LEARN BUILDING SCIENCE
APRIL 22, 2021

EARLY-STAGE BUILDING SCIENCE

An optimized approach to energy, sustainability, mechanical and enclosure design

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1075 Nelson, Vancouver
Rendering courtesy of WKK / IBI / Henson

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LEARNING OBJECTIVES

Participants will be able to…

1. Recognize the current limitations of the traditional approach to selecting building systems for a project
2. Align project milestones to best support the integrated approach and to benchmark performance iteratively
3. Pinpoint key design considerations that have a direct impact on the energy performance of the mechanical systems and the building enclosure systems
4. Understand why multiple variables and combinations must be considered when optimizing design to meet project and sustainability goals on budget

This presentation has been approved by AIA for 1 LU|HSW and AIBC for 1.0 Core LU

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INTRODUCTIONS

Catherine Lemieux, P.Eng.
Principal
Building Science Specialist

Goran Ostojic, P.Eng.
Senior Building Science Specialist

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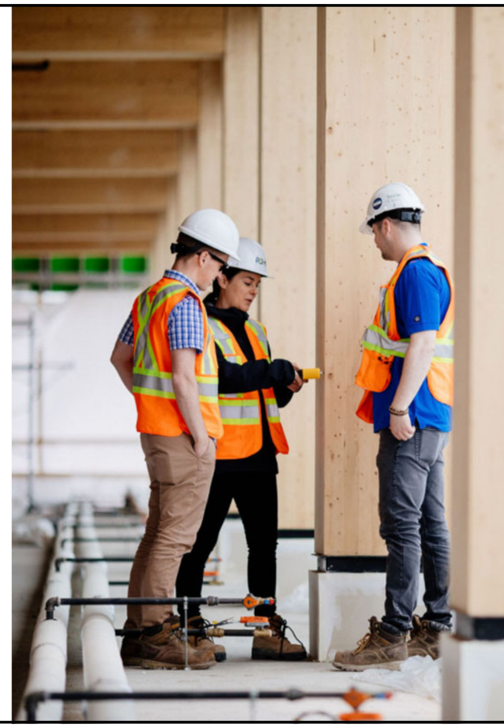
CONTENT

1. Definition
2. Context
3. **New** Design Approaches
4. Early-Stage Building Science **Case Studies**



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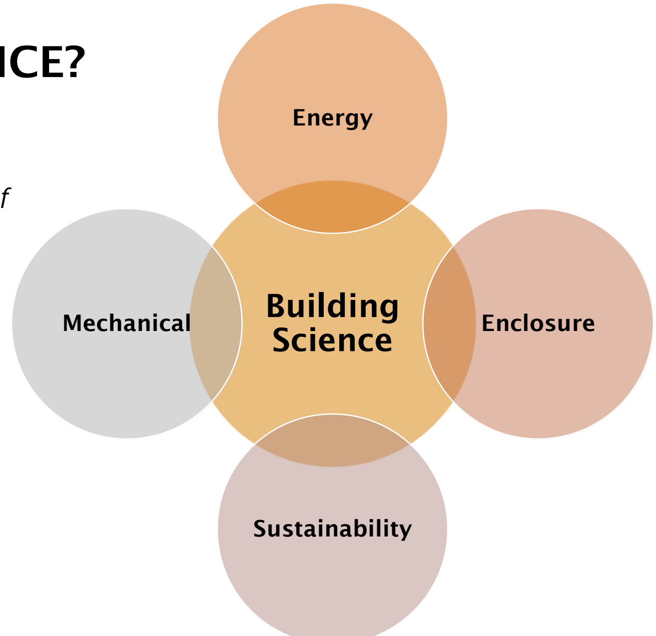
WHAT IS BUILDING SCIENCE?

Actually, it's a bit hard to say…

Building science is the cross-disciplinary collection of knowledge and experience required to understand and predict many aspects of the behaviour (performance) of buildings and their systems, specifically including durability, comfort, energy, environmental separation, indoor air quality, acoustics, lighting, economics, and constructability.

Dr. John Straube
RDH Building Science Inc.
University of Waterloo



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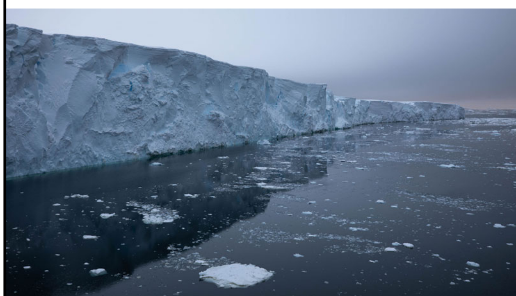
THE PLANET WE THINK WE LIVE ON NO LONGER EXISTS



Climate and Environment

Two major Antarctic glaciers are tearing loose from their restraints, scientists say

Pine Island and Thwaites glaciers already contribute 5 percent of sea-level rise.

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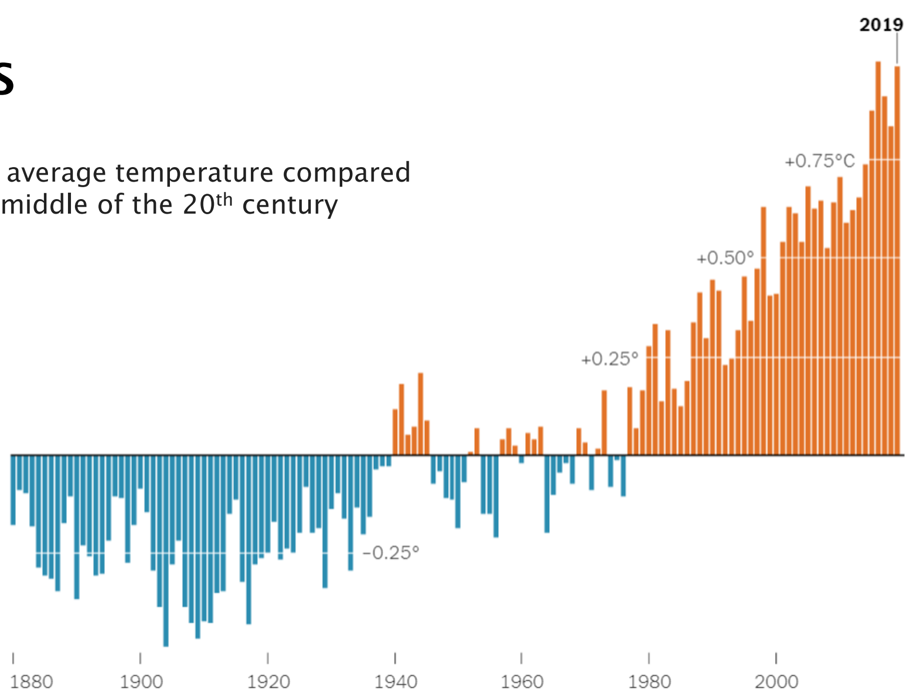
TRENDS

Global average temperature compared to the middle of the 20th century



Source: NOAA Climate.gov

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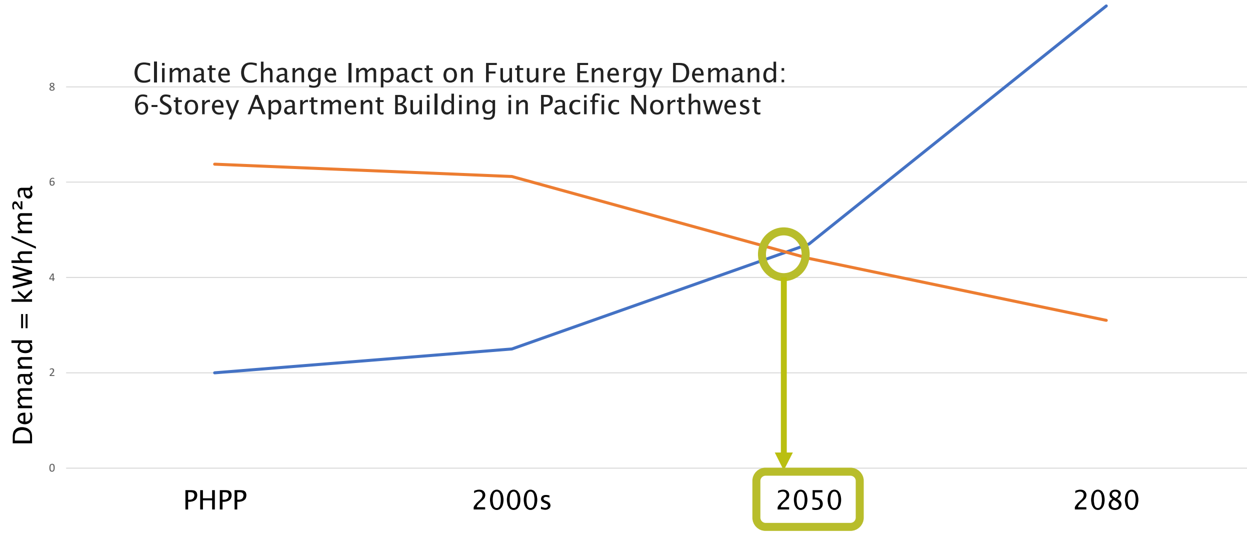
TRENDS



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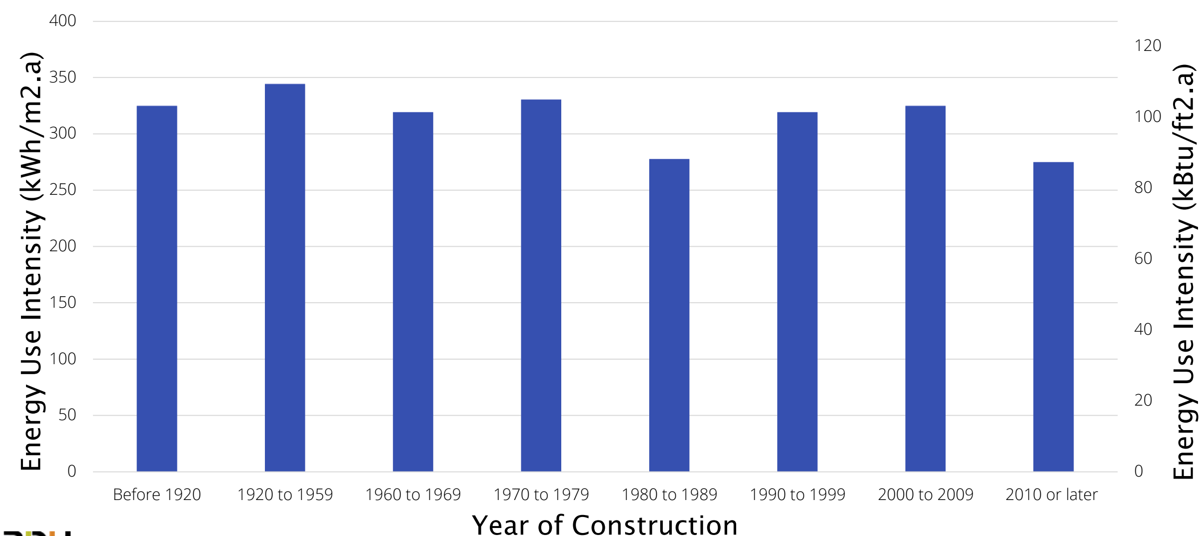
BUILDING TRENDS (?)



Source: NRCan, Survey of Commercial & Institutional Energy Use (SCIEU) – Buildings (2014)

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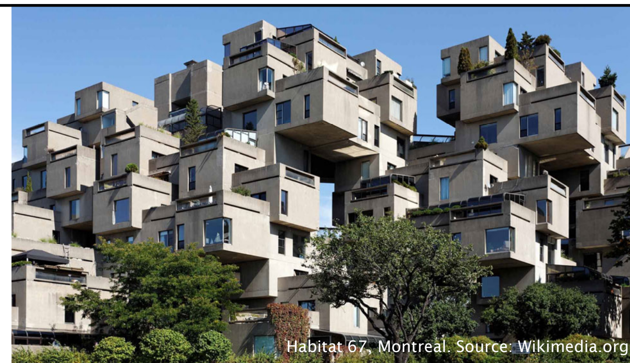
BUILDING TRENDS (?)

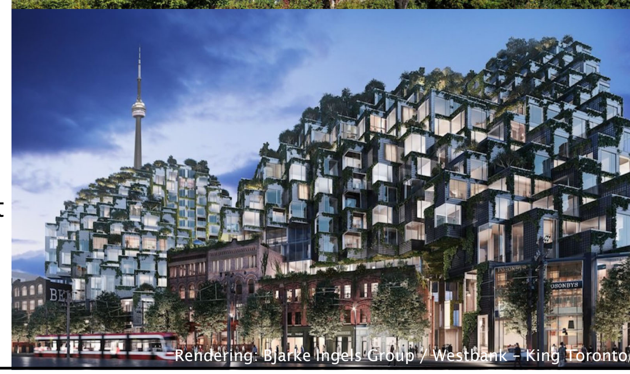
Buildings consume lots of energy:
- ~ 30% in Canada
- ~ 40% in US

Buildings emit lots of GHGs:
- ~ 25% in Canada
- ~ 40% in US

Remember…
> 80% of buildings in 2030 are already built
… Think **Energy Retrofits!**



Habitat 67, Montreal. Source: Wikimedia.org



Rendering: Bjarke Ingels Group / Westbank – King Toronto

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Source: US Energy Information Administration, *Monthly energy review-Sept. 2019*

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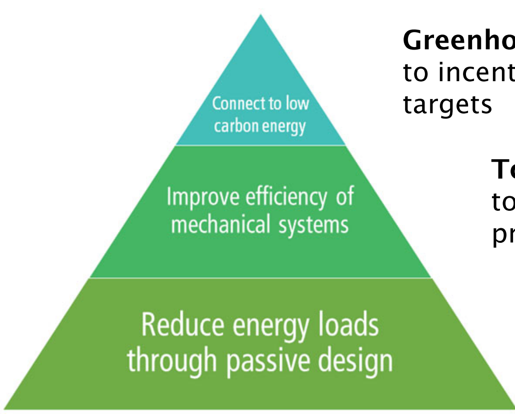
MOVE TO ABSOLUTE PERFORMANCE METRICS



Greenhouse Gas Emissions Intensity (GHGI)
to incentivize low-carbon buildings and help meet GHG targets

Total Energy Use Intensity (TEUI)
to reduce overall building consumption and alleviate pressure on the grid

Thermal Energy Demand Intensity (TEDI)
to encourage higher quality building envelopes and improve building resilience to climate change impacts

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Source: Toronto Zero Emissions Buildings Framework (2017)

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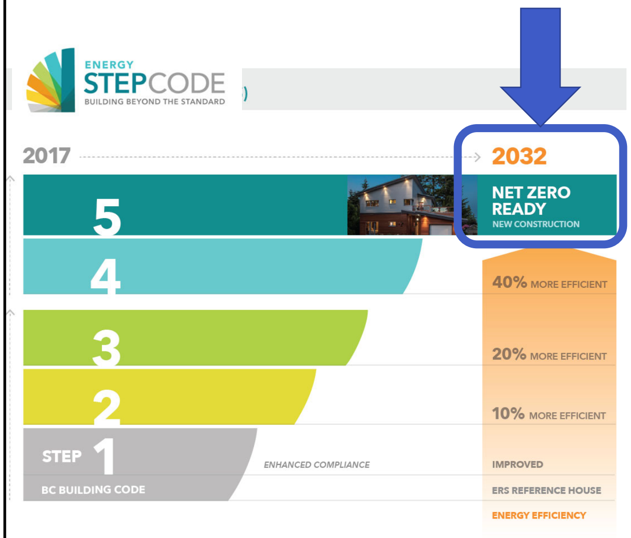
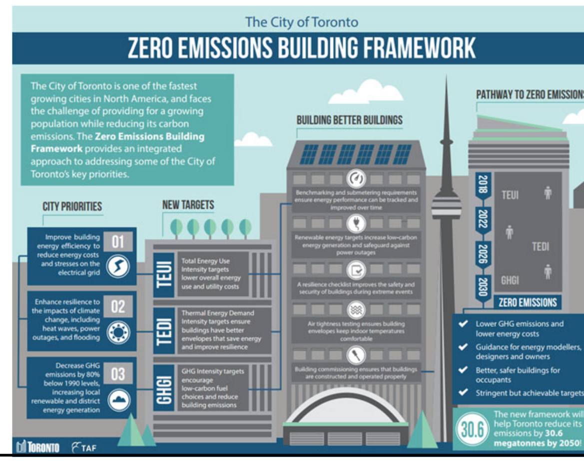
CHANGES HAPPENING NATION WIDE



PHIUS
Passive House Institute US



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RESIDENTIAL, COMMERCIAL & INSTITUTIONAL

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… it's been done before!

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BETTER PERFORMANCE MEANS NEW CHALLENGES

<u>New approach to delivering buildings</u>

- Planning
- Soft skills
- Knowledge
- True integration

1. Design Process
2. Milestones to Match the Metrics
3. Early-Stage Key Decisions
4. Optimize Decisions

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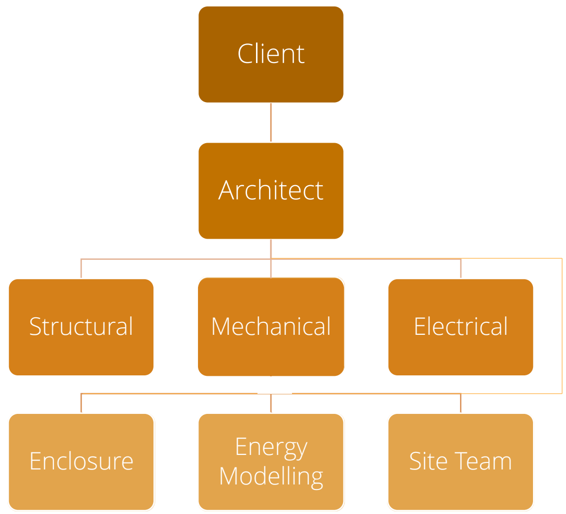
1. DESIGN PROCESS - "BUSINESS AS USUAL"

- Top-down approach
- **Design building first**, check what performance is achieved second



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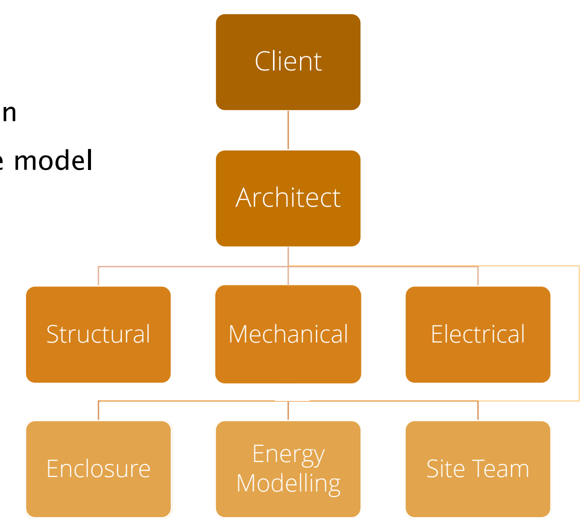
1. DESIGN PROCESS - "BUSINESS AS USUAL"

- Mechanical does energy model
- HVAC systems selected for cost, common
- Pick WWR, R-value assumptions from the model
- Push to Enclosure, who finds assumptions are wrong

This is <u>backwards</u>…

The costliest & hardest to replace system on a building is the enclosure!



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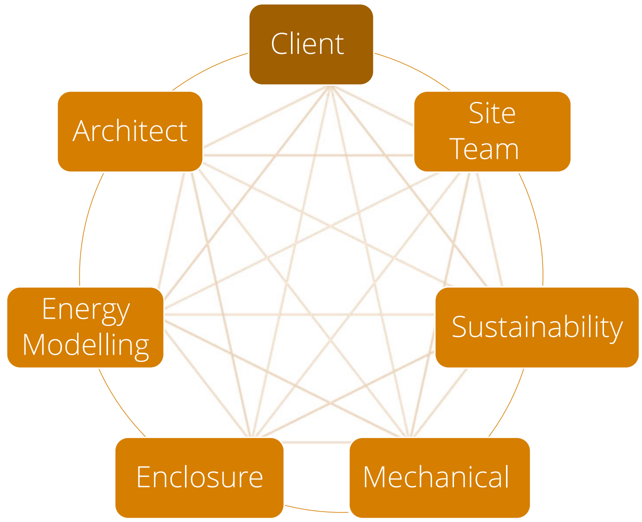
1. DESIGN PROCESS - HIGH PERFORMANCE BUILDINGS

- Circular approach
- **Set performance first**, design building to meet target second

New Characteristics

- **Quality Assurance**
- **Communication**
- **Open-book**



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1. DESIGN PROCESS - HIGH PERFORMANCE BUILDINGS

Establish:

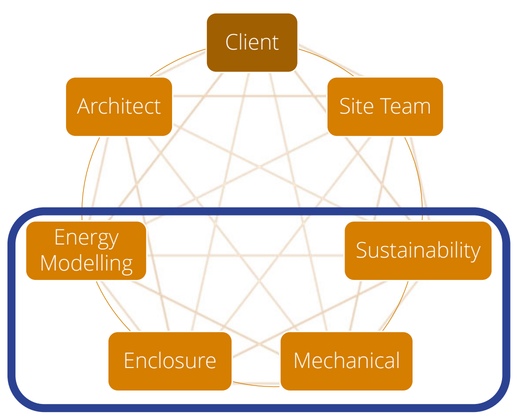
- Owner's Project Requirements (OPR)
- Budget
- Performance & Sustainability Targets
- Architect's Vision

Analyze:

- Enclosure options for Cost, R-value, Carbon
- Input into Energy Model

Optimize:

- Project-specific design for Enclosure + HVAC + Electrical



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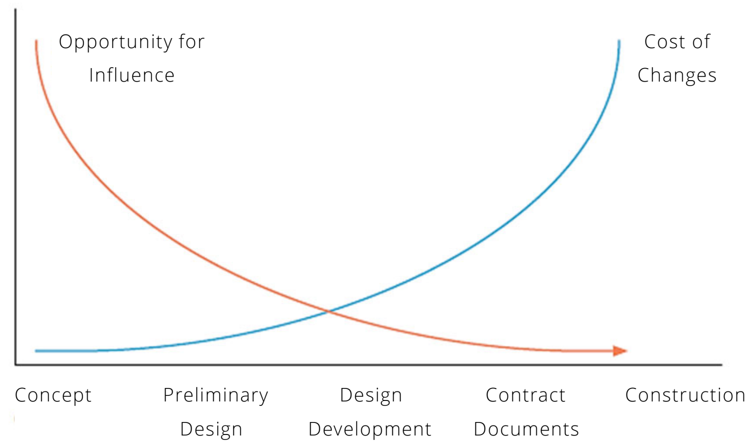
2. FRONT-LOADED DESIGN PROCESS



Most cost-effective approach to delivering buildings = make the right decisions early

(Especially) applies to high performance buildings

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2. MILESTONES TO MATCH THE METRICS

PRE-DESIGN	SCHEMATIC DESIGN	DESIGN DEVELOPMENT	CONTRACT DOCS	PRE-CONSTRUCTION	CONSTRUCTION	OCCUPANCY
Owner's Project Requirements	Integrated Design Charette	1st Draw the details that matter most	Complete the design & QA/QC checks	Construction kick-off	Site visits & testing	Feedback loop
Hire experienced builder & consultants	All hands on deck	Thermal models of key junctions	Clash detection	Construction mock-ups	Enclosure reviews	Final as-built package
Set milestones that match project metrics	Identify each discipline's strategy	Identify windows & ventilation systems	Review specification for inconsistencies	Comprehensive QA/QC plans	Mechanical reviews	Debrief on lessons learned
	Review in context of energy model	2nd energy model includes key details (+ buffer)	Meet to discuss VE process	Plan milestones ahead	Ventilation commissioning	
					Air barrier testing	
					Final blower door tests	

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3. EARLY-STAGE BUILDING SCIENCE KEY DECISIONS

Key decisions that are made early may not be traditionally thought of as **'building science'**, yet they are tied together and directly impact performance (and risk!)

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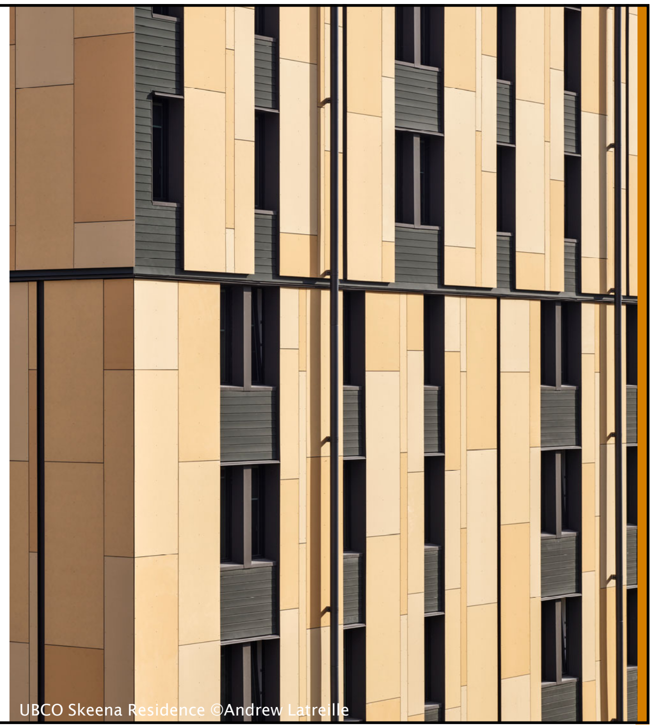

UBCO Skeena Residence ©Andrew Latreille

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3. EARLY-STAGE BUILDING SCIENCE KEY DECISIONS

A. OPR & Sustainability Targets
B. Current and Future Climate
C. Site and Form
D. Construction Methods
E. Enclosure Composition
F. Mechanical Systems

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3A. OPR & SUSTAINABILITY TARGETS

→ Energy, ventilation, carbon, comfort, views, occupancy, etc.

→ Minimum Code Req'ts vs. Owner Set Goals

2022 → 20% Better

- **> R-10 walls**
- Double glazing
- 40% WWR
- 75% efficient heat recovery

2027 → 40% Better

- **> R-10 walls**
- Triple glazing
- 40% WWR
- 80% efficient heat recovery
- Improved airtightness
- Shift to heat pumps for portion of loads

2032 → 80% Better

- **> R-20 walls**
- PH windows
- 40% WWR
- 85% efficient heat recovery
- Significant reductions in electrical loads
- Removal or thermal breaking of balconies

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Source: BC Energy Step Code for Part 3 Buildings

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3A. OPR & SUSTAINABILITY TARGETS

Source: ASHRAE.org

Renovation of 65,000 sq ft ASHRAE HQ building in Peachtree Corners, Georgia

The Draft Owner's Project Requirements (OPR) is a document that establishes ASHRAE's goals for the New ASHRAE Headquarters ahead of the selection of the Design and Construction Management Teams. It is a tool that will be used to help evaluate the selection of the teams to provide these services and their ability to meet the goals defined herein. The OPR is considered a "living" document during the design phase of the project, and as such is subject to change as the design progresses, although every effort possible has been put into the completion of this document in order to minimize future changes. By establishing the goals of the New ASHRAE Headquarters in a single document, the OPR becomes a record by which ASHRAE, and other parties involved in the project, can judge the degree of success in meeting the owner's defined objectives and criteria. In part, the success of the project will be tracked by the minimization of the need to change core tenets of this document.

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3B. CURRENT AND FUTURE CLIMATE

Current and future climate… think 2050 & need for resilience

Thermal Resilience | **Back-Up Generation** | **Flood Mitigation**

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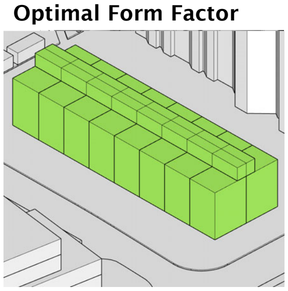
3C. SITE AND FORM

Site, Form, Massing, Solar shading, Orientation = All Considered for Energy, Comfort, Glare

E.g., Community Housing Initial Massing Study

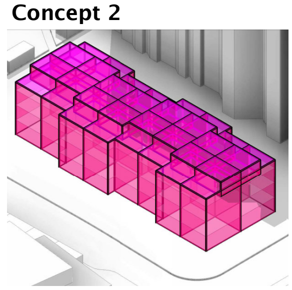
Optimal Form Factor



FF = 1.36

-8% Heat Loss

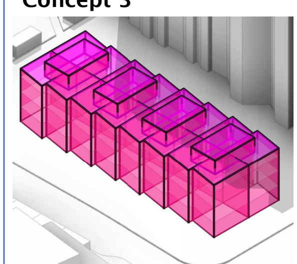
Concept 2



FF = 1.48

Baseline

Concept 3



FF = 1.61

+9% Heat Loss

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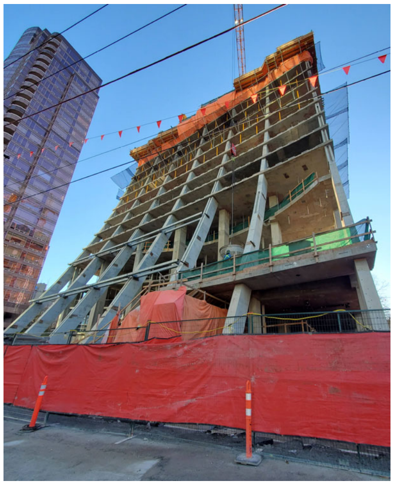
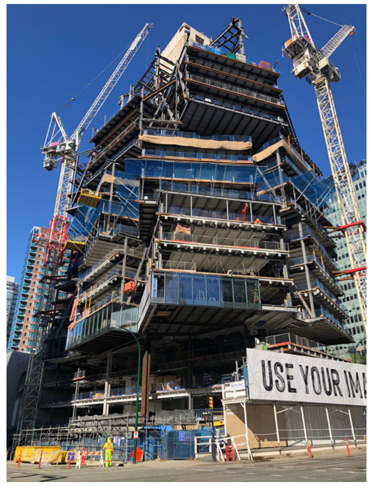
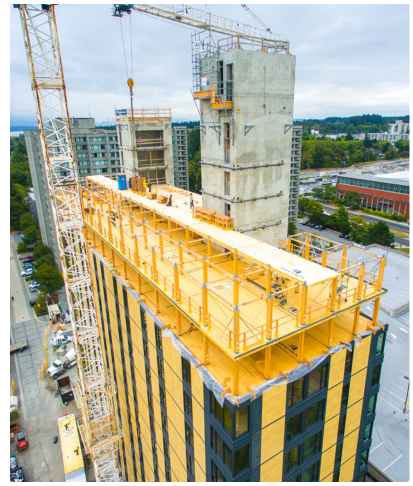
3D. CONSTRUCTION METHODS



1568 Alberni by Kengo Kuma
& Merrick Architecture



400 West Georgia by OSO
& Merrick Architecture



Brock Commons by Acton Ostry Architects
©Naturally Wood

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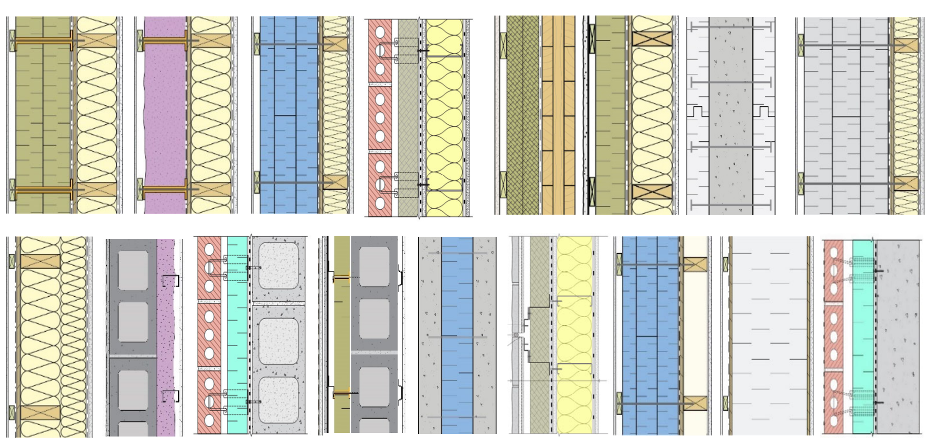
3E. ENCLOSURE COMPOSITION



… More than one way to get there!

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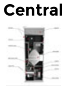
3F. MECHANICAL SYSTEMS

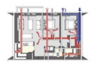
HRV

Central

Semi Central



Individual



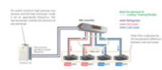
	System	Air Source VRF		ASHP with Boiler top-up		Split System with Electric Reheat	
	Criteria	All equipment on the roof with a fan coil unit in a closet		ASHP on the roof with boiler operating below 0ºC with Fan Coil unit in a closet		Each Townhome has a Split System with Electric Reheat	
		Engineer	Client	Engineer	Client	Engineer	Client
1	First Cost	2		2		3	
2	Life Cycle Cost	2		3		2	
3	Maintenance	2		3		2	
4	Suitability	2		3		2	
5	Noise	3		3		2	
6	Life Span	2		3		2	
7	Constructability	2		3		1	
8	Metering	1		3		2	
9	Energy Benefits	3		3		2	
10	Redundancy	2		3		1	
11	Environmental Health Attributes	2		3		2	
12	Impact on Building Design Elements	2		2		1	

Mechanical Engineering Evaluation
3 Best
2 Good
1 Not Good

Client Evaluation
Client to provide weight factor

Energy H/C

VRF



ASHP

Electric Baseboard

	System	Air Source VRF		ASHP with Boiler top-up		Split System with Electric Reheat	
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12	Impact on Building Design Elements	2		2		1	

Mechanical Engineering Evaluation
3 Best
2 Good
1 Not Good

Client Evaluation
Client to provide weight factor

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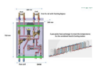
ETC



ASHP

Gas

	System	Air Source VRF		ASHP with Boiler top-up		Split System with Electric Reheat	
	Criteria	All equipment on the roof with a fan coil unit in a closet		ASHP on the roof with boiler operating below 0ºC with Fan Coil unit in a closet		Each Townhome has a Split System with Electric Reheat	
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Mechanical Engineering Evaluation
3 Best
2 Good
1 Not Good

Client Evaluation
Client to provide weight factor

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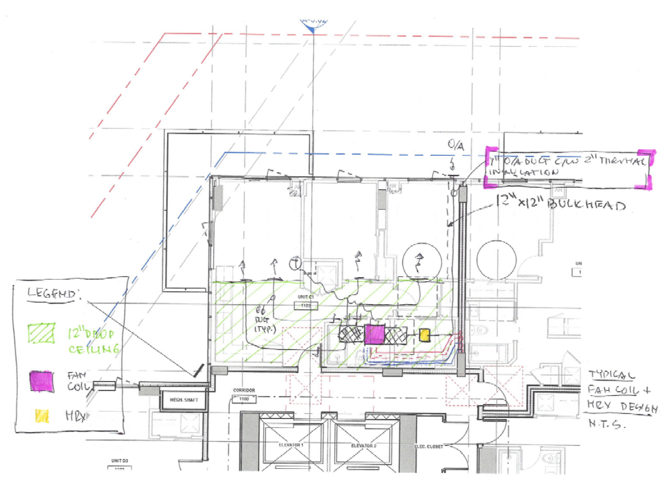
3F. MECHANICAL SYSTEMS



Current Mechanical Design

- Maximize views and minimize mechanical at perimeter
- 12'' drop ceiling in main entrance + bulkhead for outdoor air
- Difficult servicing and large number of access panels

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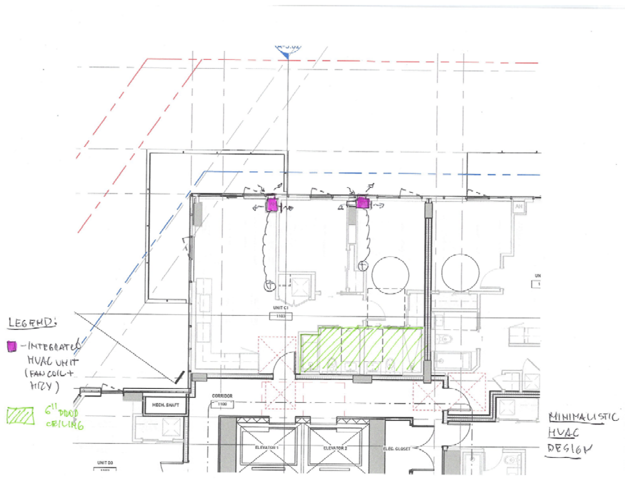
3F. MECHANICAL SYSTEMS



Minimalistic Design

- Envelope has 50:50 window/wall ratio
- Main heating and cooling load are at perimeter
- Integrated HVAC unit with HRV at perimeter
- Minimize drop ceiling and 6'' savings in height
- Better control, no ductwork, $5K cost reduction per suite
- Integrated HVAC unit can be vertical at perimeter wall, between two rooms, below window (2ft height), ceiling mounted (7'' deep)

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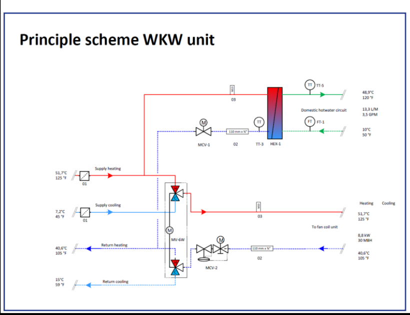
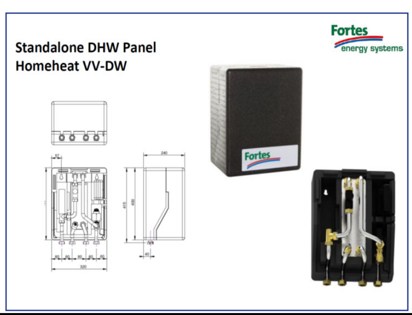
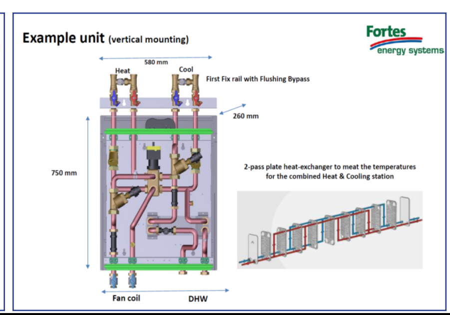
3F. MECHANICAL SYSTEMS

Energy Transfer Center

- Eliminate Domestic Hot Water Distribution and Recirculation lines
- Instantaneous domestic hot water
- Suitable for low temperature water supply of 125F typical for heat pump technology
- Savings: $5K per suite







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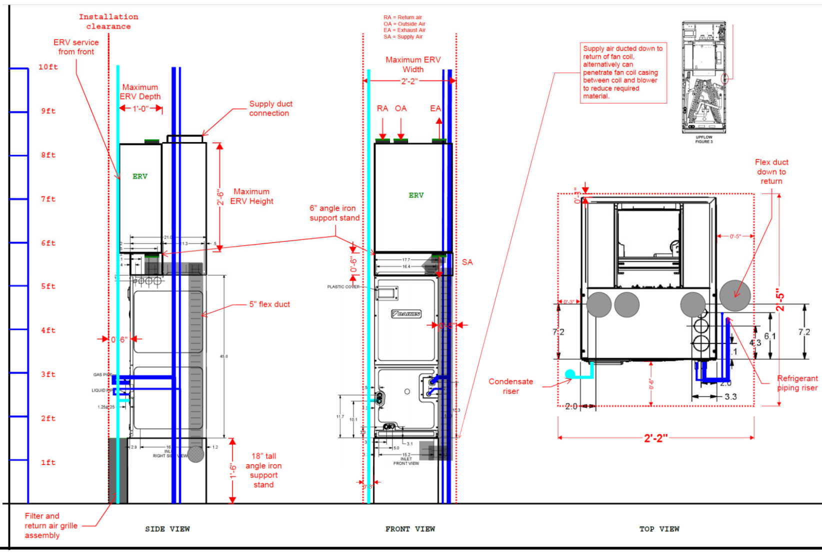
3F. MECHANICAL SYSTEMS

Vertical Integrated VRF + HRV Unit



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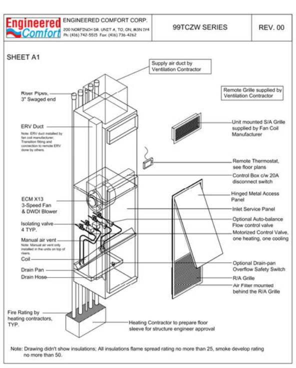
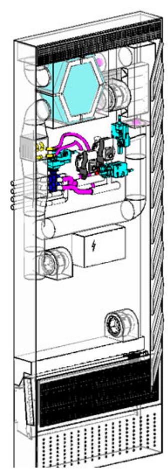
3F. MECHANICAL SYSTEMS

Integrated HVAC Hydronic Units



→ Typical square 24''x24'' fan coil + HRV Unit



→ Slim integrated chilled beams with HRV with radiant surface and displacement supply

→ 7'' deep with installation at perimeter, between two rooms, under window or ceiling

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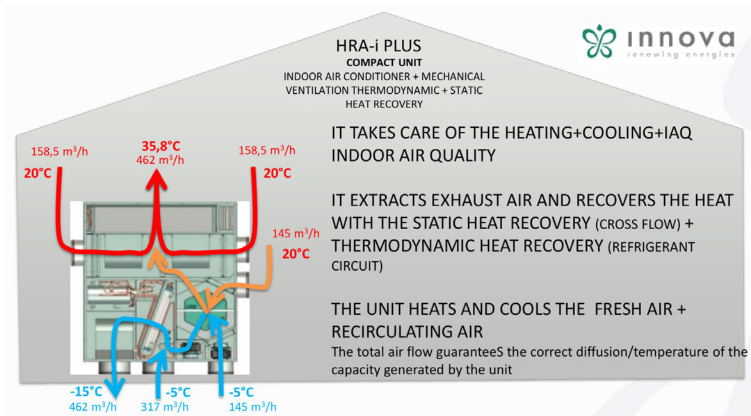
3F. MECHANICAL SYSTEMS

Integrated PTAC Unit with HRV

- Only require power connection (120 / 1 phase) and envelope penetrations
- 10'' deep

Issues:

- Refrigerant 134a and capacity



HRA-i PLUS 50/15

Fresh air flow = 145 m³/h → house 107 m² or commercial/tertiary room (ex. classroom with 6pax)

Totale Air flow (fresh air + recirc. air) = 462m³/h → 462/290=1,59 Vol/h

Total heating capacity A-5/A20 = 3,71 kW (di cui 1,06 dal rec.statico e 2,65 dal rec.termodin.)

Space heating capacity without fresh air load A-5/A20 = 3,71 – (145x25x0,34/1000) = 2,47 kW

Espulsion exhaust air/supply fresh air = 145/145 m³/h (+317 m³/h recirculating air)

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3F. MECHANICAL SYSTEMS

Hysopt

- Unique design software getting the most from heating & cooling hydronic systems
- Increased efficiency 10-30%
- Reduced installation cost 10-40% through digital model
- Reduced energy consumption
- Precision through mathematical model

hysopt
hydronic system optimisation

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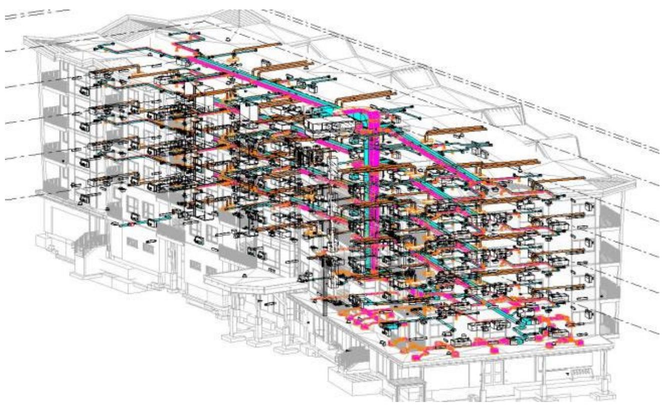
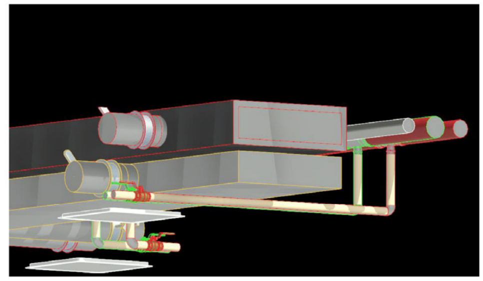
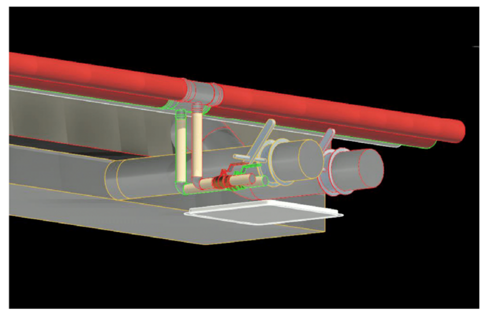
3F. MECHANICAL SYSTEMS

BIM Software







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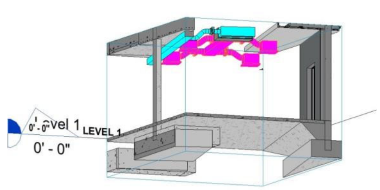
3F. MECHANICAL SYSTEMS

Prefabrication



→ Mechanical plant

→ Mechanical equipment

→ Bathrooms

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4. LACK OF OPTIMIZATION

- Selection of building systems done in **silos**
- Difficult to know the **implications** on performance targets
- Unexplored design **alternatives** for enclosure and mechanical
- Forgetting about **costs**
- **Too late** to make changes later in the project without pain

Optimization at early-stage is key!

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Source: By Os Gemeos, Granville Island DailyHive.com, meunierd/ Shutterstock

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4. OPTIMIZE KEY DECISIONS

- What's the best combination of solutions for this specific building?
- Explicitly consider the interaction between building's enclosure performance and mechanical system performance in meeting overall building performance objectives
- Optimize for Performance, Cost, Carbon for 10,000s of variables

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4. OPTIMIZE KEY DECISIONS

Case Study – 1770 Pendrell, Vancouver

→ Biggest criteria was façade budget vs. preserving architecture

→ We ran optimization scenarios

→ Focused on:

Triple glazed system
vs.
Double glazed + Thermal breaks at slab

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4. OPTIMIZE KEY DECISIONS

Opaque Enclosure Cost Optimal Combinations	>R-4.00	>R-4.25	>R-4.50	>R-4.75	>R-5.00
Effective Total Enclosure R-Value [ft²·°F·hr/Btu]	4.0	4.5	4.5	4.8	6.2
Opaque Enclosure R-Value [ft²·°F·hr/Btu]	14.1	11.5	11.5	11.5	11.5
Incremental Cost for Step [$]		$772,000	$0	$75,000	$742,000
Total Cost [$]	$14,730,000	$15,502,000	$15,502,000	$15,577,000	$16,319,000
Incremental Cost		$772k	$0	$75k	$742k

Balancing thermal performance and cost

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Intermission…
Any Questions?

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4. Early-Stage Building Science Case Studies
Rendering: IBI Group

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EARLY-STAGE BUILDING SCIENCE CASE STUDIES

- **Joyce Centre, Mohawk College**
- **University of Victoria Student Housing**
- **1075 Nelson**

1. Design Process
2. Milestones to Match the Metrics
3. Early-Stage Key Decisions
4. Optimize Decisions

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JOYCE CENTRE, MOHAWK COLLEGE

- OPR – **Net Zero Energy**
- For every kilowatt-hour of energy that is used, the building will produce a kilowatt-hour of renewable energy
- Funding req't – Project to be completed in **25 months** from start of Design to end of Construction

CaGBC's Innovation in Sustainability award, Ontario Sustainable Energy Association's Sustainable Project of the Year award, and OSPE's Engineering Project of the Year

1. Design Process

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JOYCE CENTRE, MOHAWK COLLEGE

Energy Targets – First Design Meeting:
We have an energy budget, including enclosure!

R10 window + wall

Ontario SB-10 Climate Zone 5 Requirement: R4.7
Target also selected to enable nearly any HVAC system!

75 ekWh/m²-yr

CIEBUS College/University Average: 211ekWh/m²-yr
Target taken from prior project experience

2. Milestones to Match the Metrics

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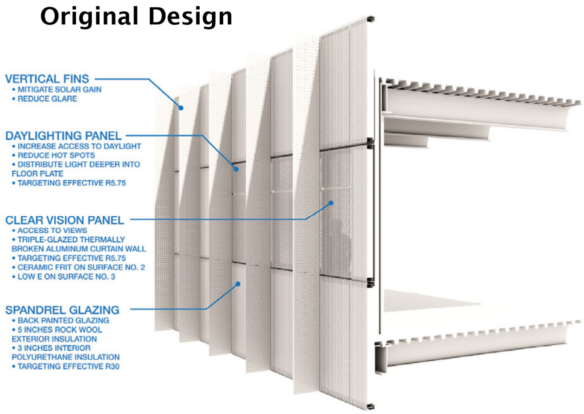
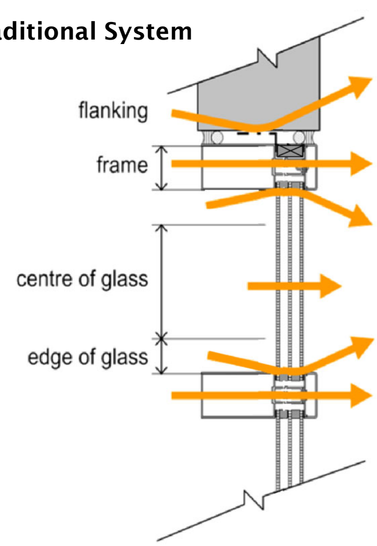
JOYCE CENTRE, MOHAWK COLLEGE

Original Design



Rendering courtesy of B+H Architects

More Traditional System



3. Early-Stage Key Decisions

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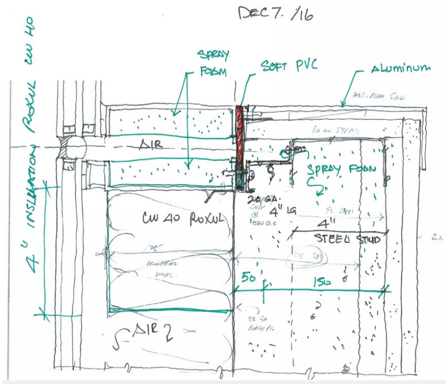
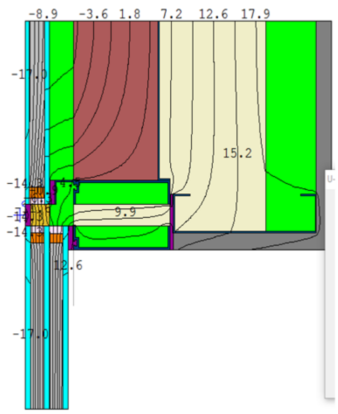
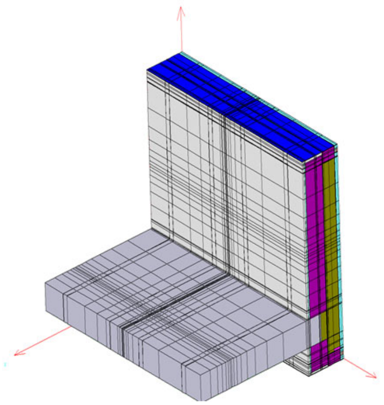
JOYCE CENTRE, MOHAWK COLLEGE







3D Results:
R-21.5 hr-ft²-°F/Btu,
incl. Slab & Flanking

3. Early-Stage
Key Decisions

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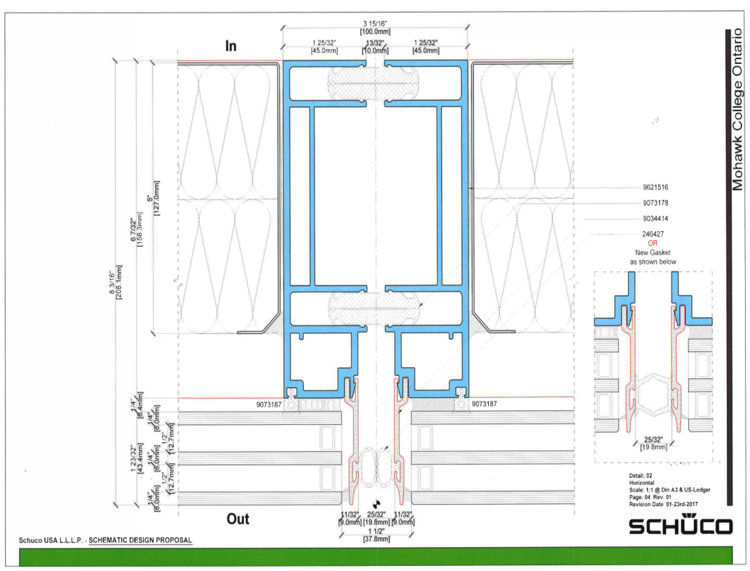
JOYCE CENTRE, MOHAWK COLLEGE



3. Early-Stage
Key Decisions

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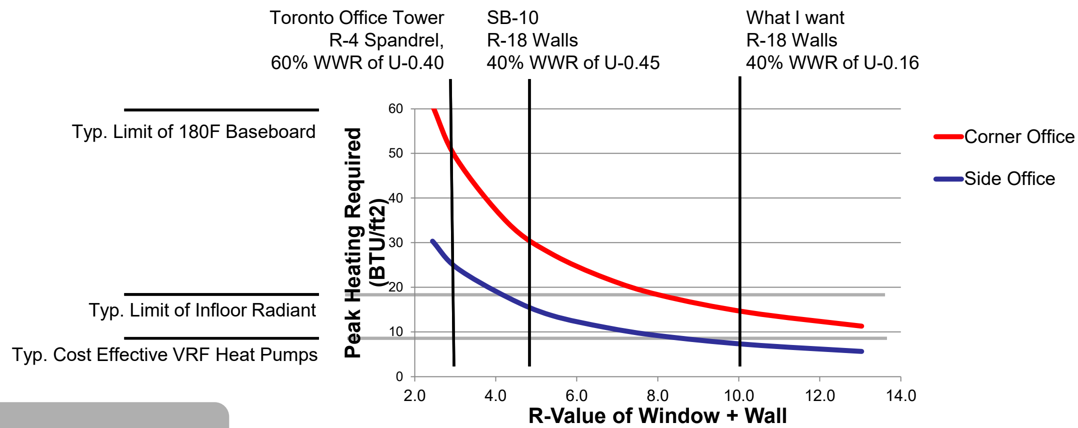
JOYCE CENTRE, MOHAWK COLLEGE

Example Peak Heating Loads



4. Optimize Decisions

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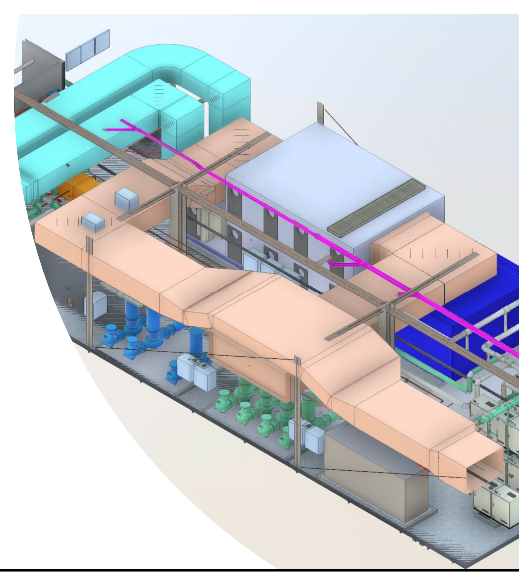
JOYCE CENTRE, MOHAWK COLLEGE

HVAC Systems Used

- Heat Pump system – Water Cooled VRF
- Geothermal field
- Dedicated outdoor air system (DOAS)
- Solar thermal for preheating DHW
- Heat pump “templifier” for aux DHW heating



4. Optimize Decisions

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JOYCE CENTRE, MOHAWK COLLEGE

- For every kWh of energy used, the building will produce a kWh of renewable energy
- Difficult to get to Net Zero Energy with buildings > 2 storeys tall
- Campus solution

4. Optimize Decisions

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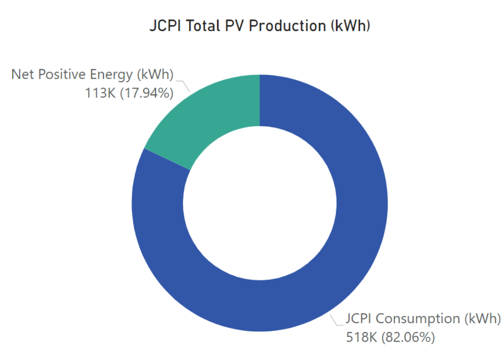
JOYCE CENTRE, MOHAWK COLLEGE

M & V – We are Net Positive!

- Measured Air Leakage: 0.54 L/s-m² @ 75 Pa
- Building Consumption 20% less than expected
- PV Production is 2% less than expected



4. Optimize Decisions

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UNIVERSITY OF VICTORIA STUDENT HOUSING

- Integrated design with:
  - Owners
  - Architect
  - Mechanical Consultant
  - Kitchen Consultant
  - RDH = Passive House + Enclosure Consultant

1. Design Process

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UNIVERSITY OF VICTORIA STUDENT HOUSING

- District Energy System
- Typical Building Construction Design is LEED Gold
- Go Beyond with Passive House
- Climate Resilience

2. Milestones to Match the Metrics

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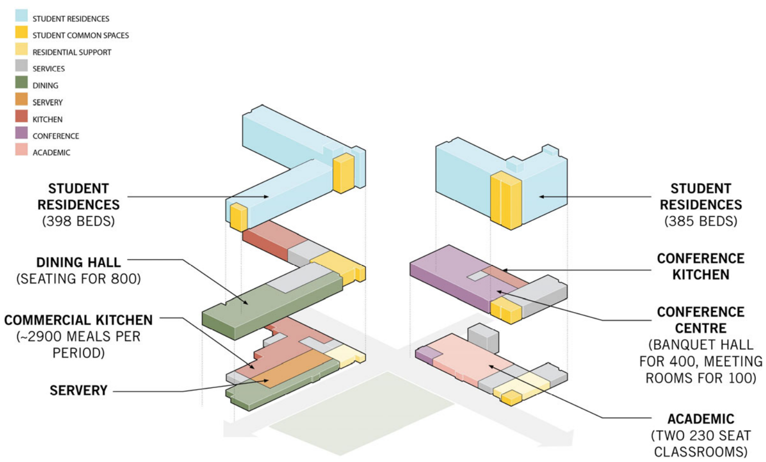
UNIVERSITY OF VICTORIA STUDENT HOUSING

- → Passive House
- → Onboarded during SD phase
- → Realization no plan to tackle the kitchen
- → Commercial grade kitchen serving ~ 8,700 meals/day **= New Typology!**
- → Backtracked SD until a plan was set



2. Milestones to Match the Metrics

Drawing courtesy Perkins+Will

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UNIVERSITY OF VICTORIA STUDENT HOUSING

→ Setting Targets

			COMBINED	RESIDENTIAL	NON-RESIDENTIAL
	Treated floor area	m²	11247.3	6660.0	4587.4
Space heating	Heating demand	kWh/(m²a)	15	9.8	23
	Heating load	W/m²	15	11.9	20
Space cooling	Cooling & dehum. demand	kWh/(m²a)	1.2	1.2	1
	Cooling load	W/m²	0.0	0.0	0
	Frequency of overheating (> 25 °C)	%	0.0	-	-
	Frequency of excessively high humidity (> 12 g/kg)	%	0.1	0.2	0

Space Heating Demand TARGETS	15	8	25

3. Early-Stage Key Decisions

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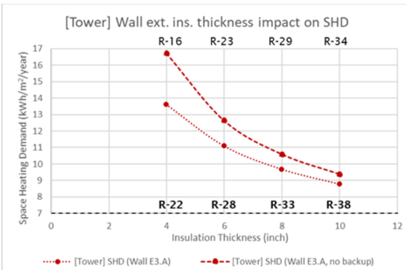
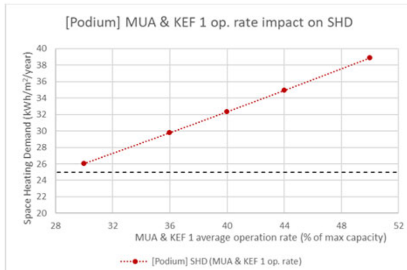
UNIVERSITY OF VICTORIA STUDENT HOUSING

Starting Point: Design Levers,
i.e. Sensitivity analysis to understand elements with largest impact on PHPP models

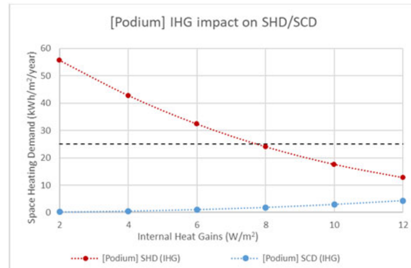
Exterior Insulation Thickness



Kitchen Ventilation Operation Rate



Internal Heat Gains



Conclusion: Biggest levers are Kitchen Ventilation, Equipment & Hot Water

4. Optimize Decisions

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- 60-Storey Passive House – the tallest in the world when complete
- Integrated approach – key disciplines at the table from the start
  - Owners
  - Architect
  - Mechanical Consultant
  - RDH = Passive House + Enclosure + Façade Consultant

1. Design Process

Courtesy Henson Developments, WKK Architects / IBI Architects

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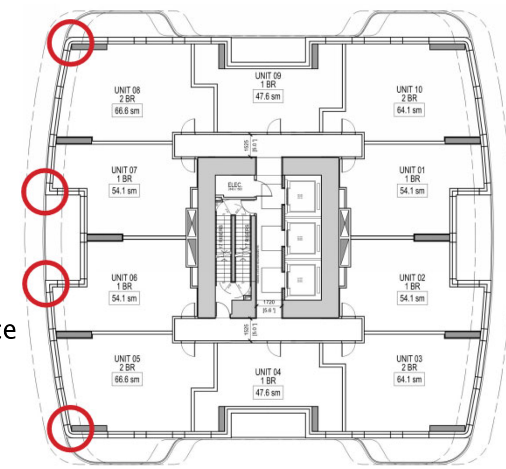
- **Early-stage workshop:**
  - Precedence for tall Passive House buildings
  - Their performance
  - Methodologies to get there
- Established the **baseline for expectations**
- **Internal meetings:**
  - Enclosure options and impact on PH compliance
  - What's constructible?
  - What technology is available?
  - Small tweaks
- **City-driven milestones** & plan to match



2. Milestones to Match the Metrics

Courtesy Henson Developments, WKK Architects / IBI Architects

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OPR:

- Passive House, <u>never in doubt!</u>
- Appearance of curtain wall
- 50% WWR
- Marketability

3. Early-Stage Key Decisions

Courtesy Henson Developments, WKK Architects / IBI Architects

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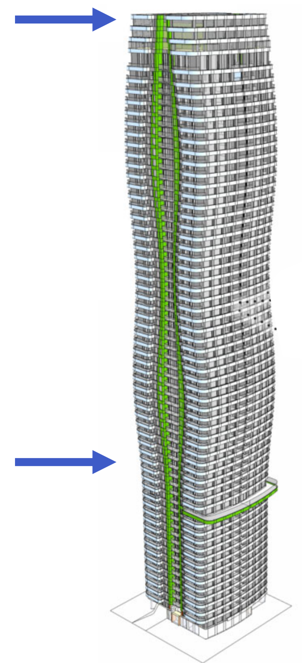
Mechanical – **HRVs**:

- → Per suite / per floor / per 3 floors?
- → Central HRVs on 17th floor and on the roof
  - → Minimized size of ducts
  - → Minimized # of penetrations (PH airtightness & maintenance)
  - → Interconnected the HRVs as redundancy
- → CoV – exclude HRVs and shafts from FSR



3. Early-Stage
Key Decisions

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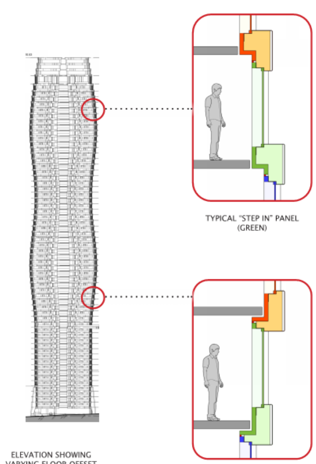

Façade – **Prefabricated**:

- → How do we build a R-30 'curtain wall'?
- → Size of panels?
- → Cost?
- → Architectural vision?

Language – **Practical terms**:

- → If you change _____, you get _____% WWR

3. Early-Stage
Key Decisions

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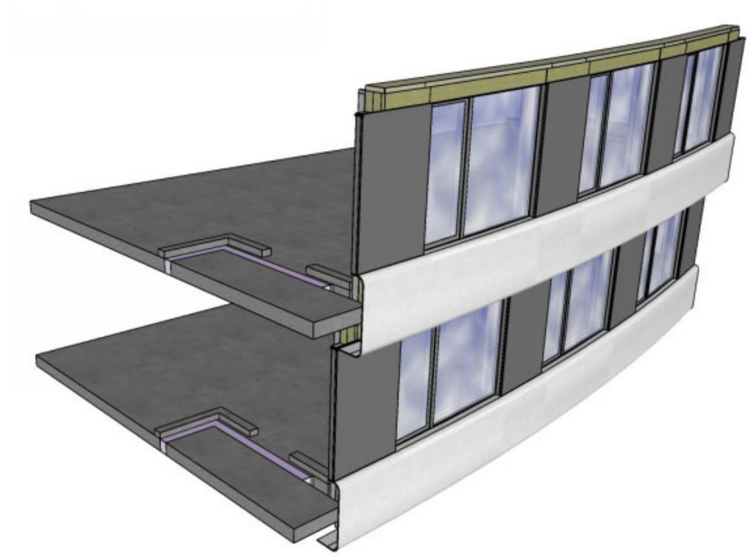
Performance Metrics
Iterative optimization with PHPP team throughout the design

Façade Optimization
- → Complexity of curvature
- → Geometry
- → Streamline # of panels
- → Floorplate alignment
- → Transition details



4. Optimize Decisions

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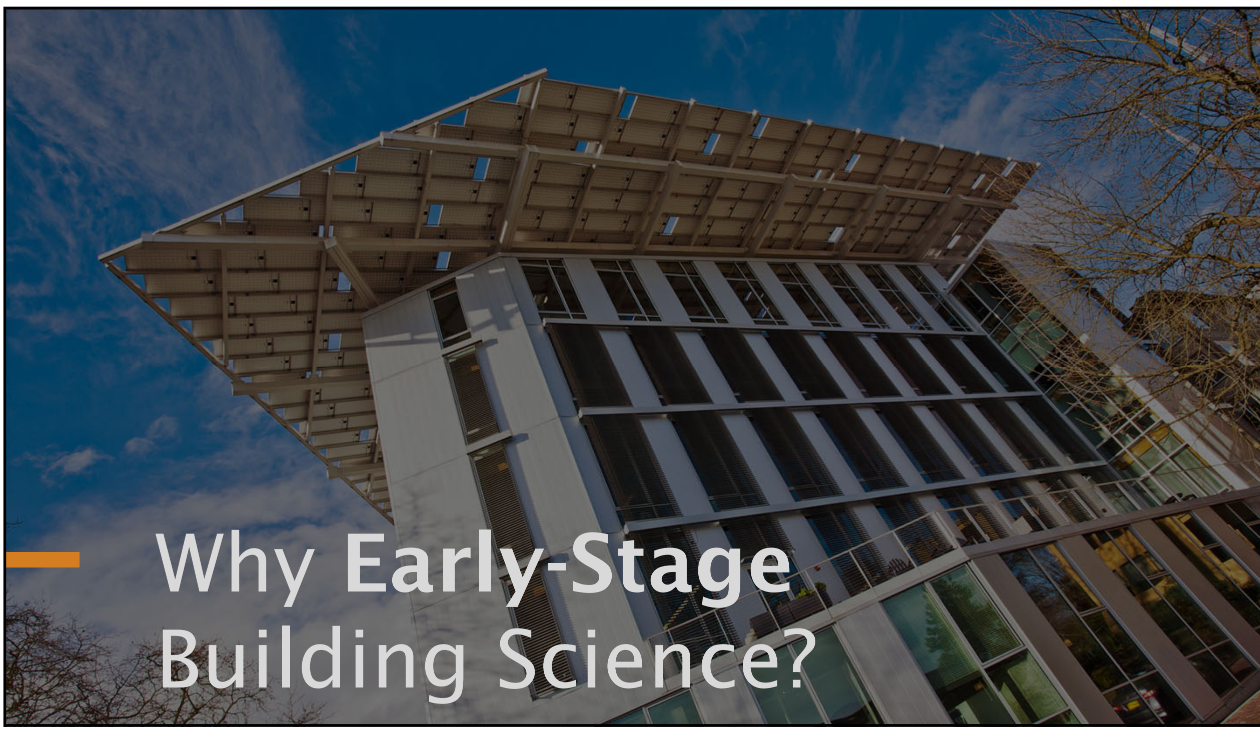

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EARLY-STAGE BUILDING SCIENCE

1. Switch the **Design Process** from Reactive to Proactive
2. Make the **milestones match the metrics**
3. Make the **key decisions early** with the whole team
4. **Optimize** the 10,000s of variables for what matters to the project:
    - Performance
    - Cost
    - Carbon

1. Design Process

2. Milestones to Match the Metrics

3. Early-Stage Key Decisions

4. Optimize Decisions

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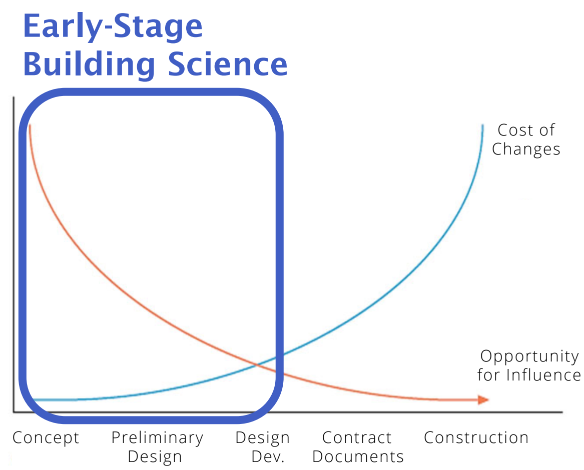
PATH AHEAD

No matter the project:

1. Single-point accountability to **reduce risk**
2. **Efficiencies** gained in time and effort
3. **Better certainty** in cost and performance
4. **Reduction** in value engineering



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HOW CAN WE HELP?

- Building enclosure
- Mechanical systems
- Energy & sustainability
- Façade design
- Façade structure

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INDUSTRY LEADERSHIP

- Develop many current codes and standards
- Author technical guideline documents
- Assist all levels of government with policy development

We have insight on current requirements and what is coming

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THANK YOU!

clemieux@rdh.com

gostojic@rdh.com

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