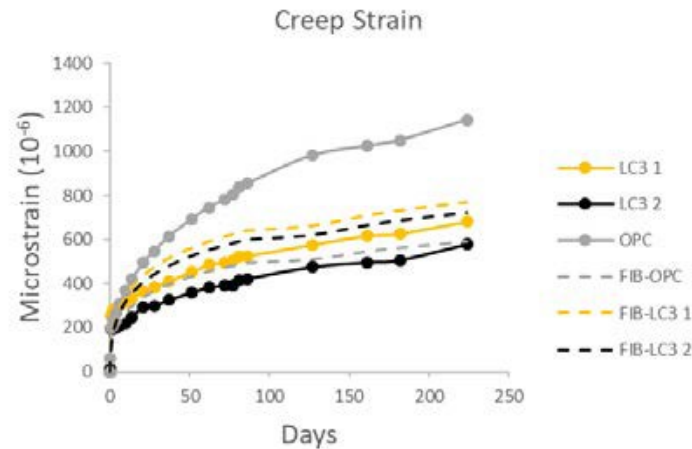
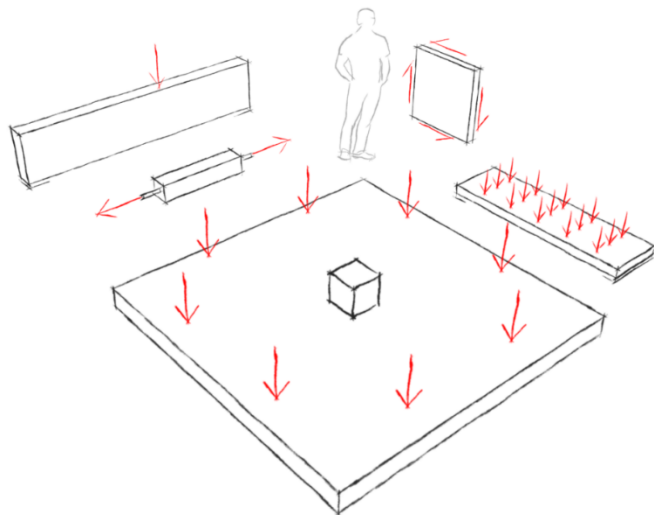


Structural PANDA

Delayed loading



Limestone Calcined Clay Cement (LC³)



Ömer Behçet
Ph.D. candidate
(joint LMC)

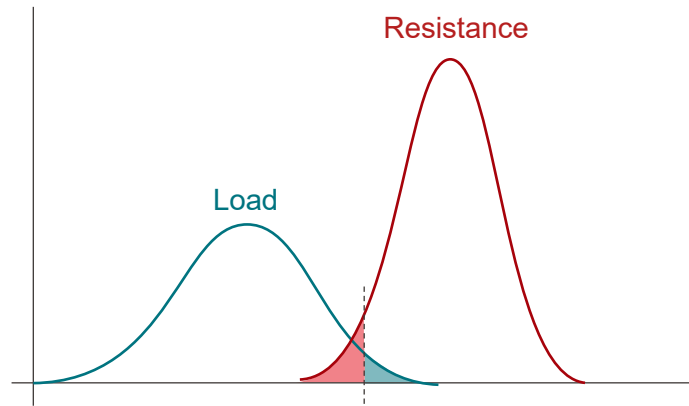


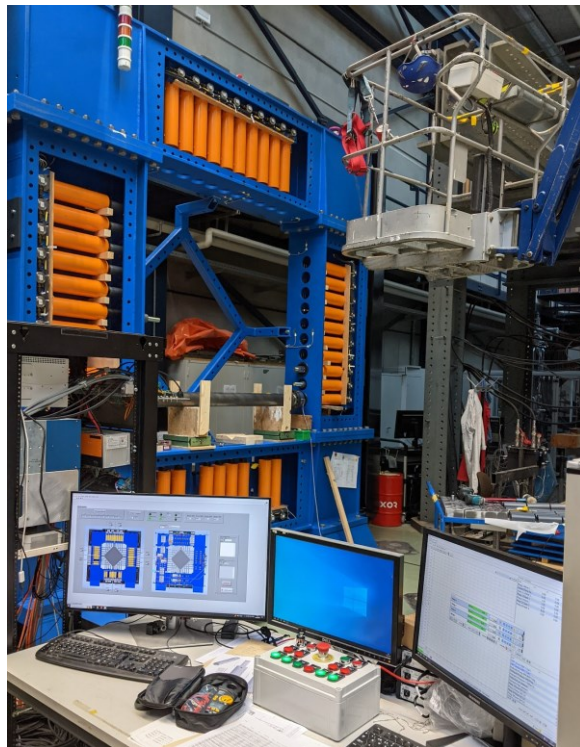
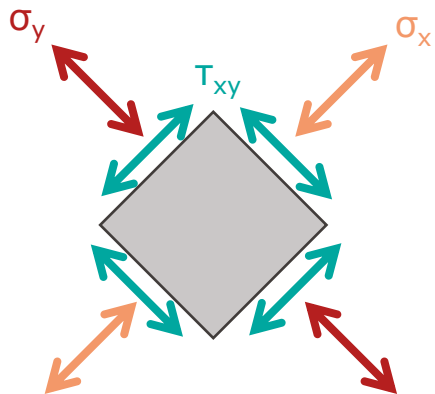
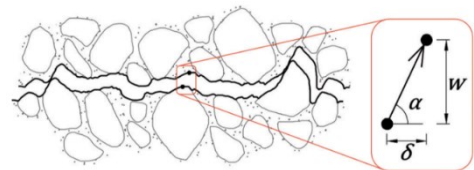
Table 3.3-5: Recommended target reliability indices β for structures to be designed, related to the specified reference periods

Limit states	Target reliability index β	Reference period
Serviceability		
reversible	0.0	Service life
irreversible	1.5	50 years
irreversible	3.0	1 year
Ultimate		
low consequence of failure	3.1	50 years
	4.1	1 year
medium consequence of failure	3.8	50 years
	4.7	1 year
high consequence of failure	4.3	50 years
	5.1	1 year

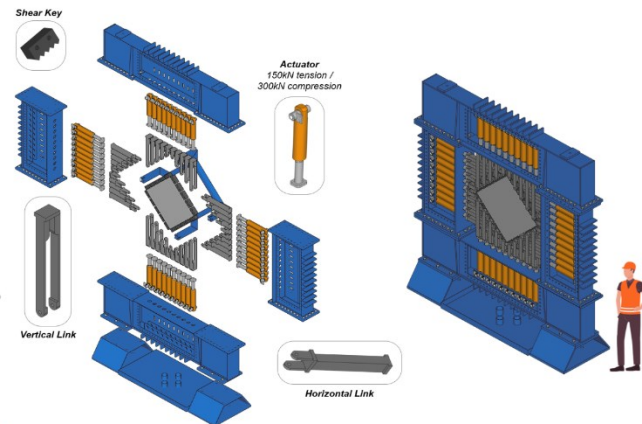
1 in 1000
 1 in 14000
 1 in 120000

fib Model Code for Concrete Structures 2010



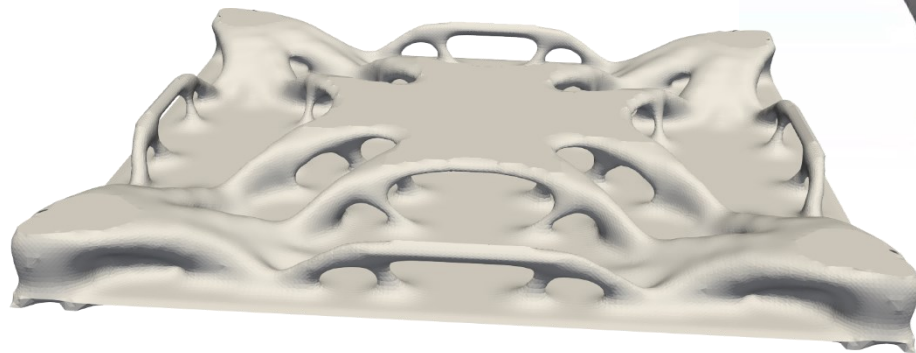


Elias Merhi
Ph.D. candidate

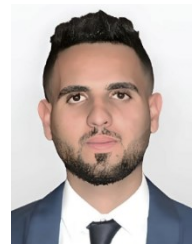


Structural optimization of slabs

Optimization with filling constraint



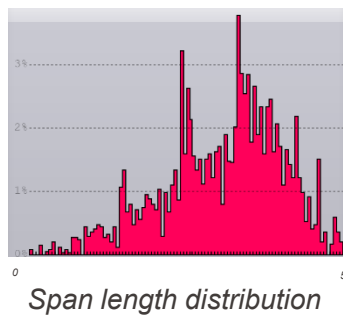
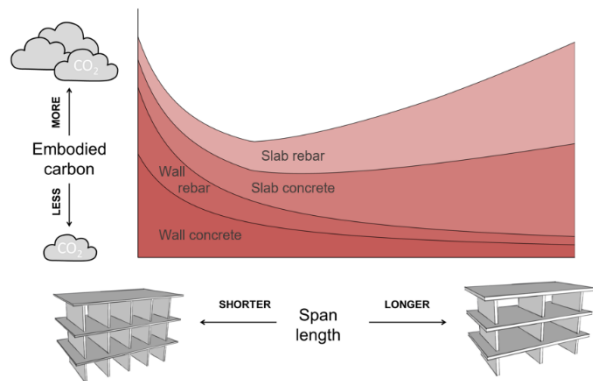
Freeform 3D optimization



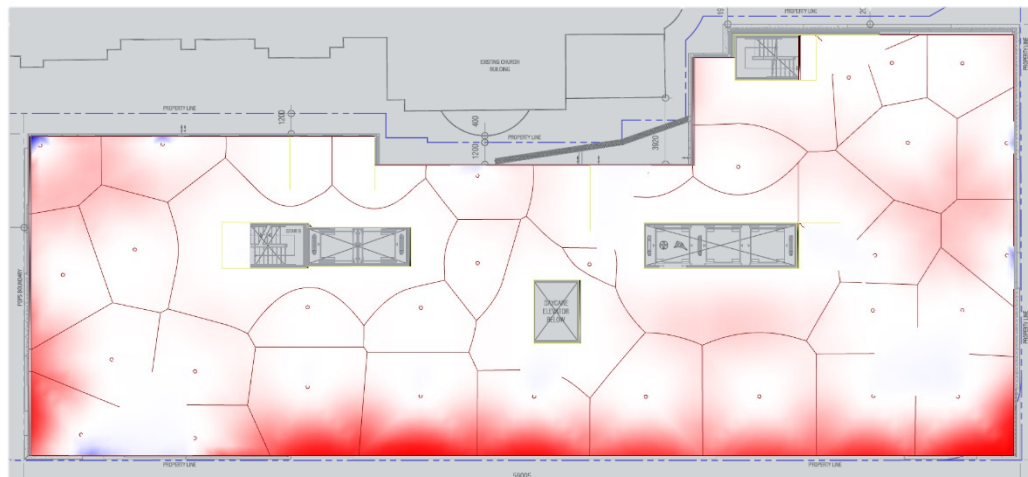
Ahmad Majdouba
Ph.D. candidate

Reuse of structural components



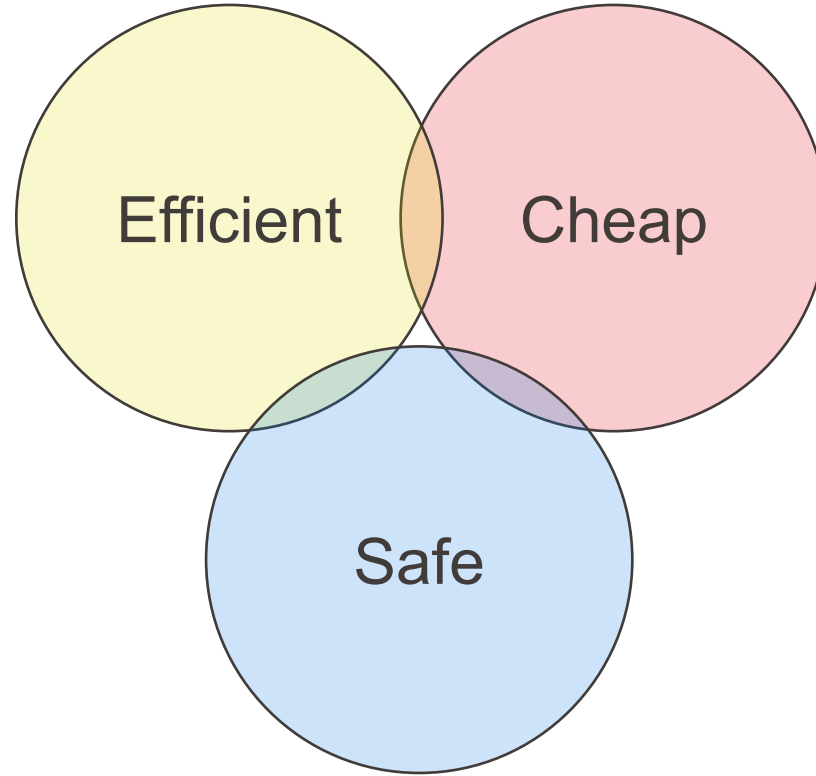


Sjonnie Boonstra
Former postdoctoral
researcher



Deflection/span ratio

Value in structural design



A Promise to Future Generations



All appropriate measures shall be taken to ensure that the rights of future generations are protected and not sacrificed for the expedience and convenience of the present generation.

Oath for graduating Civil Engineering students at the University of Toronto





Questions?