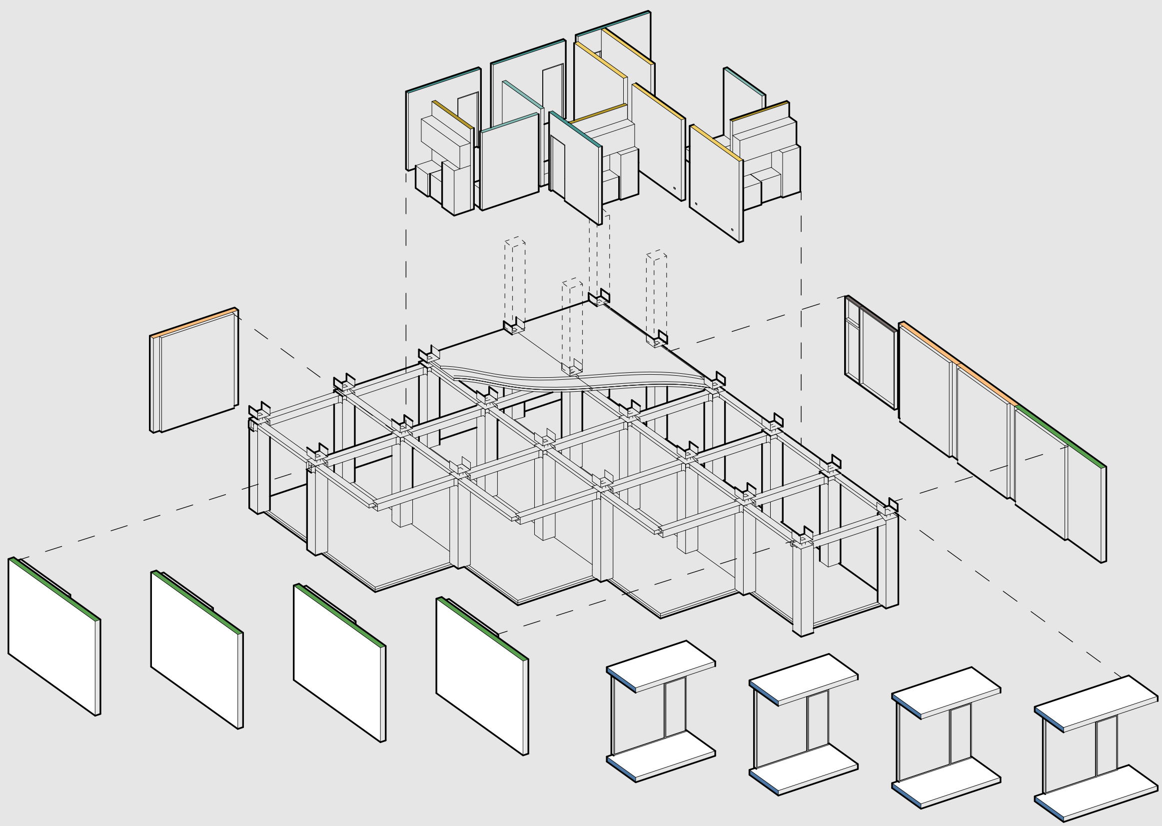


CARBON RESEARCH STUDIO 2021
DESIGNING FOR LOW EMISSIONS
A COMPUTATIONAL APPROACH TO MASS TIMBER BUILDINGS

TOMÁS MÉNDEZ ECHENAGUCIA AND CHRISTOPHER MEEK

W UNIVERSITY *of* WASHINGTON

THE OBJECTIVE OF THE STUDIO IS TO INVESTIGATE THE POTENTIAL OF MASS-TIMBER BUILDINGS TO REDUCE BOTH EMBODIED AND OPERATIONAL CO2 EMISSIONS WITH THE HELP OF PARAMETRIC MODELS, BUILDING PERFORMANCE SIMULATION AND COMPUTATIONAL STRUCTURAL DESIGN TOOLS

TABLE OF CONTENTS

Edited and assembled by:
Preston Pape
Tomas Mendez Echenagucia
Christopher Meek

STUDIO INSTRUCTORS

TOMÁS MÉNDEZ ECHENAGUCIA

Assistant Professor, University of Washington

Tomás Méndez Echenagucia is an Assistant Professor in the Department of Architecture in the University of Washington. He is an architect whose research is focused on the use of simulation, computational geometry and optimization algorithms to make building and building components more sustainable. In particular, his focus lies on structural design, building acoustics and energy performance. He obtained a double degree in Architecture from the Universidad Central de Venezuela and the Politecnico di Torino in 2007, as well as a PhD in Architecture and Building Design also from the Politecnico di Torino in 2014. He has practiced as an architect and consultant in Europe and South America, he has designed and built several research pavilions and prototypes, including the “Armadillo Vault'' for the Venice Biennale in 2016, the ETH Pavilion for the Ideas City Festival in New York City in 2015. He recently completed a five year postdoctoral research position at the Block Research Group - ETH Zürich, where he was a project lead in the HiLo research unit for the NEST building in Dübendorf Switzerland, currently under construction. Tomás also has a big interest in the development of open source tools for the AEC industry, he is a co-developer of the COMPAS framework, an ecosystem of modeling, design and simulation tools, ranging from Finite Element Analysis to geometric acoustics.

CHRISTOPHER MEEK, AIA, IES

Associate Professor, University of Washington
Director, Integrated Design Lab

Christopher Meek is Associate Professor of Architecture at the University of Washington and Director of the Center for Integrated Design at the University’s College of Built Environments. Professor Meek’s areas of research include building energy performance for new construction and retrofits, daylighting, visual comfort, electric lighting, and climate responsive design. His work bridges practice, research, and education with collaboration between practitioners, faculty, and students. He is the author of two books and many technical publications. Over the past decade, Professor Meek has consulted on over 20 million square feet of commercial and institutional buildings including working, learning, and healing environments including the net-zero energy Bullitt Center in Seattle. His research has been funded by the Northwest Energy Efficiency Alliance, the National Science Foundation, the US Department of Energy, the Illuminating Engineering Society, the Bullitt Foundation, and the American Institute of Architects. Professor Meek teaches graduate and undergraduate level courses on building design and technology at the UW Department of Architecture. Professor Meek is co-author of Daylighting Design in the Pacific Northwest and Daylighting and Integrated Lighting Design. He was elevated to Fellowship in the American Institute of Architects in 2020.

STUDIO CO-INSTRUCTOR

TERESA MOROSEOS

Post-Doctoral Researcher, Integrated Design Lab

Teresa Moroseos is a Post-Doctoral Scholar at the Integrated Design Lab in the University of Washington's College of Built Environments. In this role, she provides daylighting and energy performance analysis for projects throughout the United States. She collaborates with design teams to find solutions that respond to the environment and maintain design intent, determines appropriate metrics of evaluation, and performs daylight and energy simulations. Teresa also conducts research related to building performance.

Teresa has a background in engineering and architecture. Prior to working at the IDL, she worked as a designer at Weinstein A+U, where she worked on civic buildings. Teresa has also taught undergraduate students at the University of Washington in topics of climate analysis, energy principals for buildings, passive solar design, and daylight simulations.

TOOL DEVELOPMENT

The studio tool aims to give designers insights into the embodied and operational carbon performance of their projects early in the design phase. The tool considers basic geometric parameters, climate conditions and material supply chains to calculate these numbers quickly and with minimal input from the designer. This is accomplished by means of the energy plus building simulation package, the grasshopper parametric design environment and a purpose built python library of data structures and functions to manage the geometry and data.

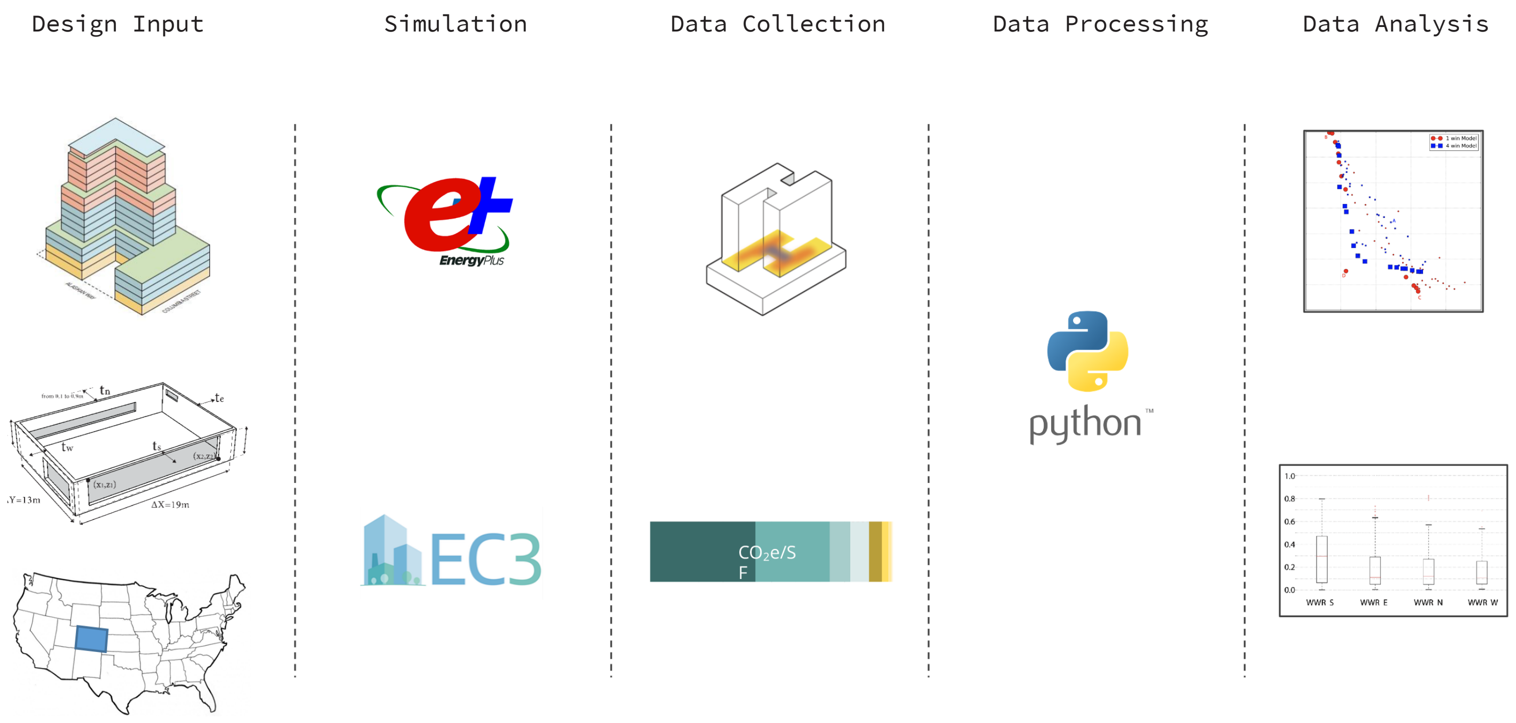
During the early phase of design, little is defined of each building and changes are constant. For this reason, it is ideal to give designers the opportunity to define their geometries, materials and layouts parametrically. In this dynamic modeling setting, designers can consider many options quickly and consider their environmental, architectural and urban impact.

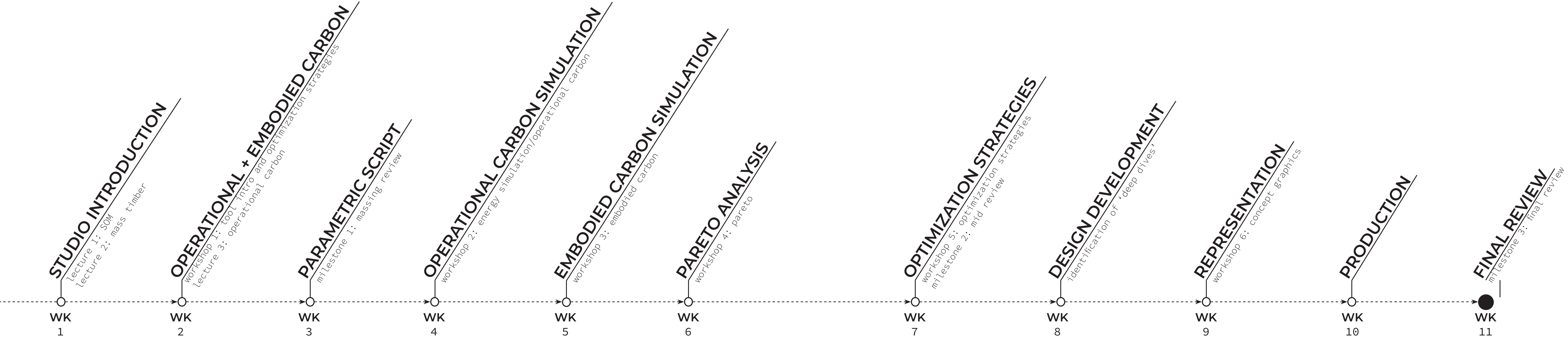
The operational carbon is estimated using the EnergyPlus building simulation package. The package is capable of estimating the heating, cooling and lighting loads of building zones, given their geometry, materials, climate, etc.

The studio tool makes use of the Honeybee Grasshopper plugin to access the energy plus functionality within the GH environment. Honeybee takes EPW files as input to locate the geographical/climate location Grasshopper is used as the go-between for EnergyPlus, Rhino, Honeybee, and our custom Python code.

Custom Python modules are used for embodied carbon and thermal properties data management via spreadsheets. This allows for easier management of data in the case that edits need to be made. Further, custom python modules created for structural accounting of embodied carbon using Compas, an architecturally-focused Python library.

Github is the repository used for tool distrobution and for pushing of updates. By using Github, we are able to push current datasets to all users of the tool to ensure uniformity. The GitHub page includes installation instructions for a smoother process.





STUDIO TIMELINE

GUESTS REVIEWERS + LECTURERS

HEATHER BURPEE

Guest Reviewer

Research Associate Professor
@ University of Washinton
Integrated Design Lab

Heather Burpee is Research Associate Professor at the University of Washington Integrated Design Lab, and is a nationally recognized scholar in high-performance buildings – buildings that reduce energy and promote healthy indoor environments. Her work bridges practice, research, and education with collaboration between practitioners, faculty, and students. Her research addresses both qualitative and quantitative aspects of buildings including tracking health impacts and synergies between environmental quality, natural systems, sensory environments, and energy efficiency. She regularly applies these roadmaps in practice, consulting with leading design teams nationally that are charged with implementing high-performance buildings.

ARATHI GOWDA,

AIA, AICP, LEED AP BD+C

Guest Reviewer + Lecturer

Associate Director
@ SOM // Chicago

Arathi Gowda, AIA, AICP, LEED AP BD+C, Associate Director is a team leader for SOM Chicago's Performative Design Group, charged with researching new technologies and recommending integrated environmental design solutions that are substantiated with computer simulation for SOM project teams worldwide. As an educator Arthi is committed to training the next generation of practitioners engaging with two Universities, as the current elected Dean of Sustainable Initiatives at Foundation University and as Part Time Professor at Roosevelt University.

ERIC LONG,

PE, SE, LEED AP

Guest Reviewer + Lecturer

Director of Structural Engineering
@ SOM // San Francisco

Eric Long, PE, SE, LEED AP is Director of Structural Engineering in the San Francisco office of SOM where he incorporates innovative structural engineering design concepts to drive new solutions in building design and construction. He works in close collaboration with the entire design team, including architectural and MEP, to develop integrated ideas and advance each project in pursuit of design excellence.

KATE SECTOR,

LEED GREEN ASSOCIATE, LFA

Guest Reviewer + Lecturer

Design Performance Coordinator

@ Lake Flato Architects

Kate Sector is part of the Design Performance team, informing firm-wide design performance efforts for projects, including post-occupancy evaluation, certification processes such as LEED, and project-specific performance goals. As the firm's Design Performance Coordinator, Kate informs firm-wide design performance efforts and coordinates with project teams at all phases, including project specific performance goal setting, building simulations, certification processes and documentation, and post-occupancy evaluation. She additionally specializes in embodied carbon research, biomimicry, and daylight and energy analysis. Kate graduated from the University of Colorado, Boulder with a Bachelor's degree in Environmental Design and a Certificate of Renewable and Sustainable Energy.

JONATHAN SMITH,

AIA, LEED AP BD+C

Guest Reviewer + Lecturer

Associate Partner

@ Lake Flato Architects

Jonathon Smith is co-leader of the Lake|Flato's Urban Development studio, which fulfills his passion for championing high-performance projects which transform entire districts. Jonathan joined Lake|Flato in 2005 with a background in large scale, mixed-use developments and multifamily residential projects. He has managed projects of varying scales, from the 1221 Broadway mixed-use development in San Antonio, TX, to an adobe bunkhouse in Marfa, TX. An active member in the local community, Jonathan was a founding board member of the ACE Mentor Program of Greater San Antonio and was the AIA San Antonio President in 2011.

SUSAN JONES,

FAIA

Guest Reviewer

Affiliate Associate Professor

@ University of Washington

Susan Jones, FAIA, in addition to being a professor at UW, former Fulbright scholar, and the founder of her own award-winning architecture firm Atelier Jones, is a national leader in the mass timber community, where she represented over 90,000 architects on behalf of the American Institute of Architects in 2016 to successfully change American building codes to allow tall mass timber buildings up to 18 stories in the US. In 2018, she published a book, Mass Timber | Design and Research, which launched in New York City, London, Tokyo and Seattle.

JACOB DUNN

Guest Reviewer + Lecturer

Associate Principial

@ ZGF Architects

Jacob Dunn is Associate Principal at ZGF Architects in Portland where he splits his time between coordinating sustainability practices at the leadership level while providing technical assistance and training across ZGF's multiple offices. Jacob holds a Master's Degree in Architecture from the University of Idaho and his professional background has pivoted between research, sustainability consulting, education, and architecture. After spending a year in London with ARUP's Foresight Innovation and Incubation group, Jacob finished his degree and started working at the University of Idaho's Integrated Design Lab (IDL).

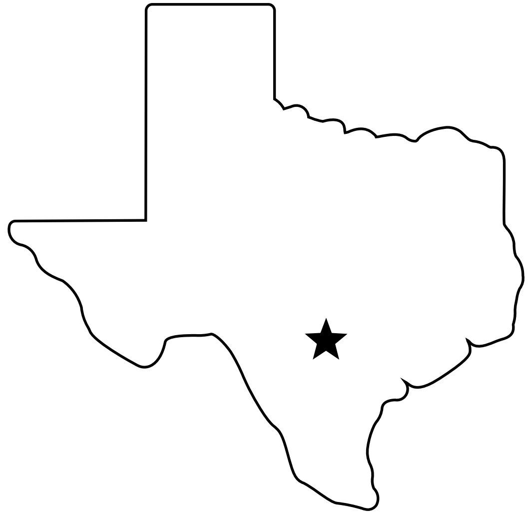
FURTHER ACKNOWLEDGEMENTS

Special thanks to all those aforementioned, as well as those listed here who gave their time and expertise to the betterment of this research studio.

Guest Reviewers:
Tate Walker .... Director of Sustainability, OPN Architects
Ursula Frick .... CAD/CAM Specialist, Blumer Lehmann AG
Indroneil Ganguly .... Research Associate Professor , UW SEFS
Emily Doe .... Senior Associate, Weber Thompson
Brad Liljequist .... Senior Program Manager, KcKinstry

Tool Development:
Teresa Moroseos .... Post Doctoral Researcher, UW IDL
Christopher Meek .... Associate Professor, UW; Director, IDL
Preston Pape .... Graduate Research Assistant, UW IDL
Tomás Méndez Echenagucia .... Assistant Professor, UW
Michael Gilbride .... Research Associate, UW IDL

This research studio was sponsored by Seattle Building Enclosure Council (SeBEC)



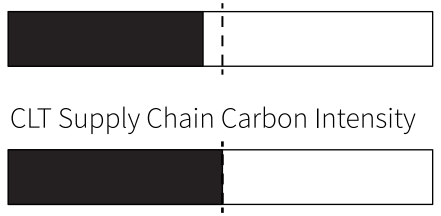
SAN ANTONIO
TEXAS
115 E. Martin St.

- IECC Climate Zone 2
- IECC Moisture Regime A
- Hot
- Humid

29.4294612N, 98.4924382W

Grid Carbon Intensity

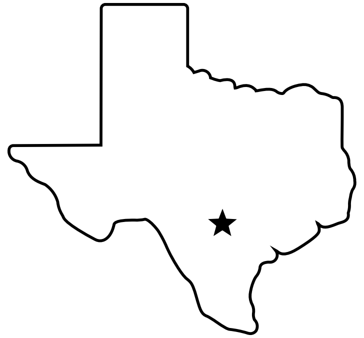
CLT Supply Chain Carbon Intensity



414 gCO_2/kWh

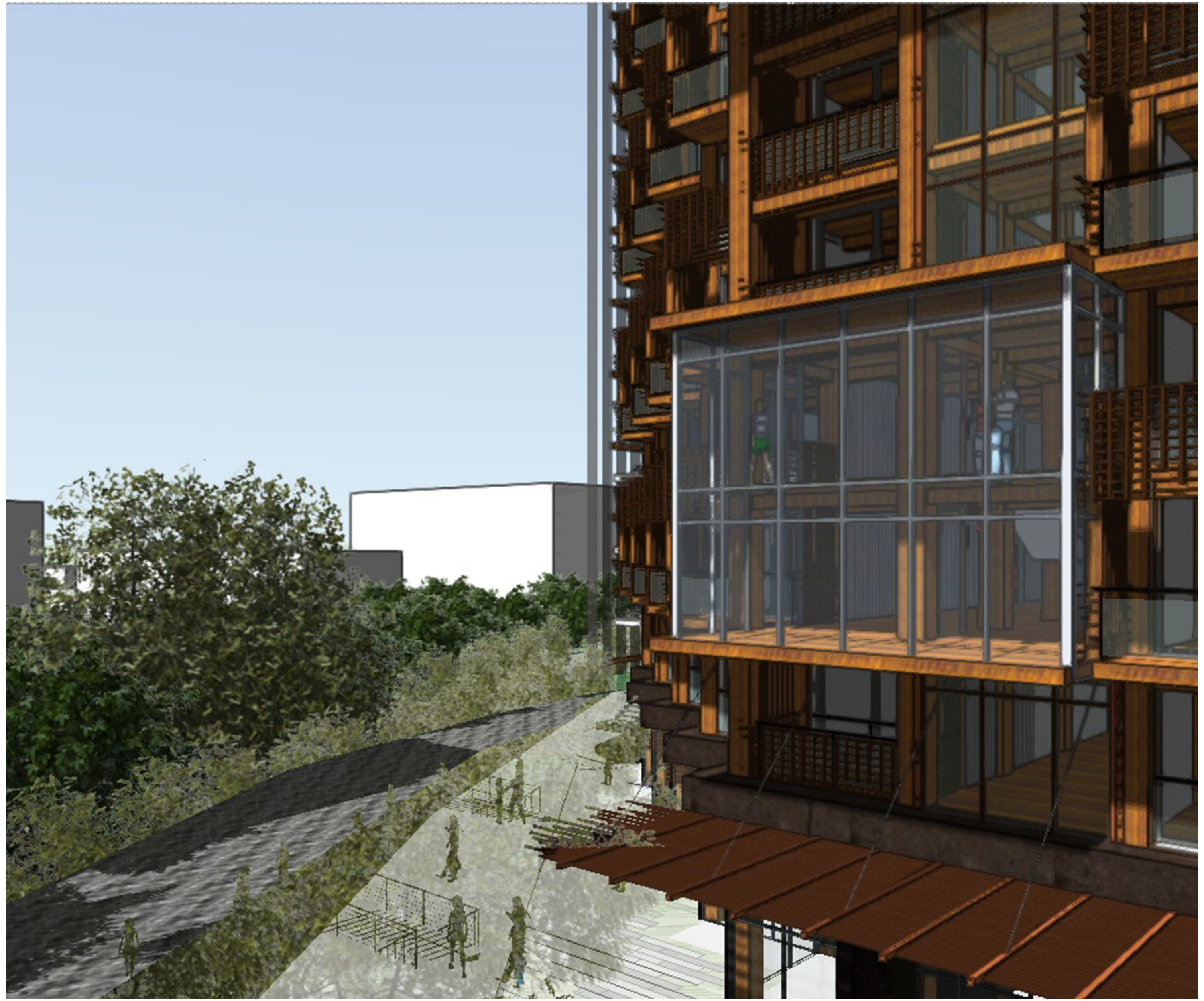
183 $kgCO_2/m^3$

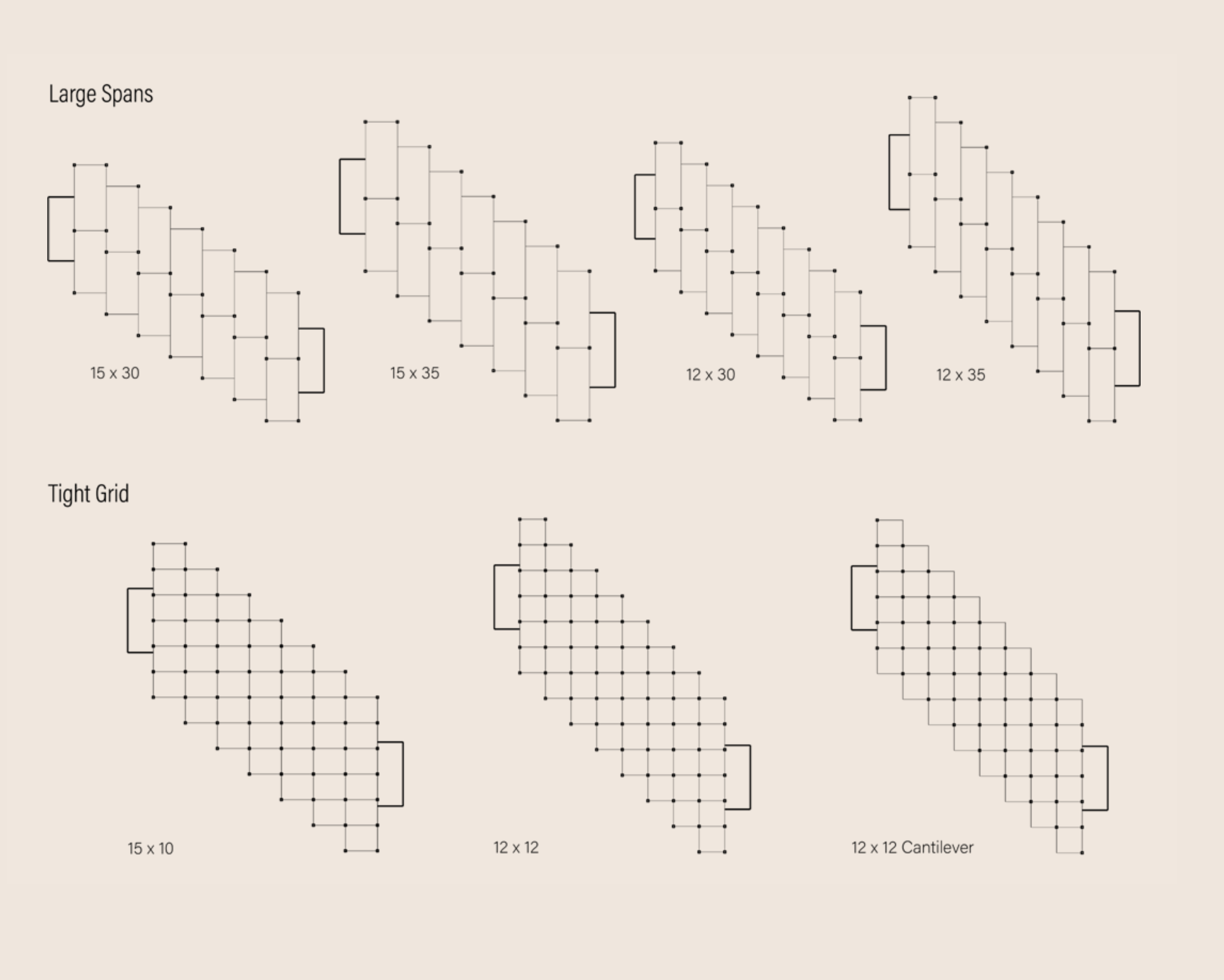
Image courtesy of Matthew LeJune via https://unsplash.com/photos/IpvDhQjrewM

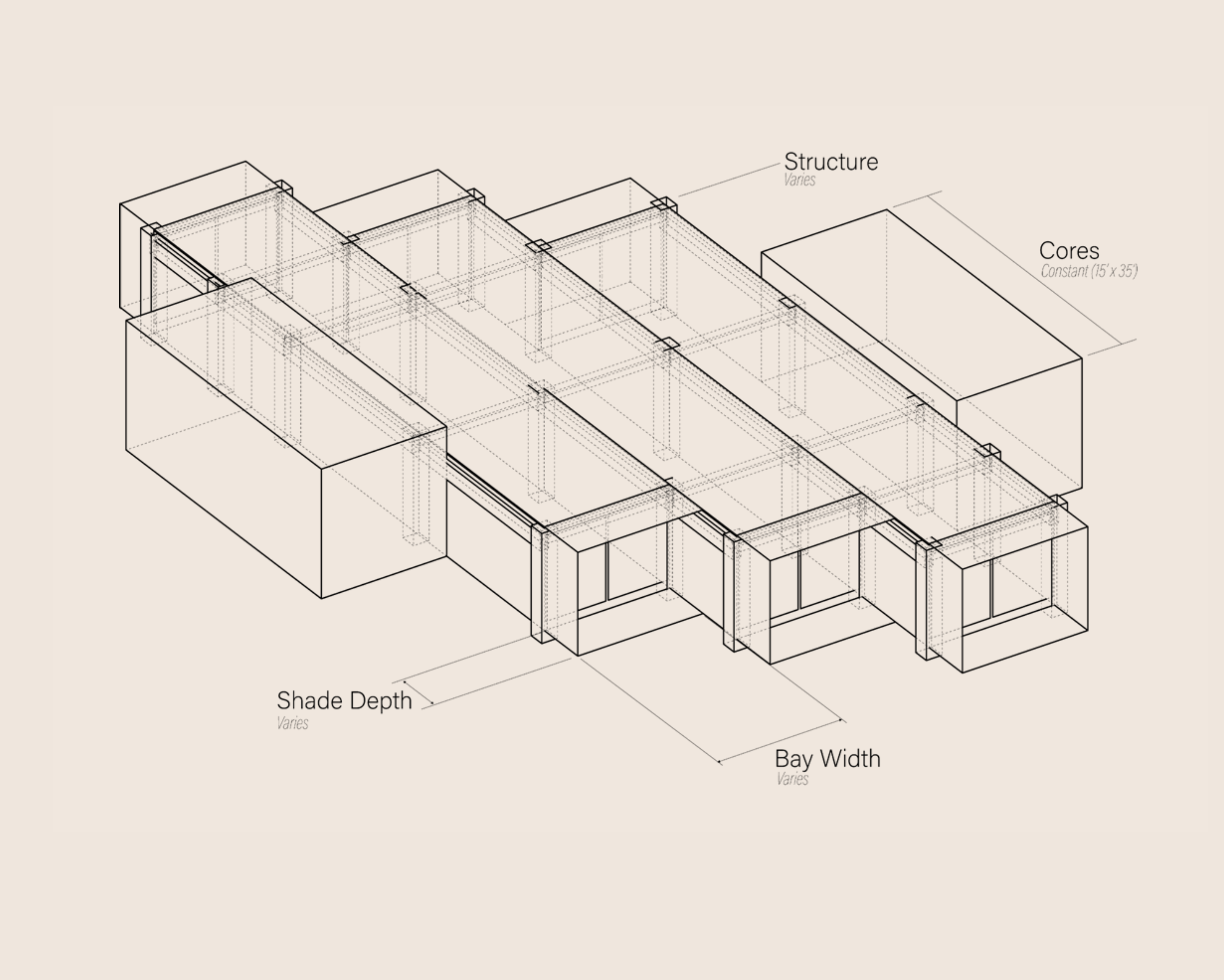


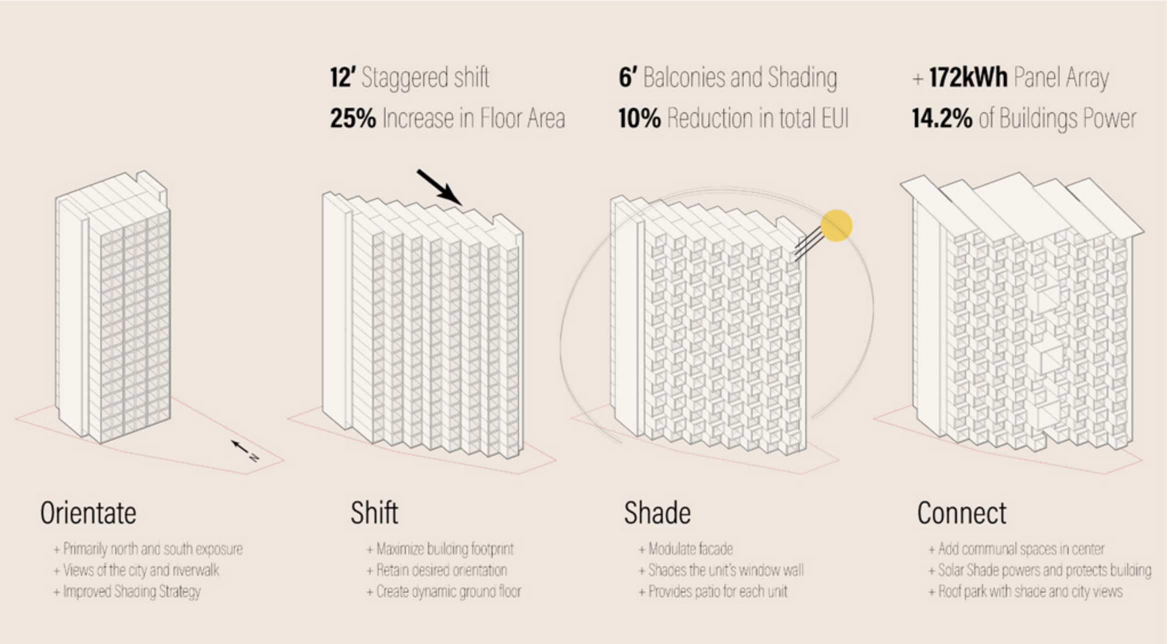
Juan Eduardo Quiroga Castillo
+
Michael Schoemaker

115 E. Martin St.
San Antonio, Texas

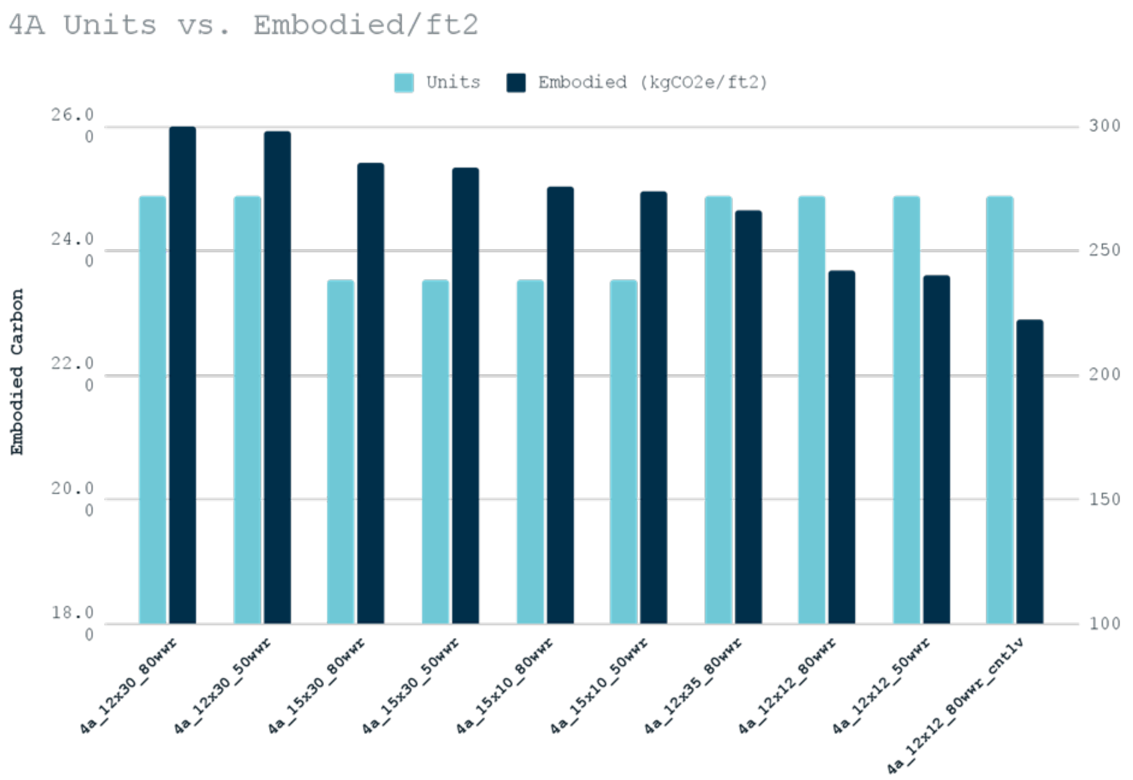


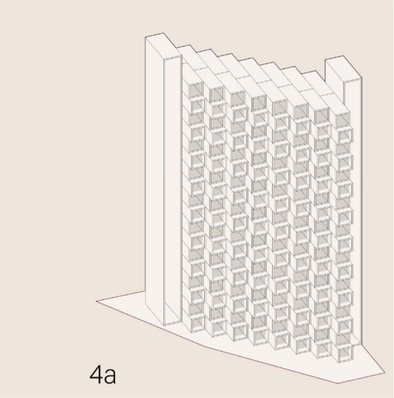

Large Spans
15 x 30
15 x 35
12 x 30
12 x 35
Tight Grid
15 x 10
12 x 12
12 x 12 Cantilever

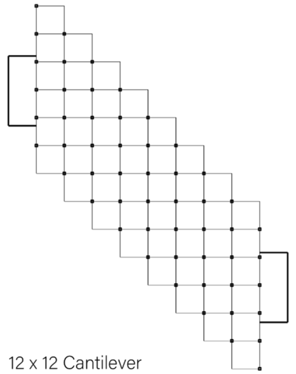

Structure
Varies
Cores
Constant (15' x 35')
Shade Depth
Varies
Bay Width
Varies



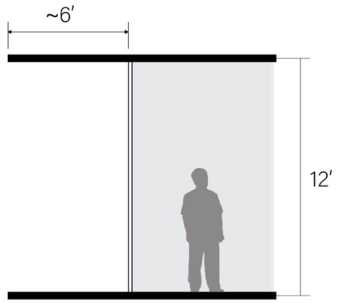
Form Process Diagram

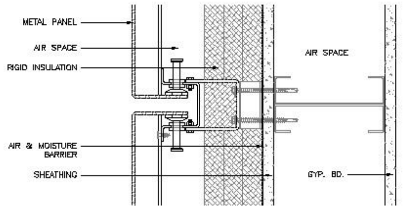






12 x 12 Cantilever

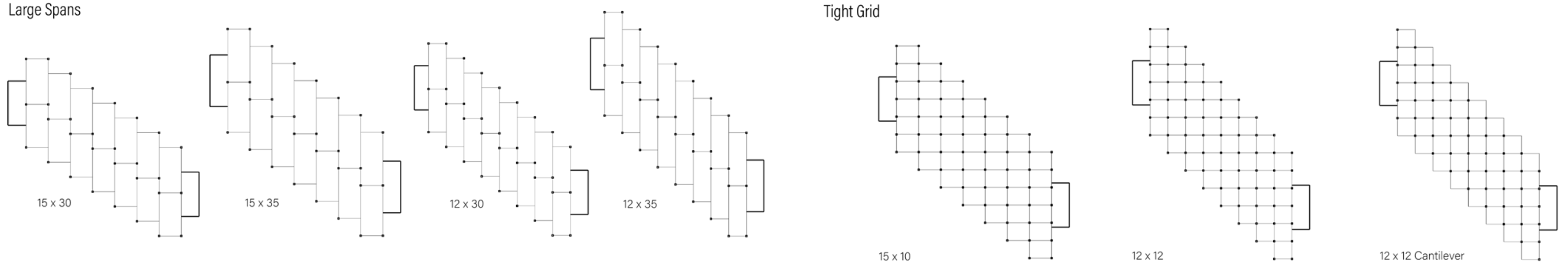




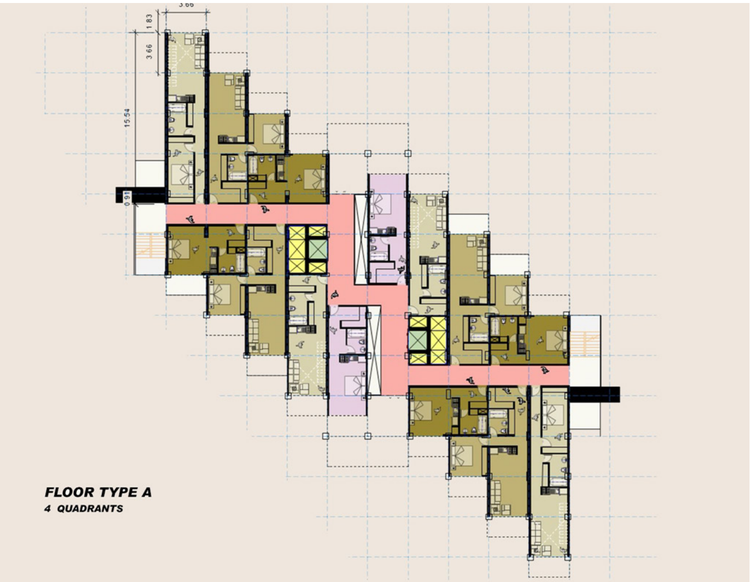
Metal Panel on 2x8 w/
Fiberglass Insul.

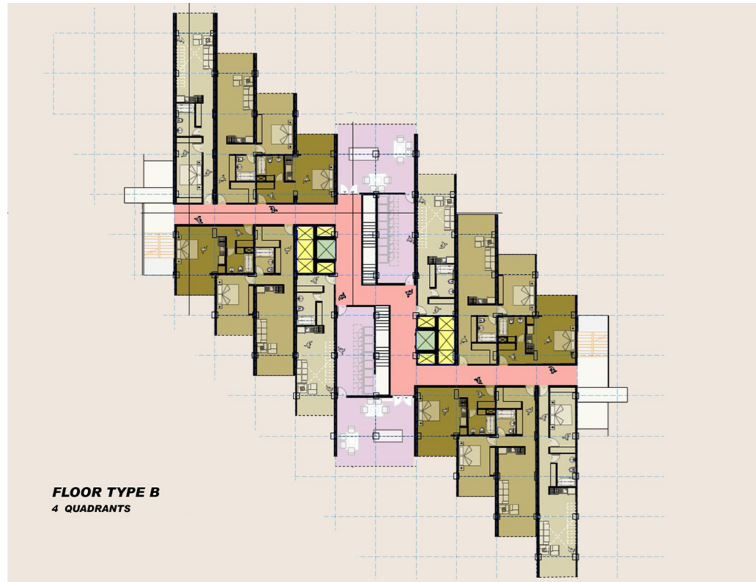
Large Spans

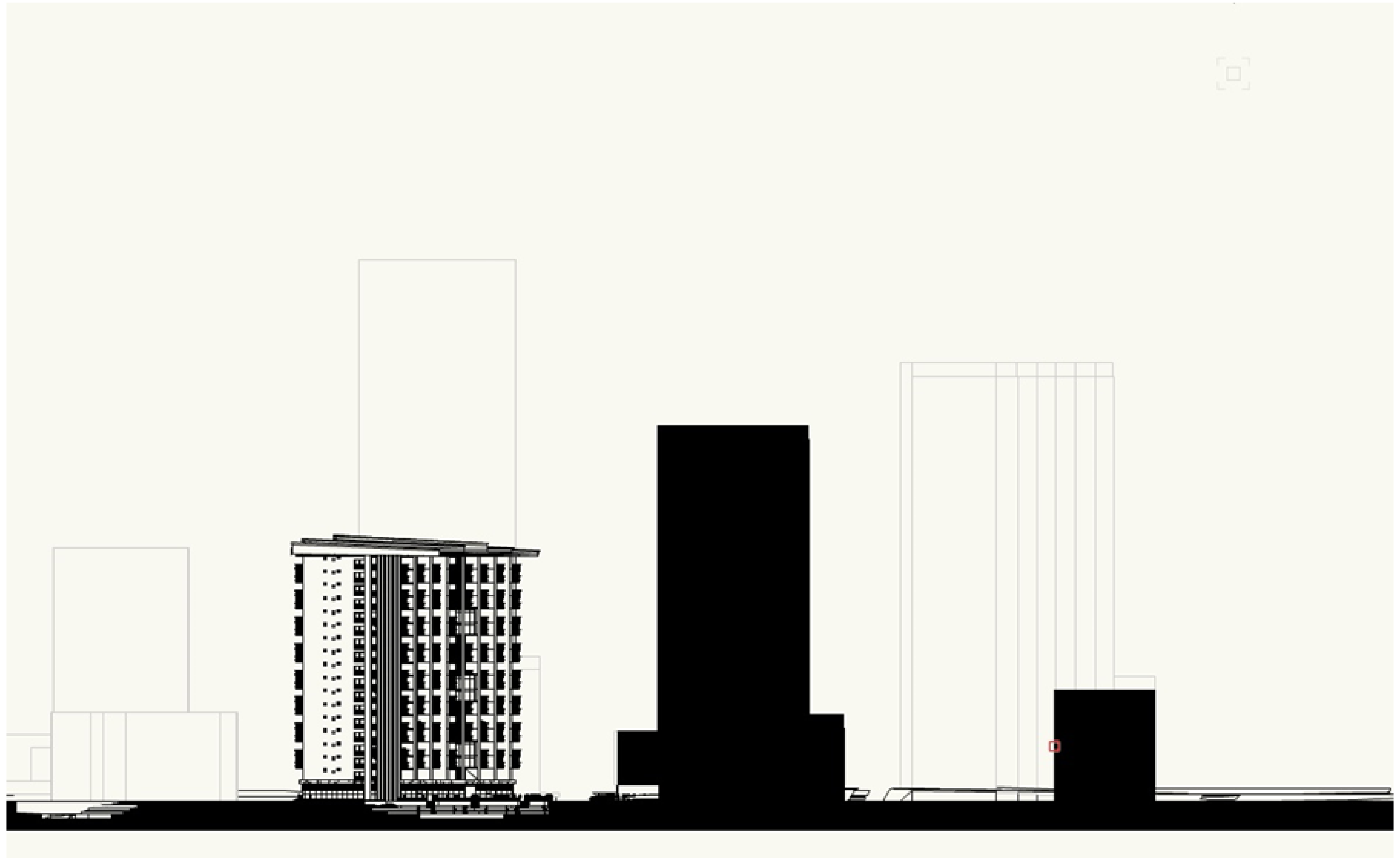
Tight Grid

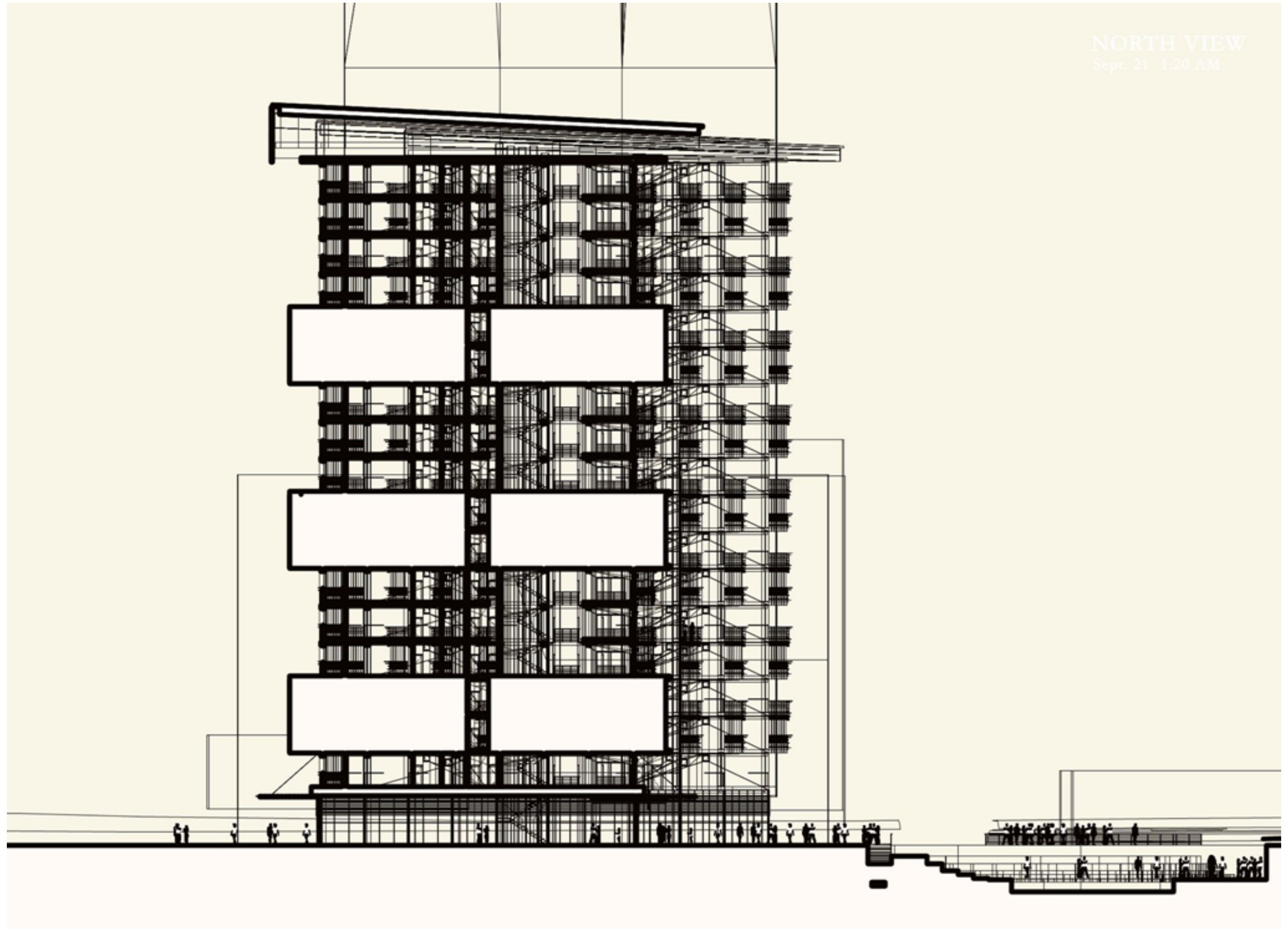


Plans / Sections / Axonometrics

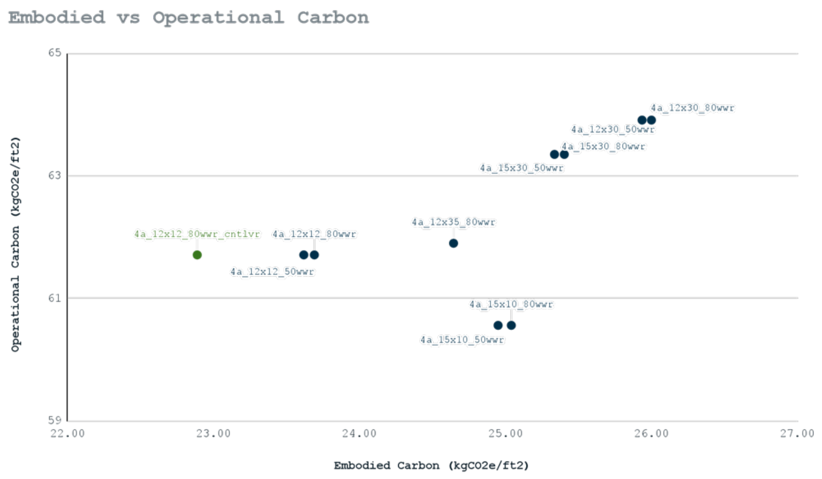


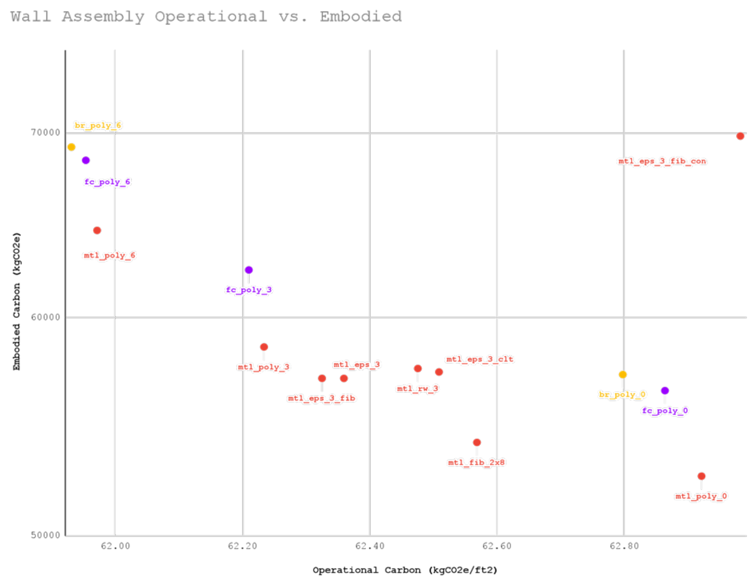


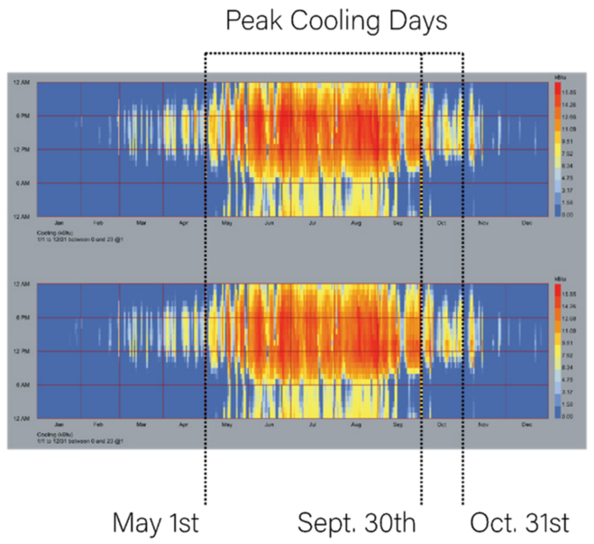


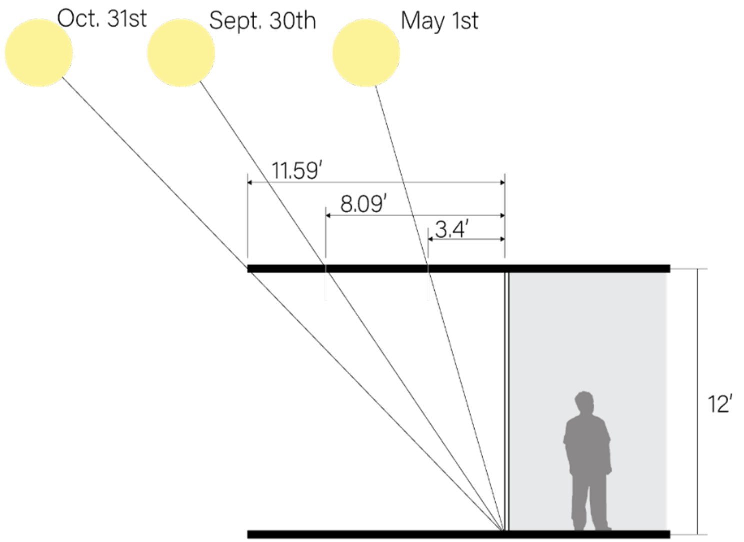

NORTH VIEW
Sept. 21 1:20 AM

Simulation Data

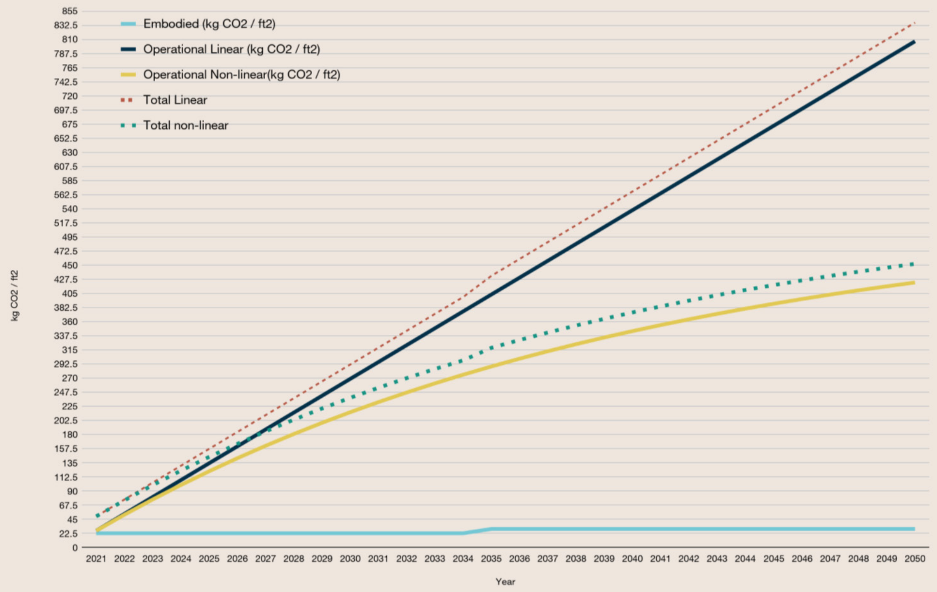




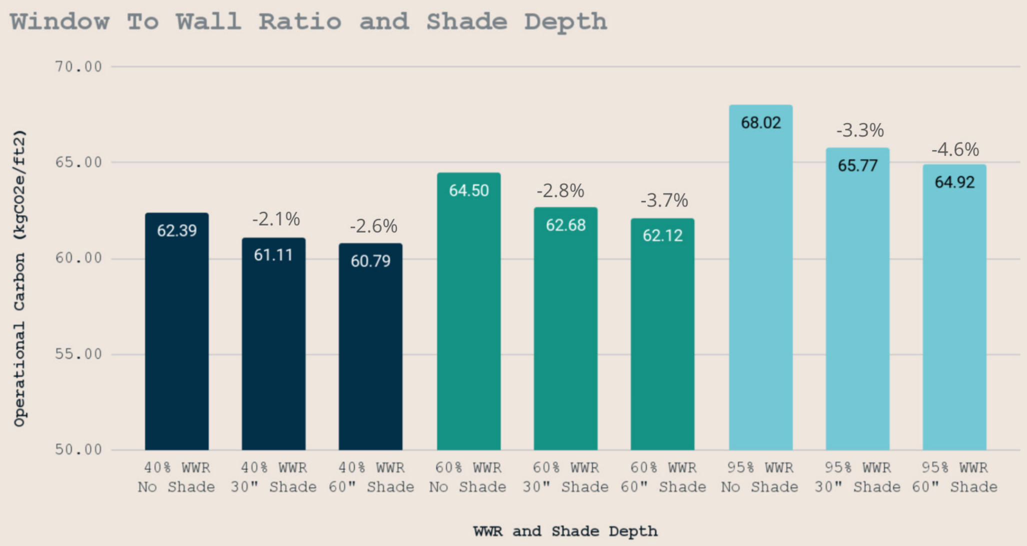




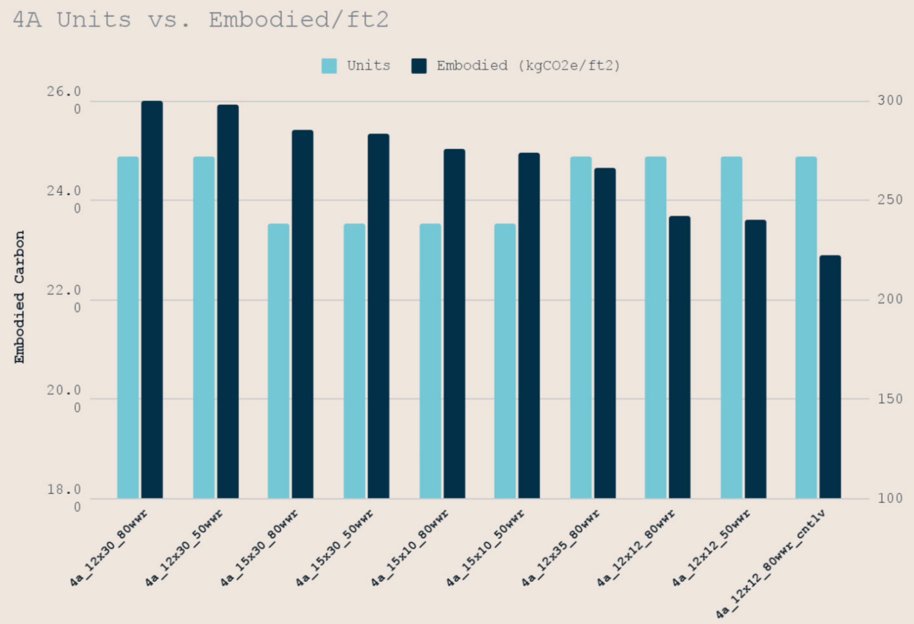
Results



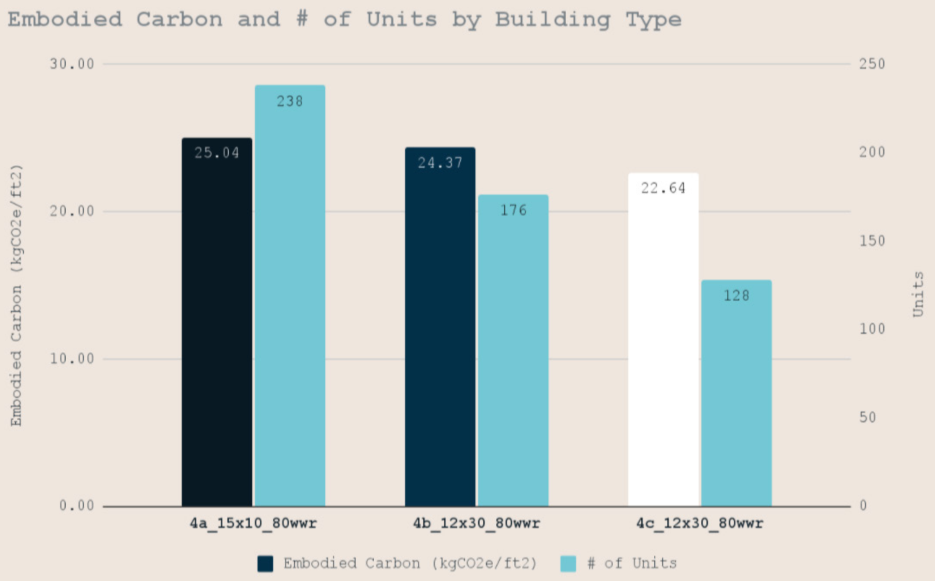
Embodied (kg CO2 / ft2)
Operational Linear (kg CO2 / ft2)
Operational Non-linear(kg CO2 / ft2)
Total Linear
Total non-linear
kg CO2 / ft2
Year



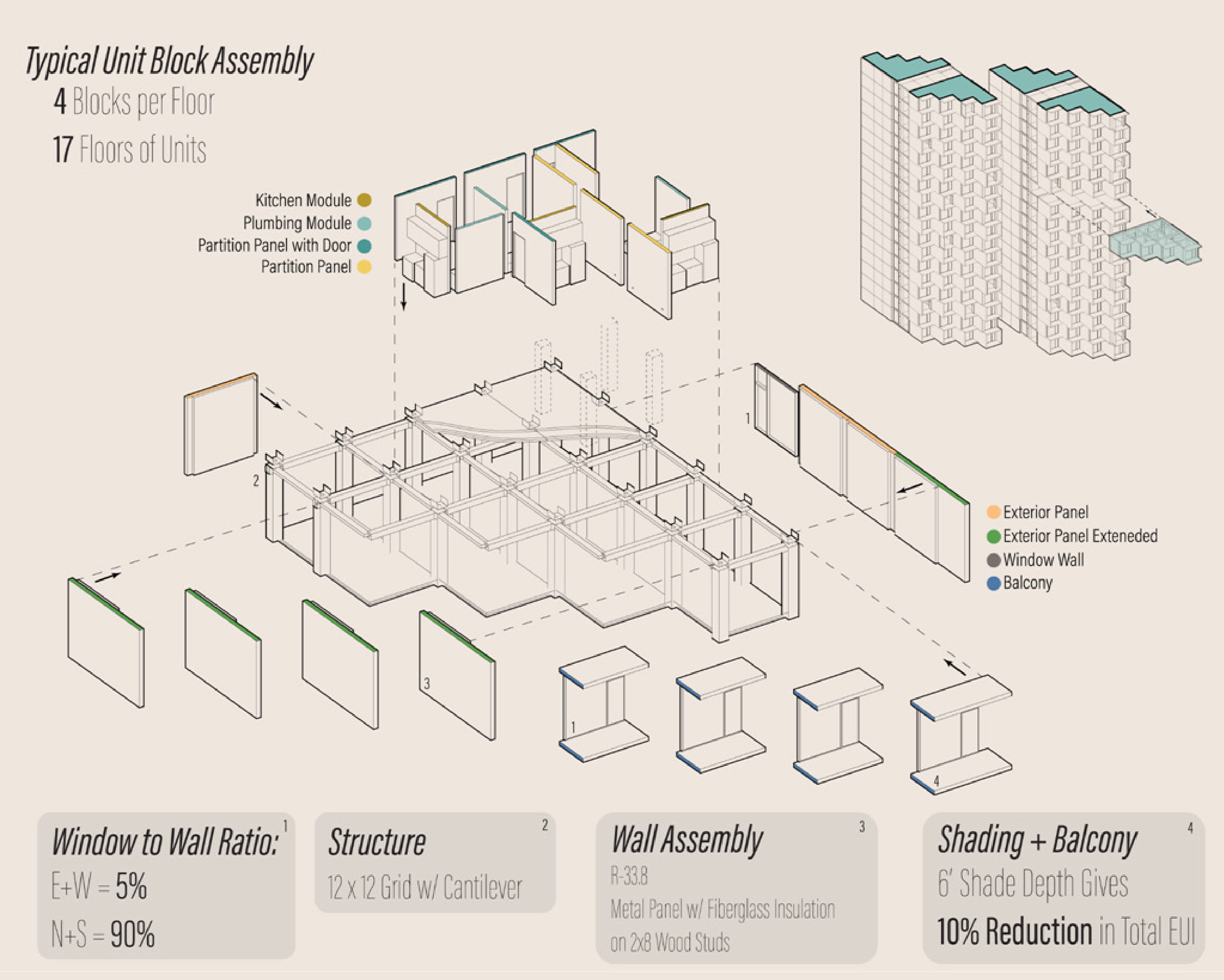
Window To Wall Ratio and Shade Depth
Operational Carbon (kgCO2e/ft2)
70.00
65.00
60.00
55.00
50.00
62.39
61.11
-2.1%
60.79
-2.6%
64.50
62.68
-2.8%
62.12
-3.7%
68.02
65.77
-3.3%
64.92
-4.6%
40% WWR No Shade
40% WWR 30" Shade
40% WWR 60" Shade
60% WWR No Shade
60% WWR 30" Shade
60% WWR 60" Shade
95% WWR No Shade
95% WWR 30" Shade
95% WWR 60" Shade
WWR and Shade Depth

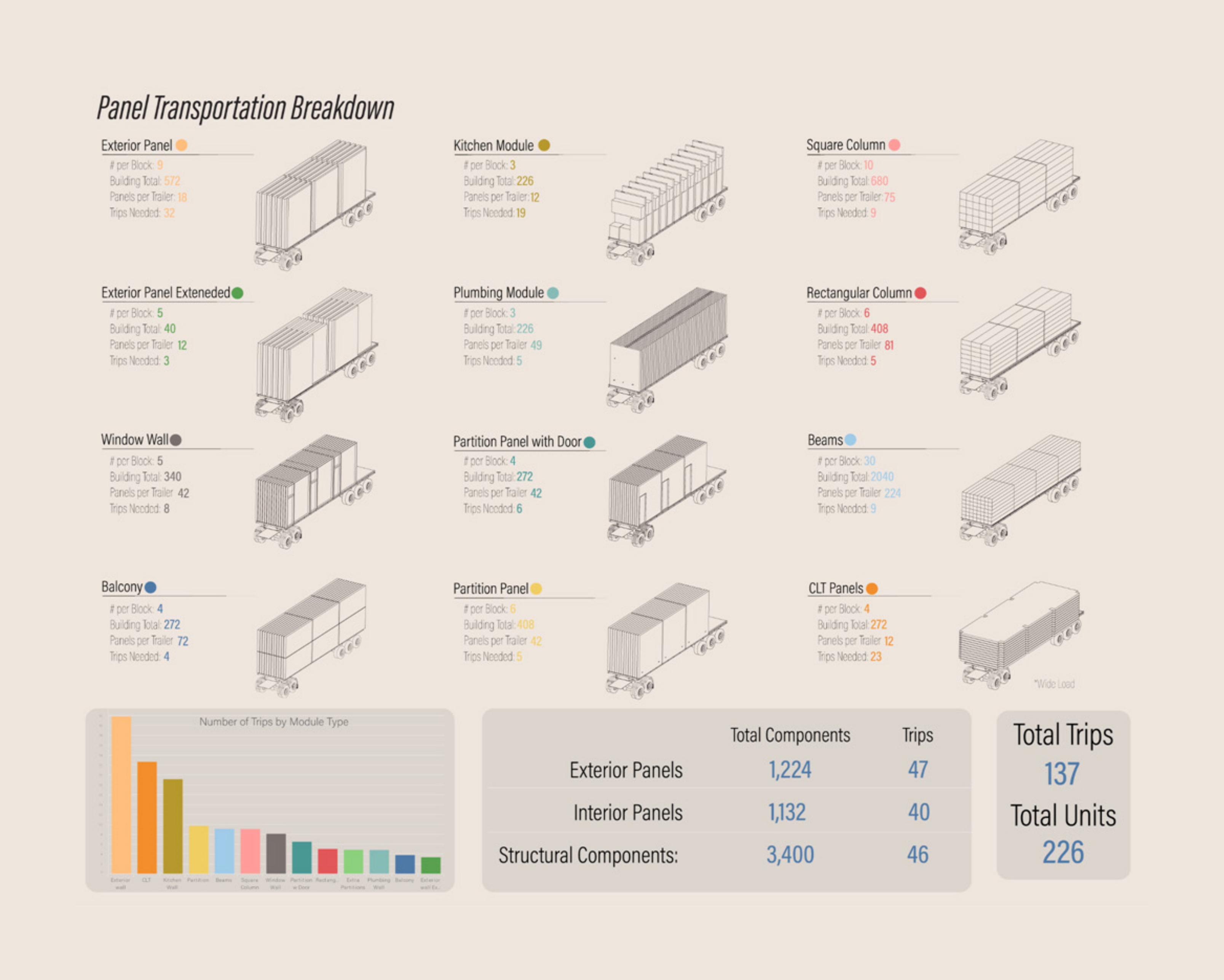


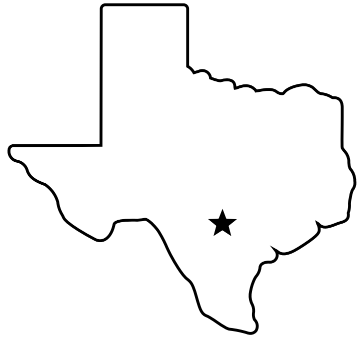
4A Units vs. Embodied/ft2
Units
Embodied (kgCO2e/ft2)
Embodied Carbon
26.00
24.00
22.00
20.00
18.00
300
250
200
150
100
4a_12x30_80wwr
4a_12x30_50wwr
4a_15x30_80wwr
4a_15x30_50wwr
4a_15x10_80wwr
4a_15x10_50wwr
4a_12x35_80wwr
4a_12x12_80wwr
4a_12x12_50wwr
4a_12x12_80wwr_cntlv



Embodied Carbon and # of Units by Building Type
Embodied Carbon (kgCO2e/ft2)
Units
30.00
20.00
10.00
0.00
250
200
150
100
50
0
25.04
238
24.37
176
22.64
128
4a_15x10_80wwr
4b_12x30_80wwr
4c_12x30_80wwr
Embodied Carbon (kgCO2e/ft2)
# of Units

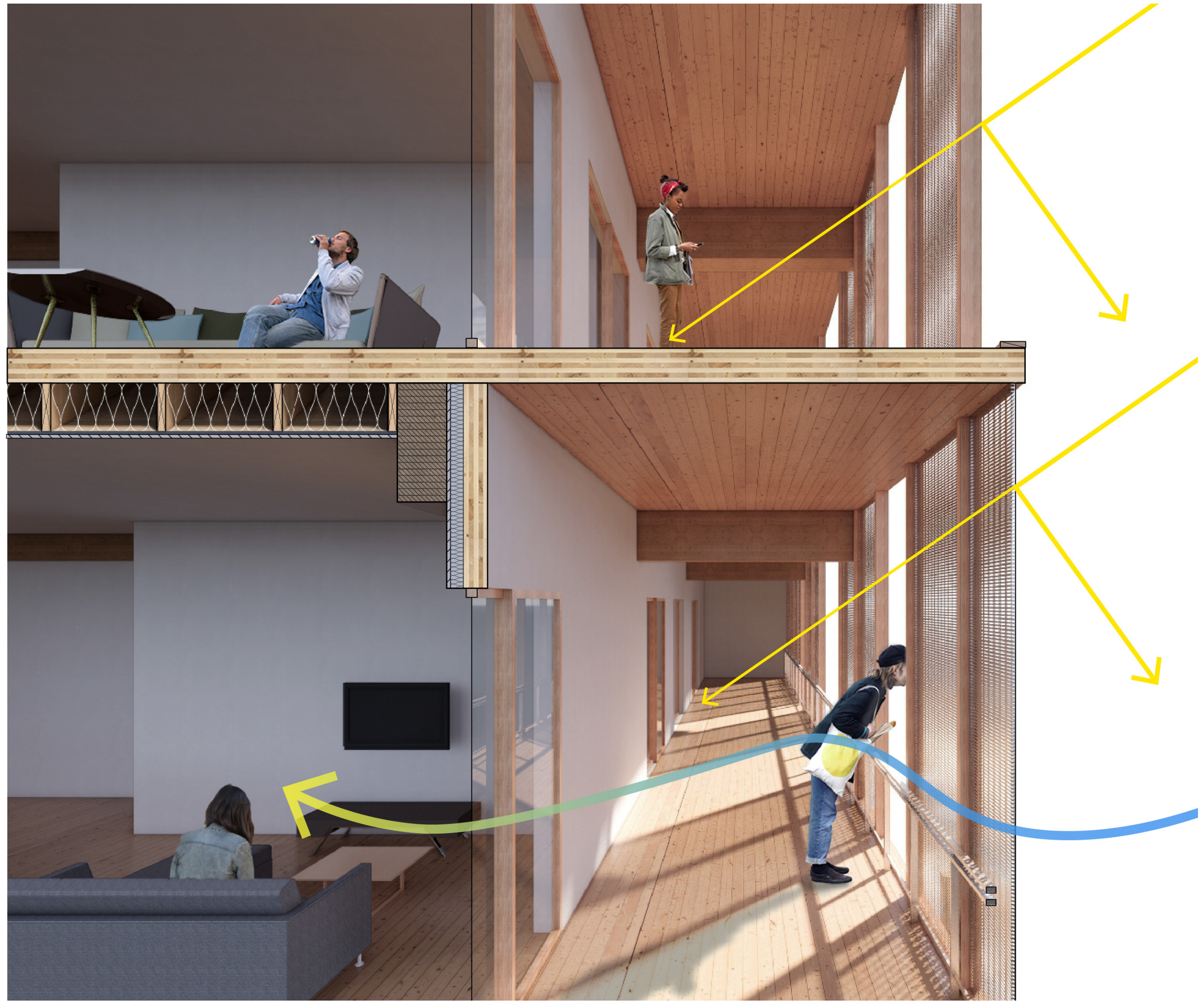

Typical Unit Block Assembly
4 Blocks per Floor
17 Floors of Units
Kitchen Module
Plumbing Module
Partition Panel with Door
Partition Panel
Exterior Panel
Exterior Panel Exteneded
Window Wall
Balcony
Window to Wall Ratio: 1
E+W = 5%
N+S = 90%
Structure 2
12 x 12 Grid w/ Cantilever
Wall Assembly 3
R-33.8
Metal Panel w/ Fiberglass Insulation
on 2x8 Wood Studs
Shading + Balcony 4
6' Shade Depth Gives
10% Reduction in Total EUI


Panel Transportation Breakdown
Exterior Panel
per Block: 9
Building Total: 572
Panels per Trailer: 18
Trips Needed: 32
Kitchen Module
per Block: 3
Building Total: 226
Panels per Trailer: 12
Trips Needed: 19
Square Column
per Block: 10
Building Total: 680
Panels per Trailer: 75
Trips Needed: 9
Exterior Panel Exteneded
per Block: 5
Building Total: 40
Panels per Trailer 12
Trips Needed: 3
Plumbing Module
per Block: 3
Building Total: 226
Panels per Trailer 49
Trips Needed: 5
Rectangular Column
per Block: 6
Building Total: 408
Panels per Trailer 81
Trips Needed: 5
Window Wall
per Block: 5
Building Total: 340
Panels per Trailer 42
Trips Needed: 8
Partition Panel with Door
per Block: 4
Building Total: 272
Panels per Trailer 42
Trips Needed: 6
Beams
per Block: 30
Building Total: 2040
Panels per Trailer 224
Trips Needed: 9
Balcony
per Block: 4
Building Total: 272
Panels per Trailer 72
Trips Needed: 4
Partition Panel
per Block: 6
Building Total: 408
Panels per Trailer 42
Trips Needed: 5
CLT Panels
per Block: 4
Building Total: 272
Panels per Trailer 12
Trips Needed: 23
*Wide Load
Number of Trips by Module Type
Total Components
Trips
Exterior Panels 1,224 47
Interior Panels 1,132 40
Structural Components: 3,400 46
Total Trips
137
Total Units
226

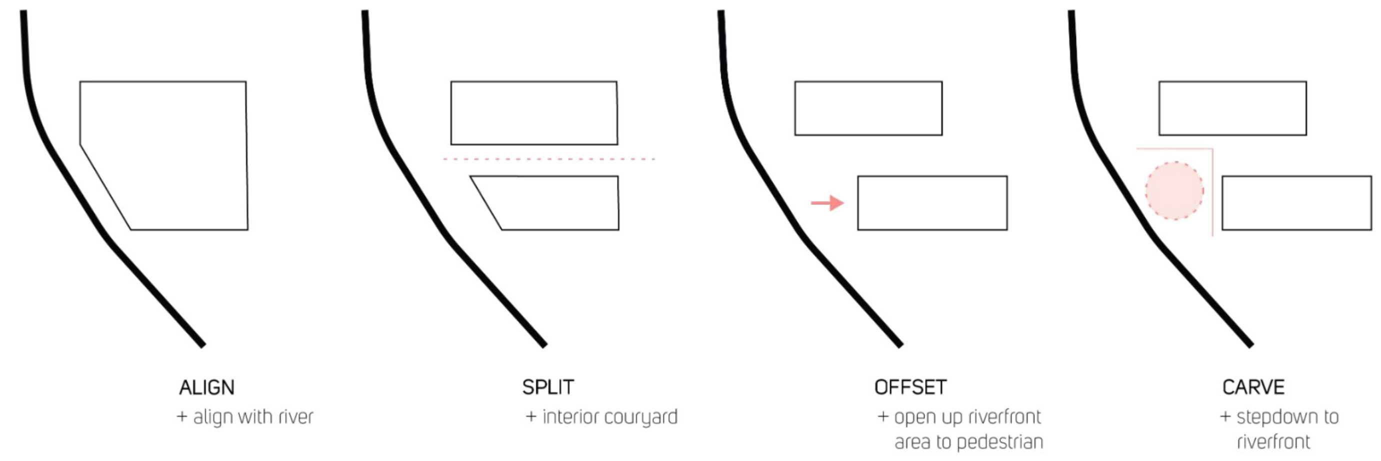


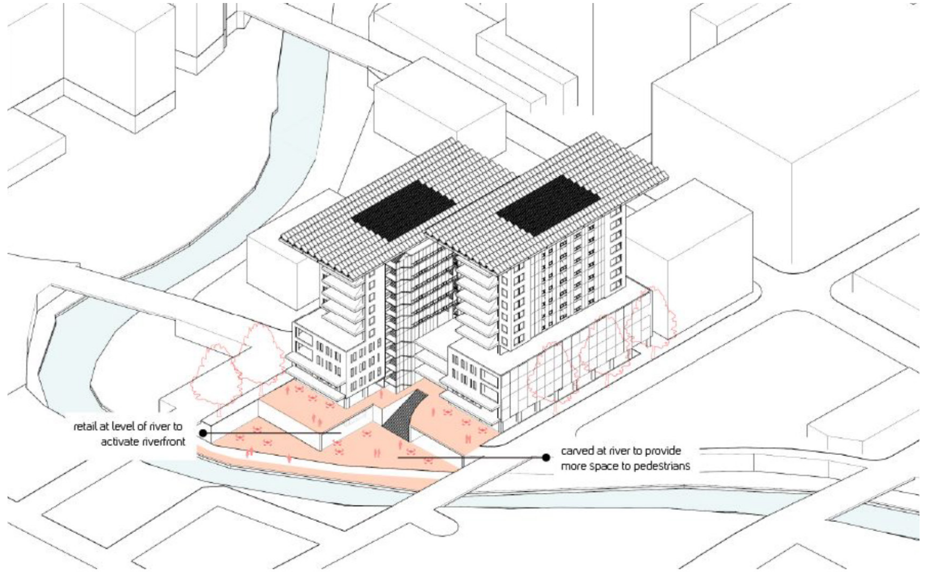
Lindsay Johnson
+
Connor Beck
+
Kevin Shane Lin

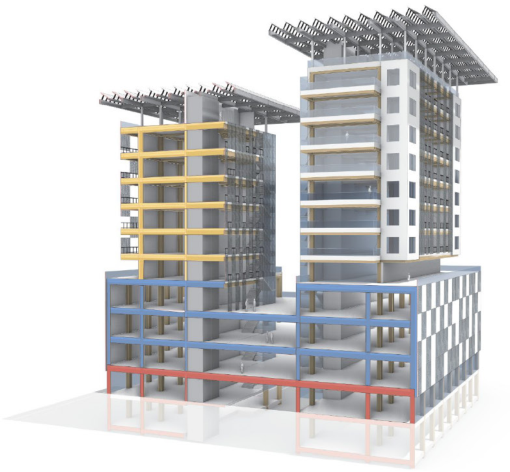
115 E. Martin St.
San Antonio, Texas

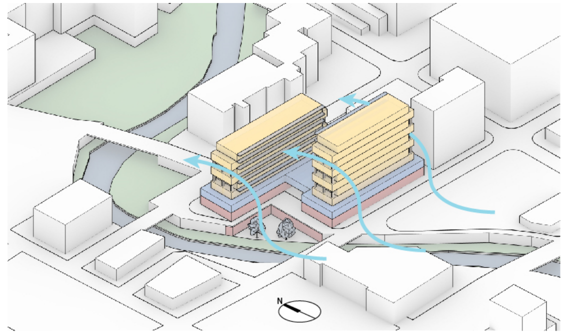


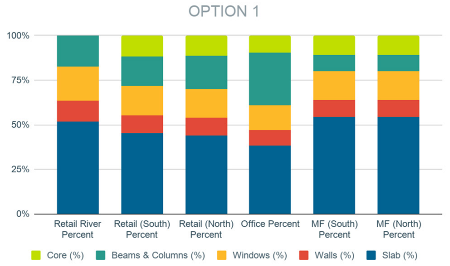
Programming / Massing

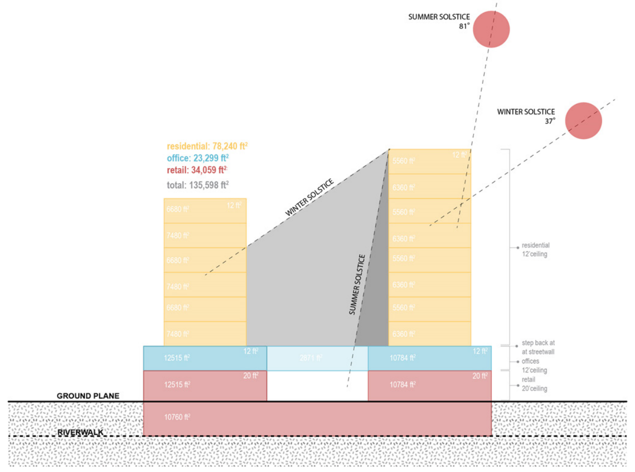


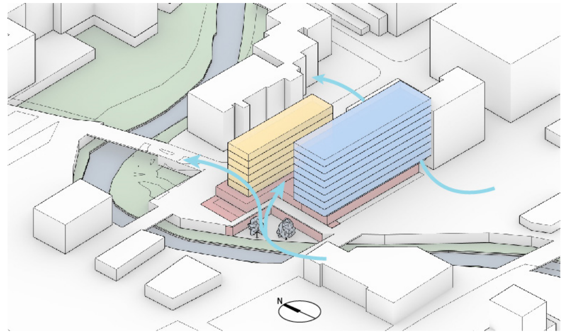


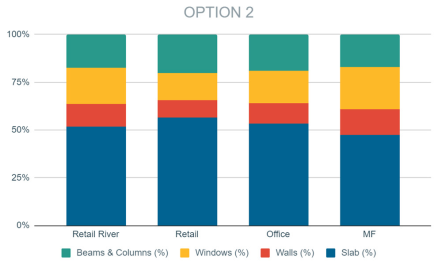


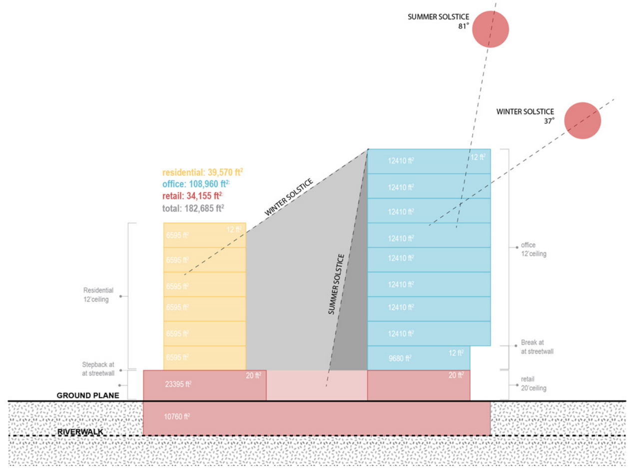




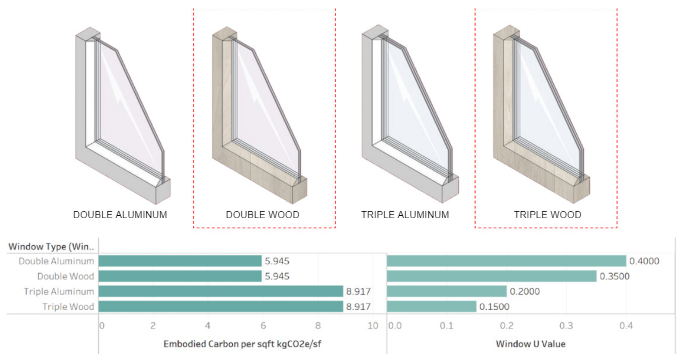


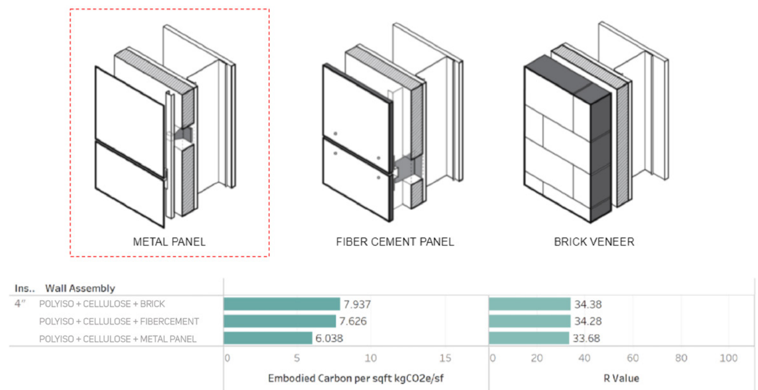


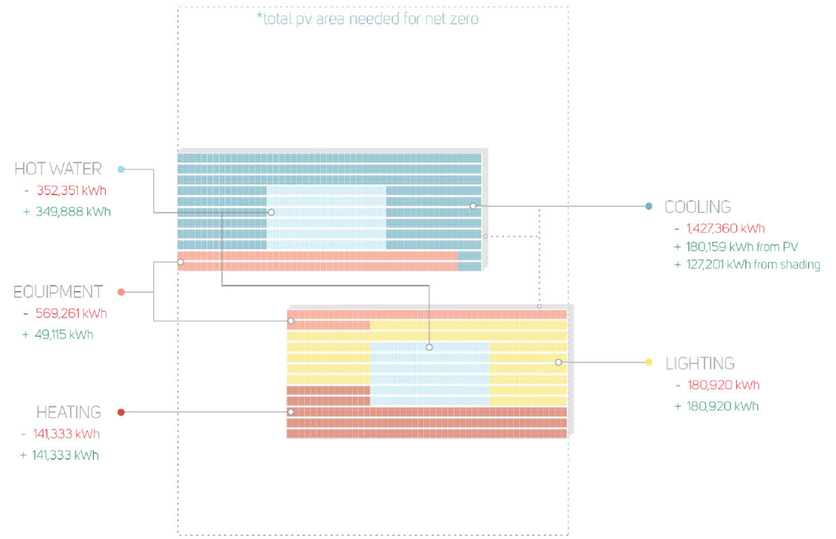


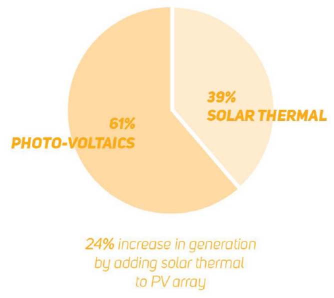


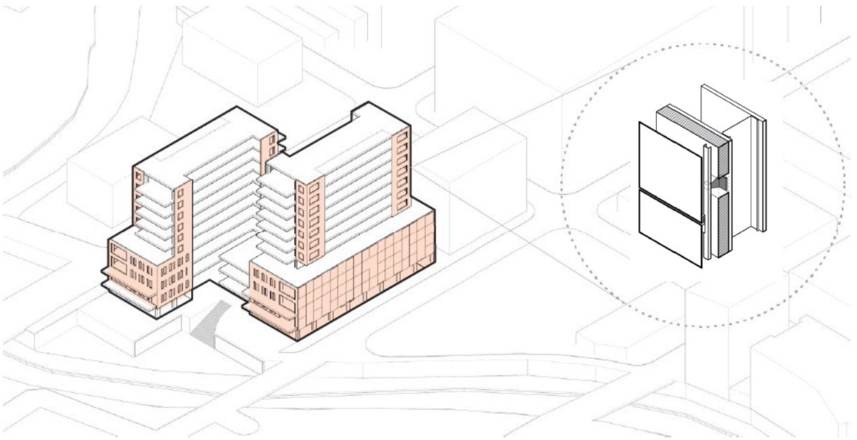
Process / Analysis

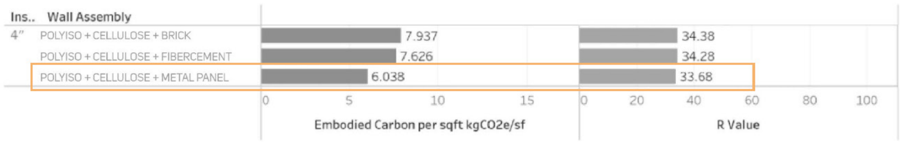


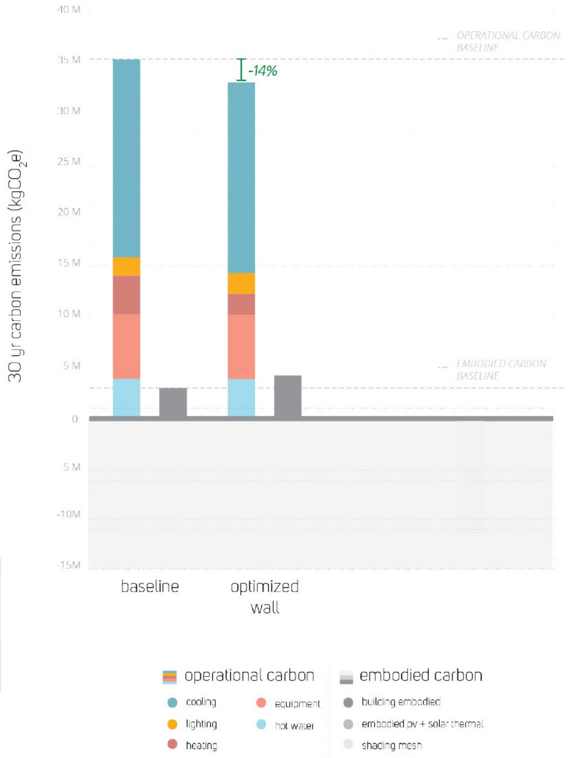


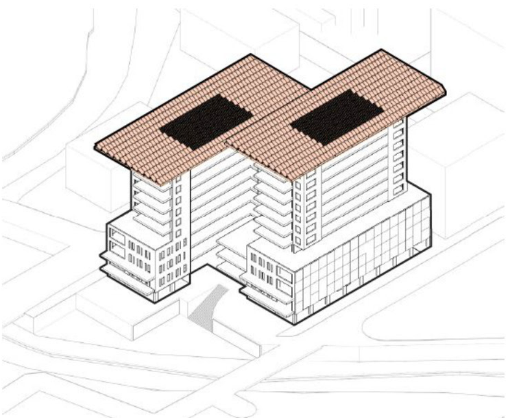


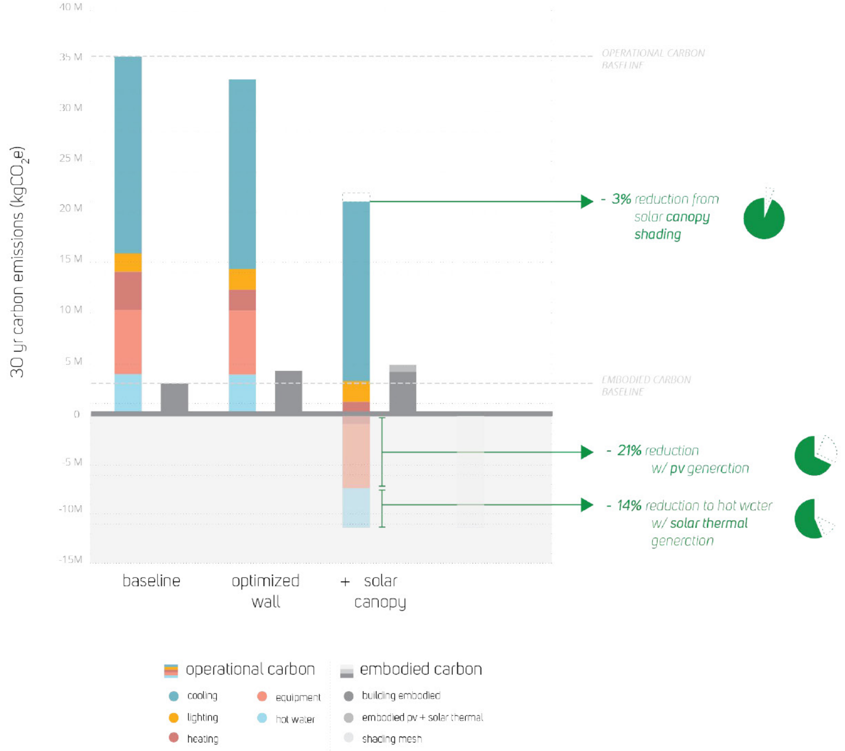




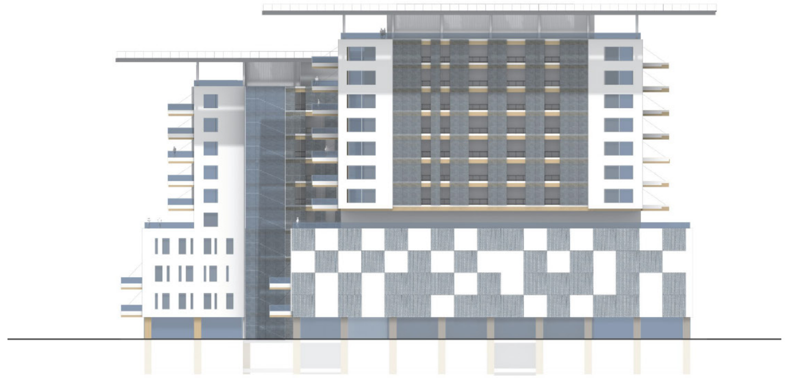






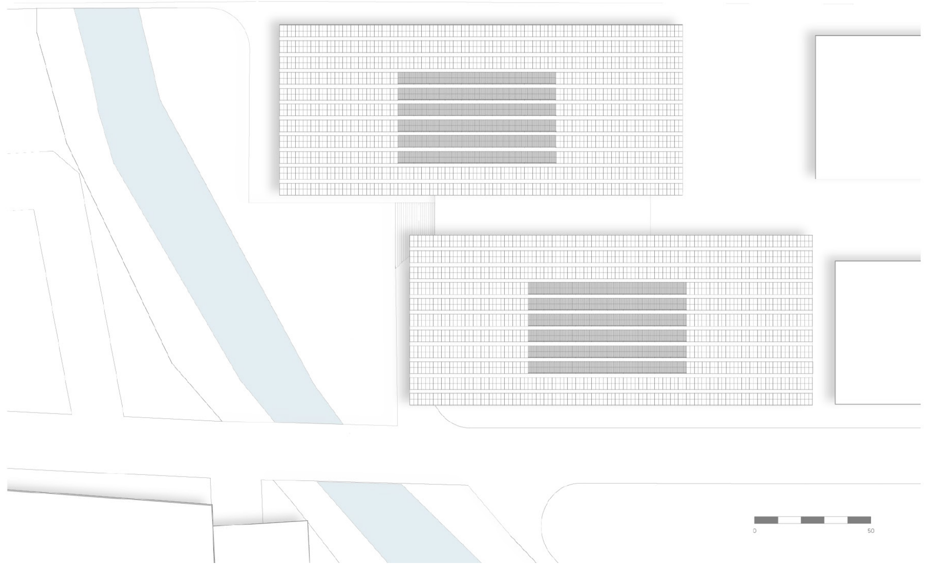


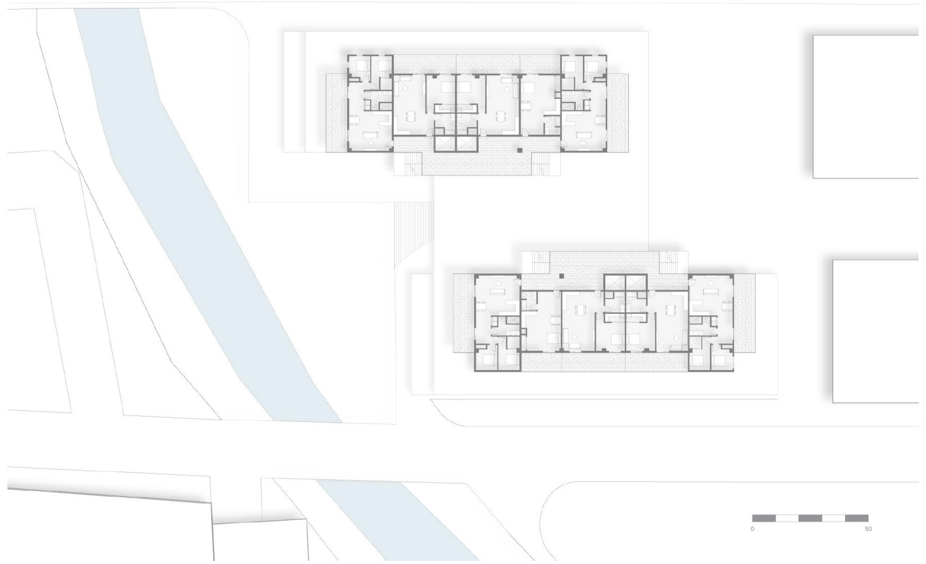
Plans / Sections / Axonometrics



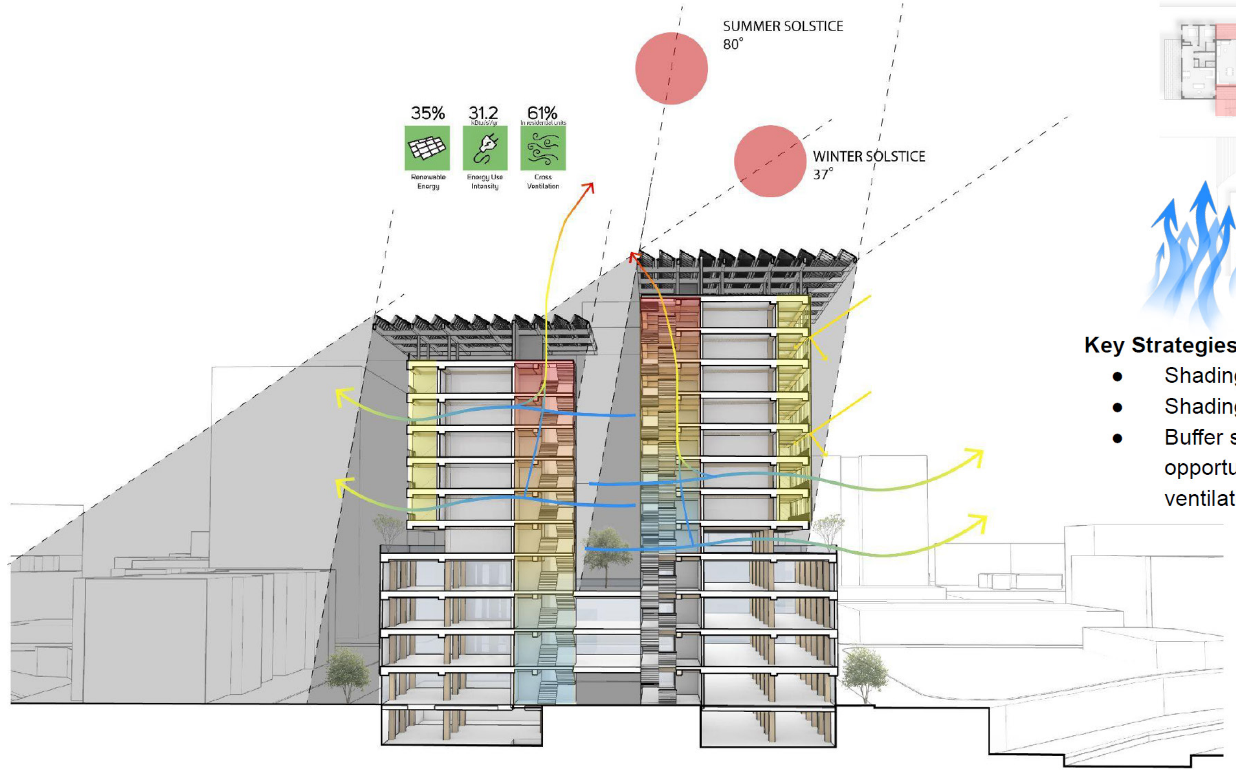
South Elevation

West Elevation



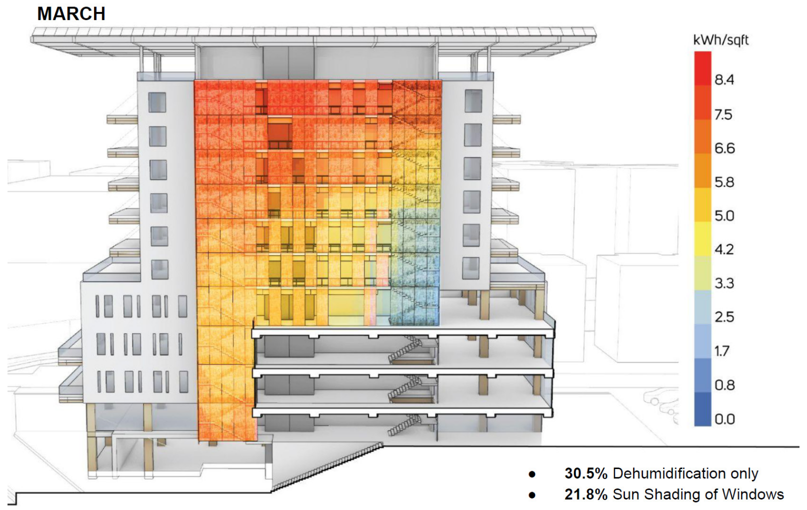


Simulation Data

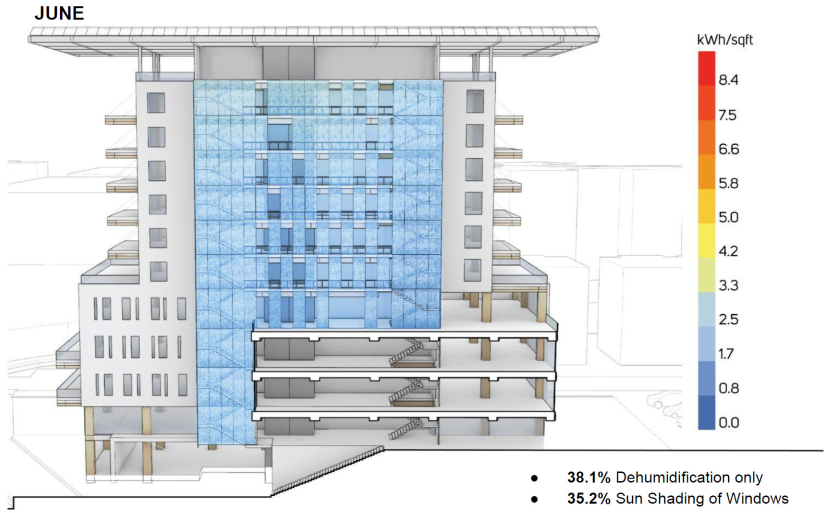


Key Strategies

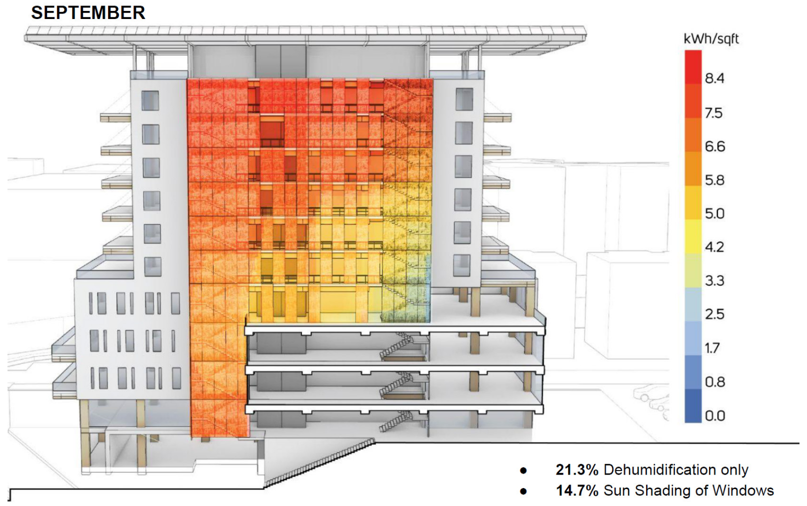
- Shading from South Building
- Shading from PV Canopy
- Buffer space that also acts as opportunities for cross and stacked ventilation



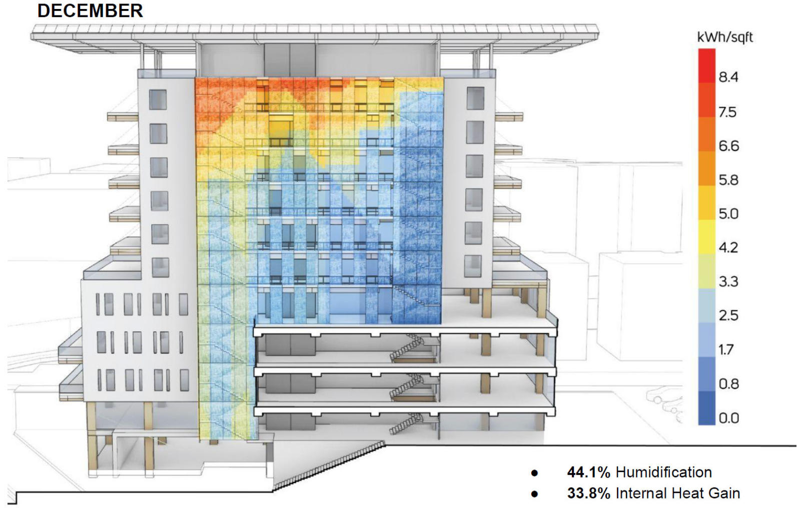
- **30.5%** Dehumidification only
- **21.8%** Sun Shading of Windows



- **38.1%** Dehumidification only
- **35.2%** Sun Shading of Windows



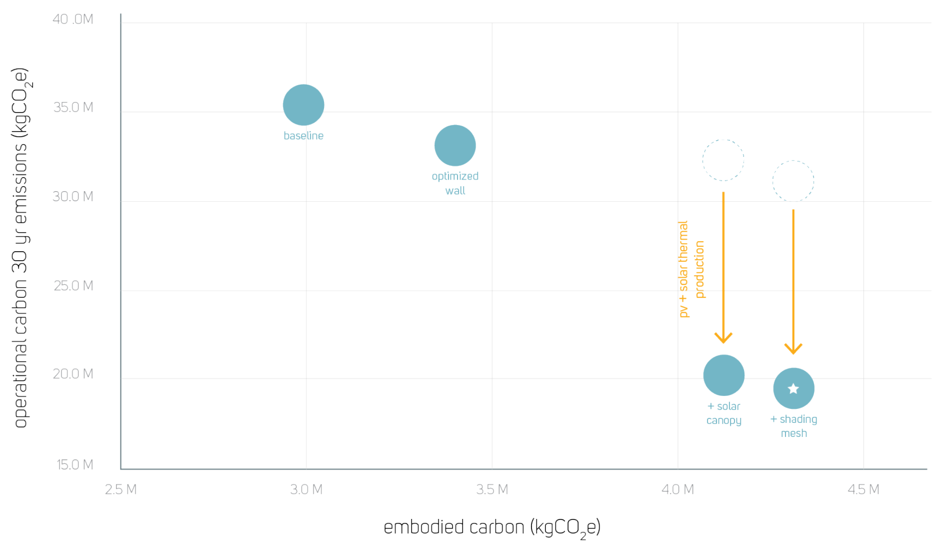
- **21.3%** Dehumidification only
- **14.7%** Sun Shading of Windows

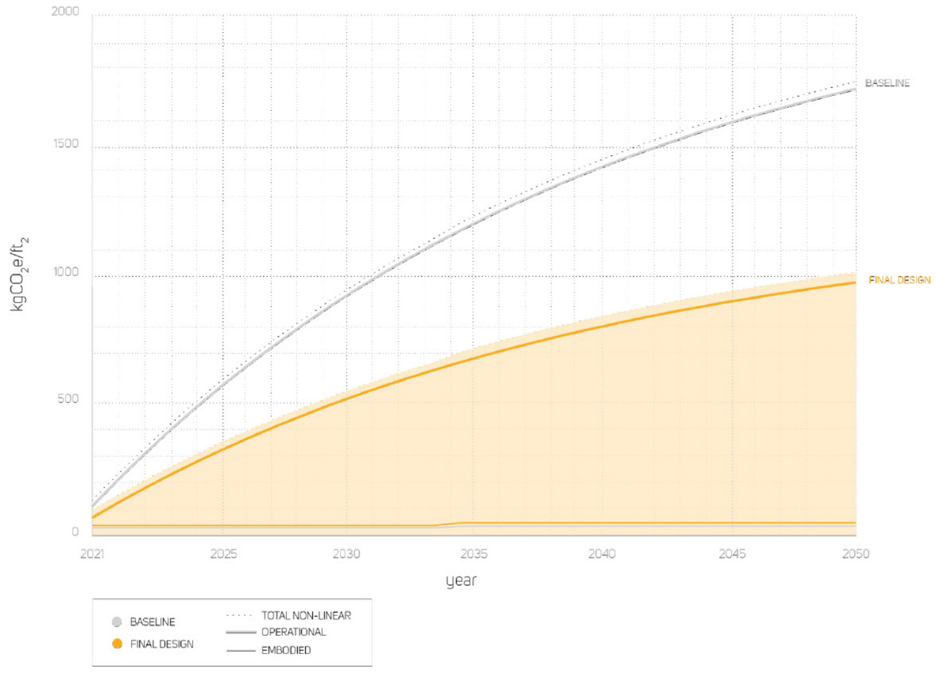


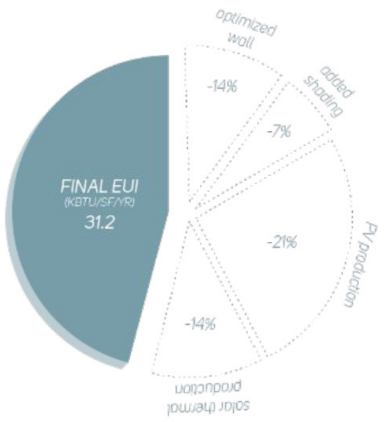
- **44.1%** Humidification
- **33.8%** Internal Heat Gain

Results

DESIGN OPTIONS | CARBON EMISSIONS

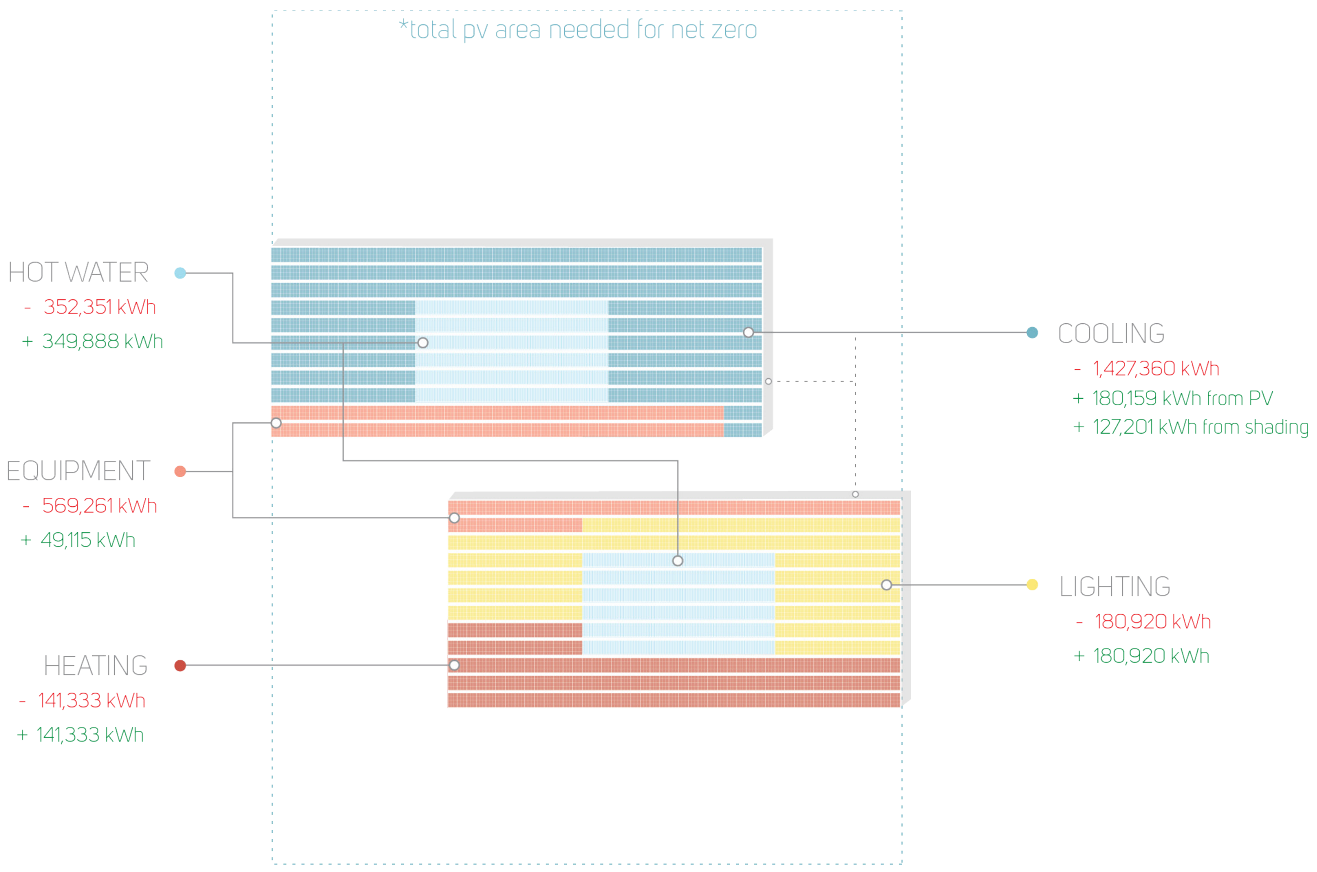


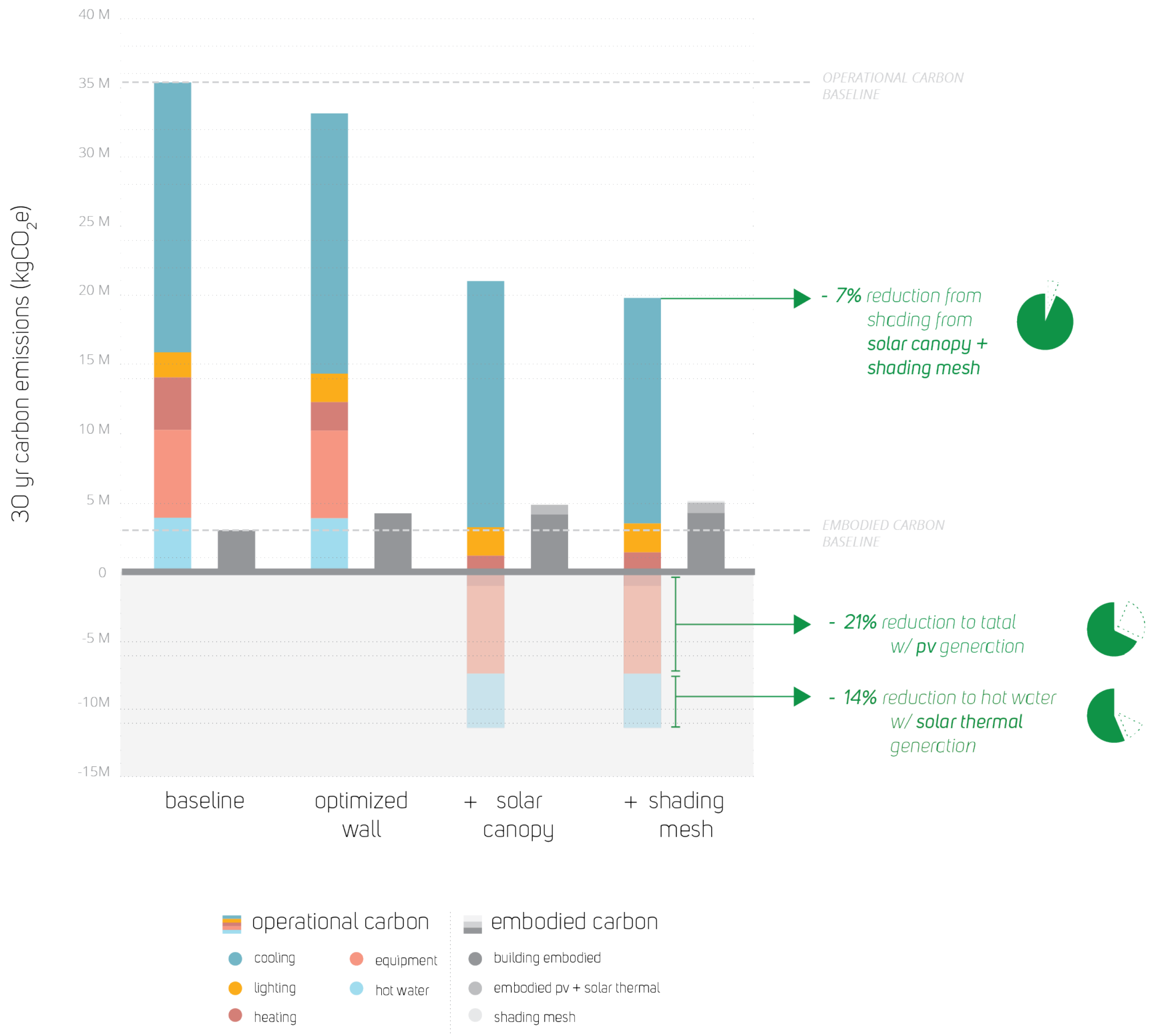


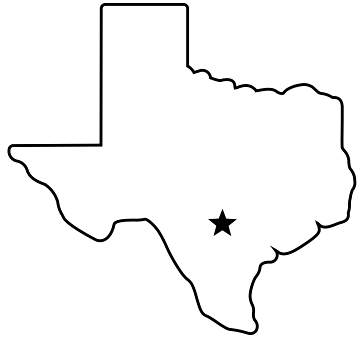


- 56 % total reduction from operational energy baseline

Infographics

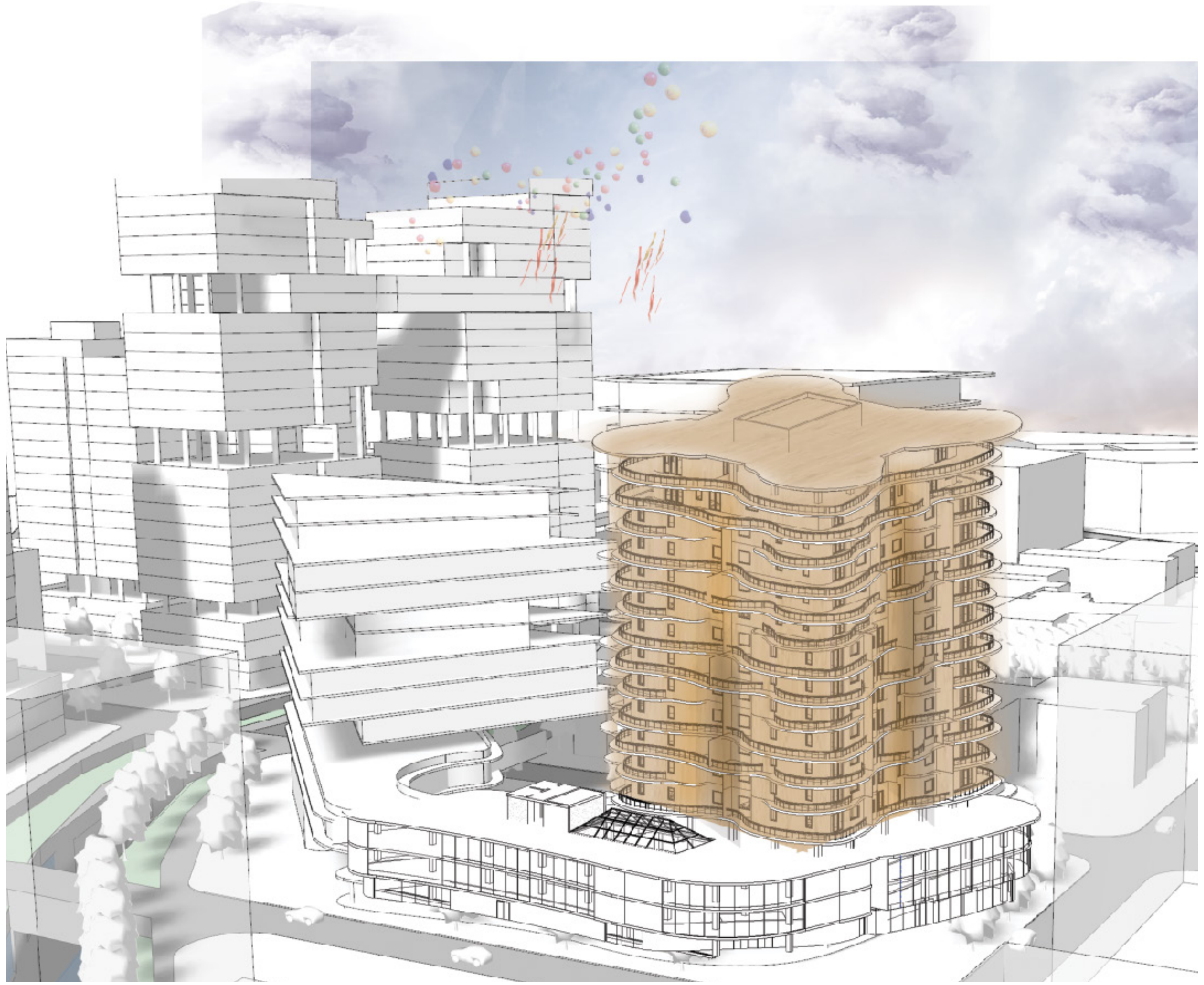




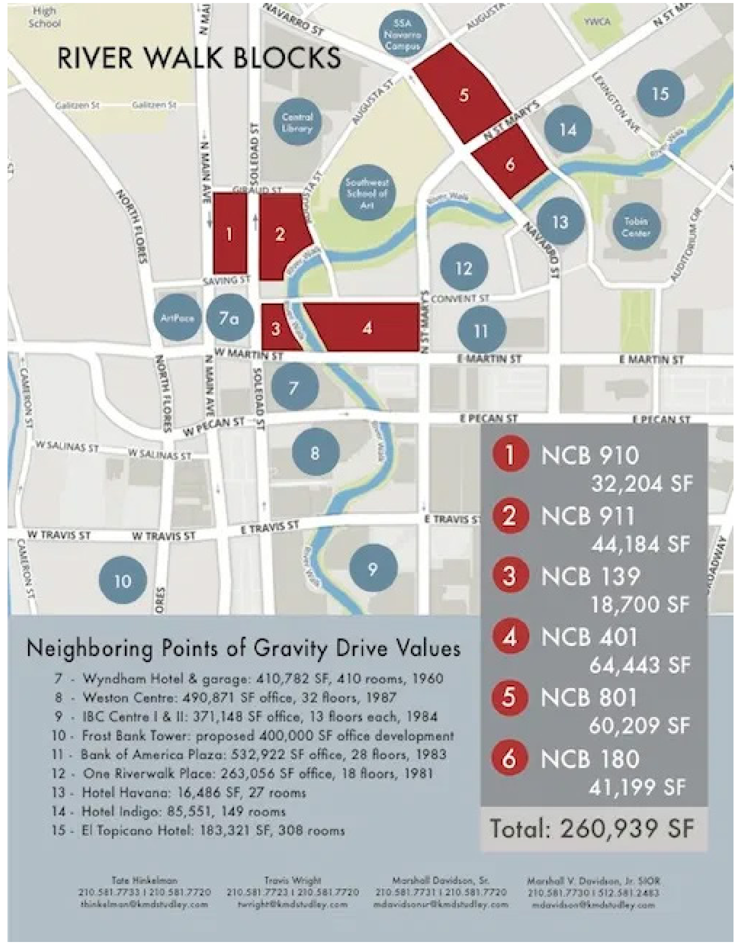


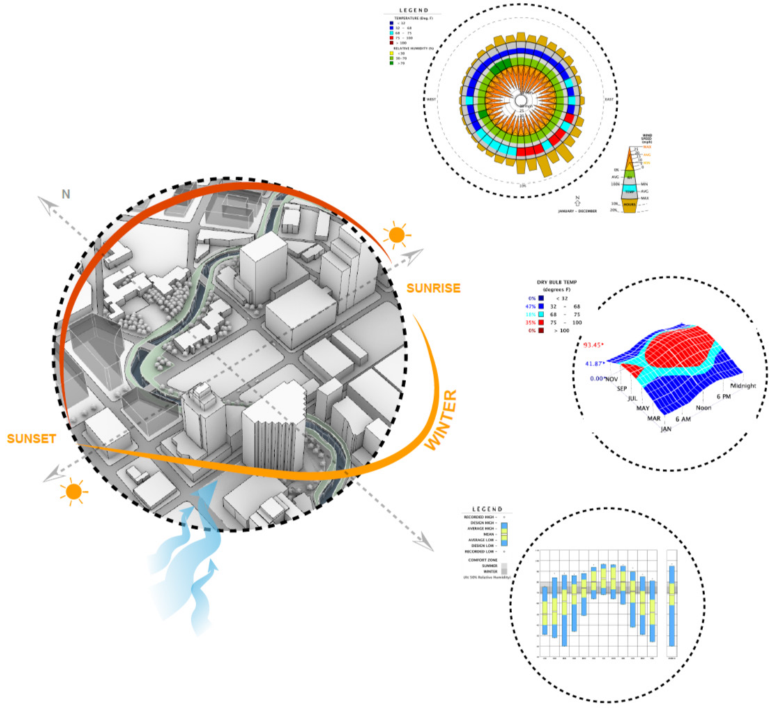
Zining Cheng
+
Yiran Wang

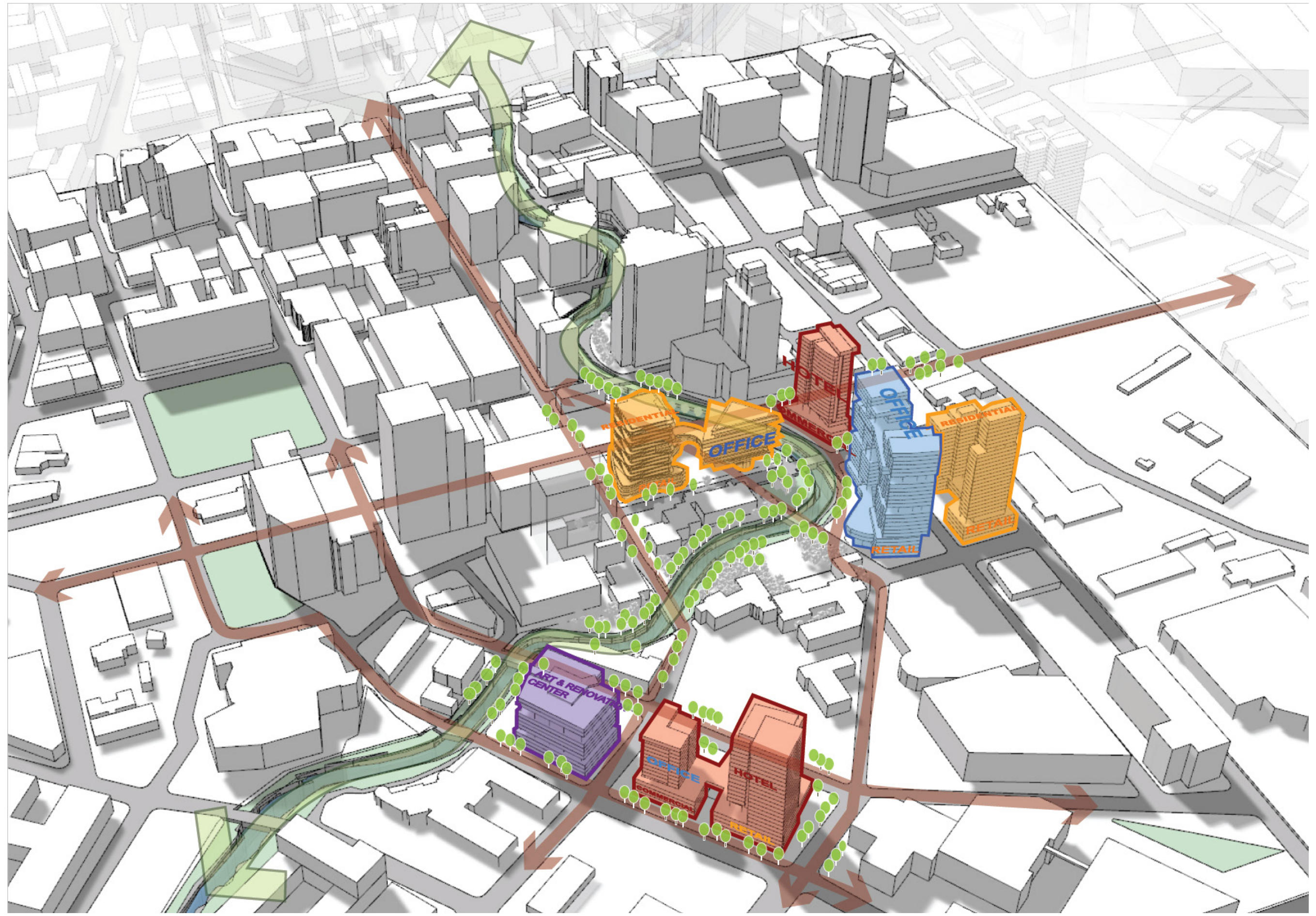
115 E. Martin St.
San Antonio, Texas

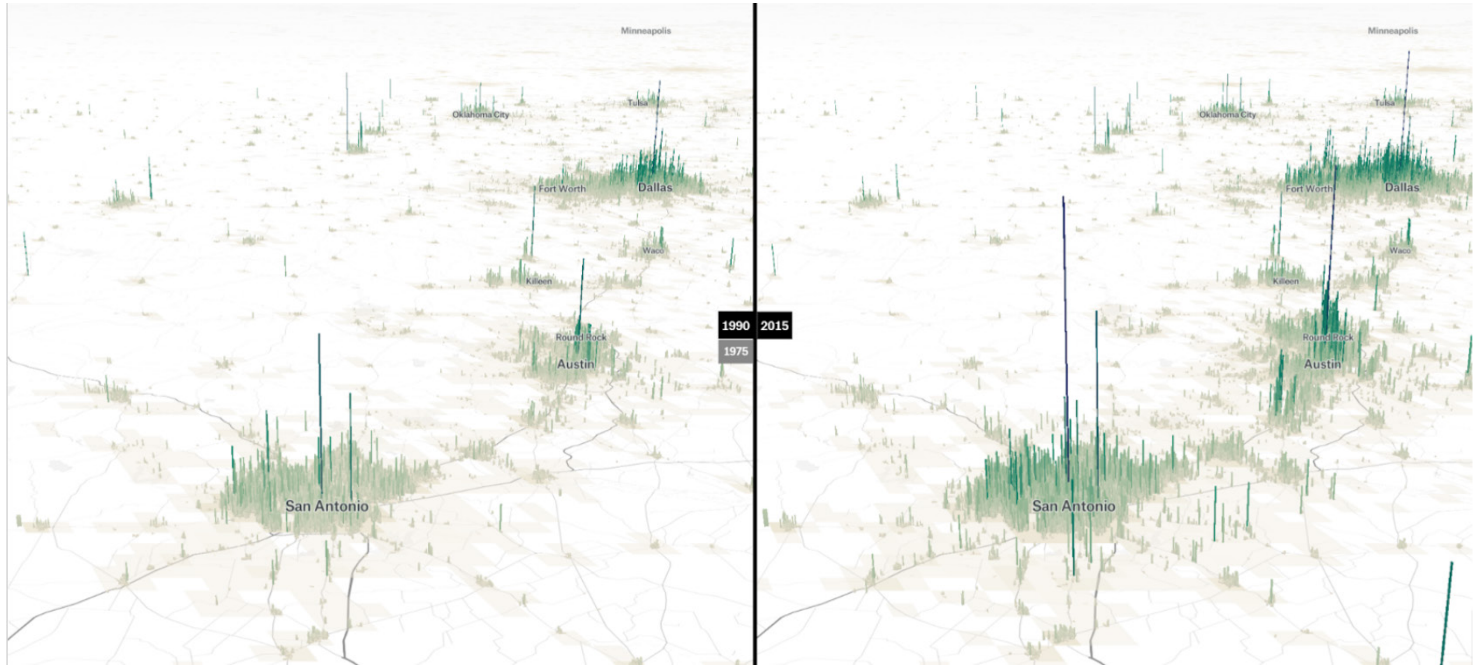


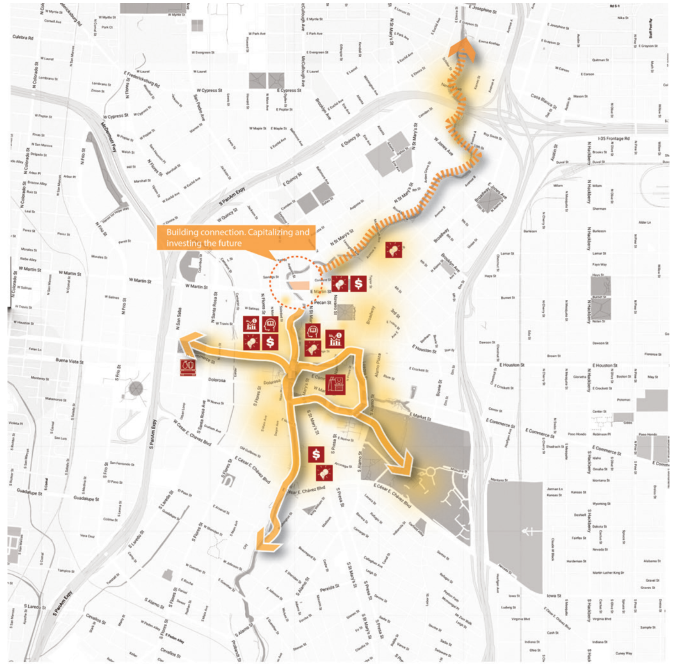
Programming / Massing



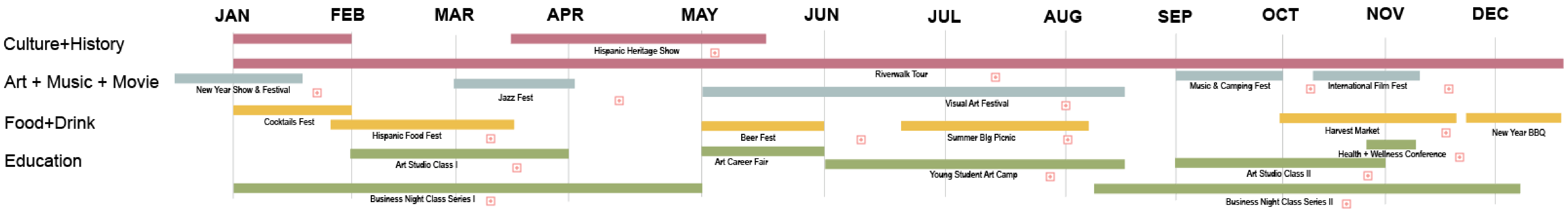




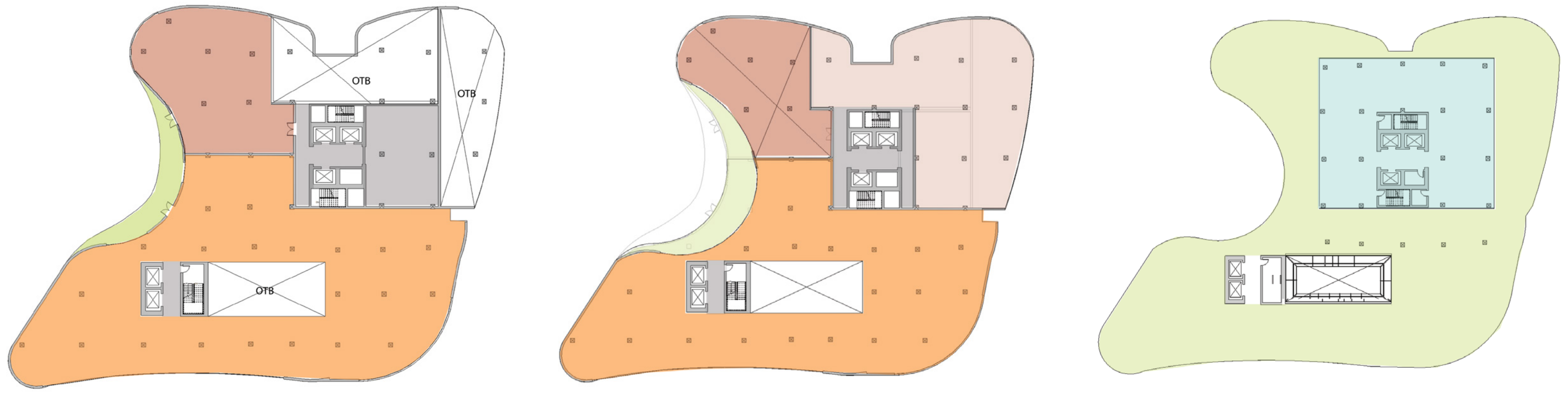


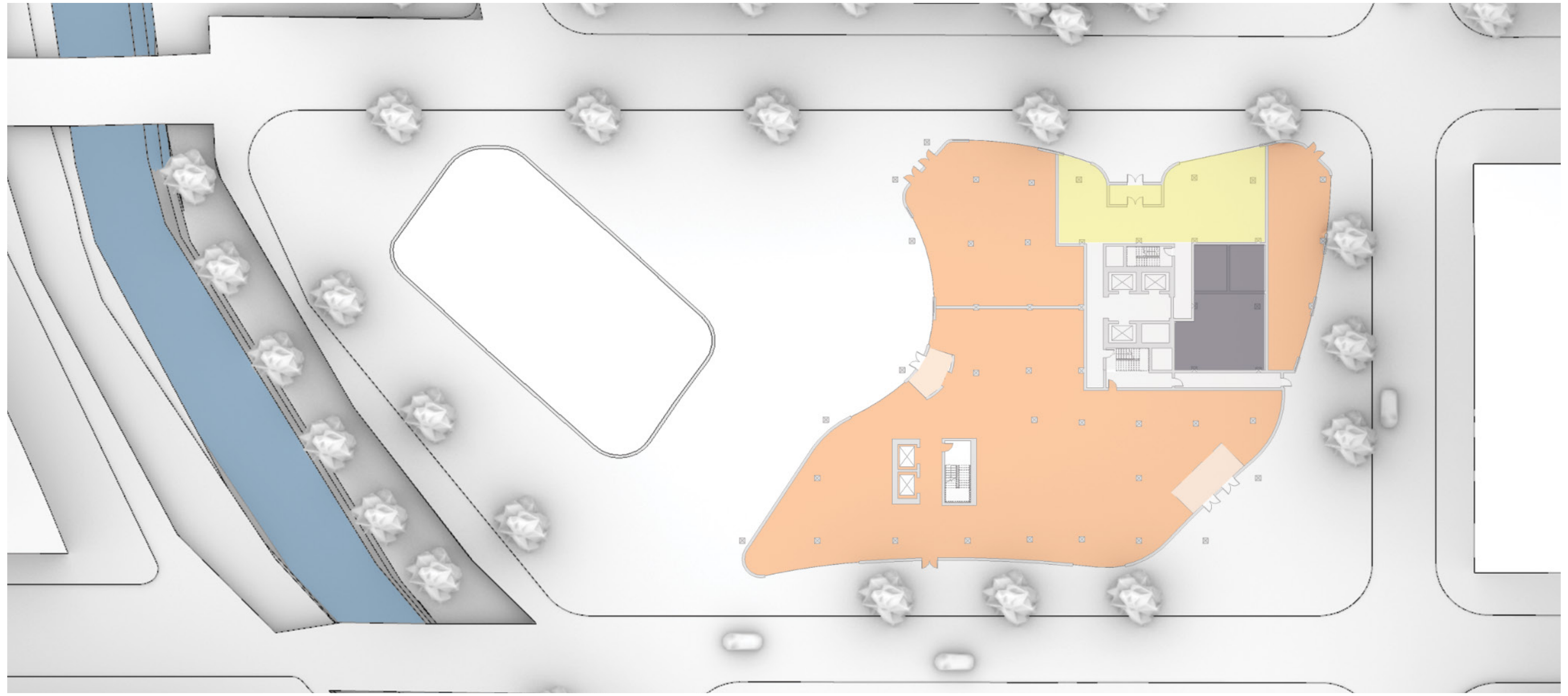


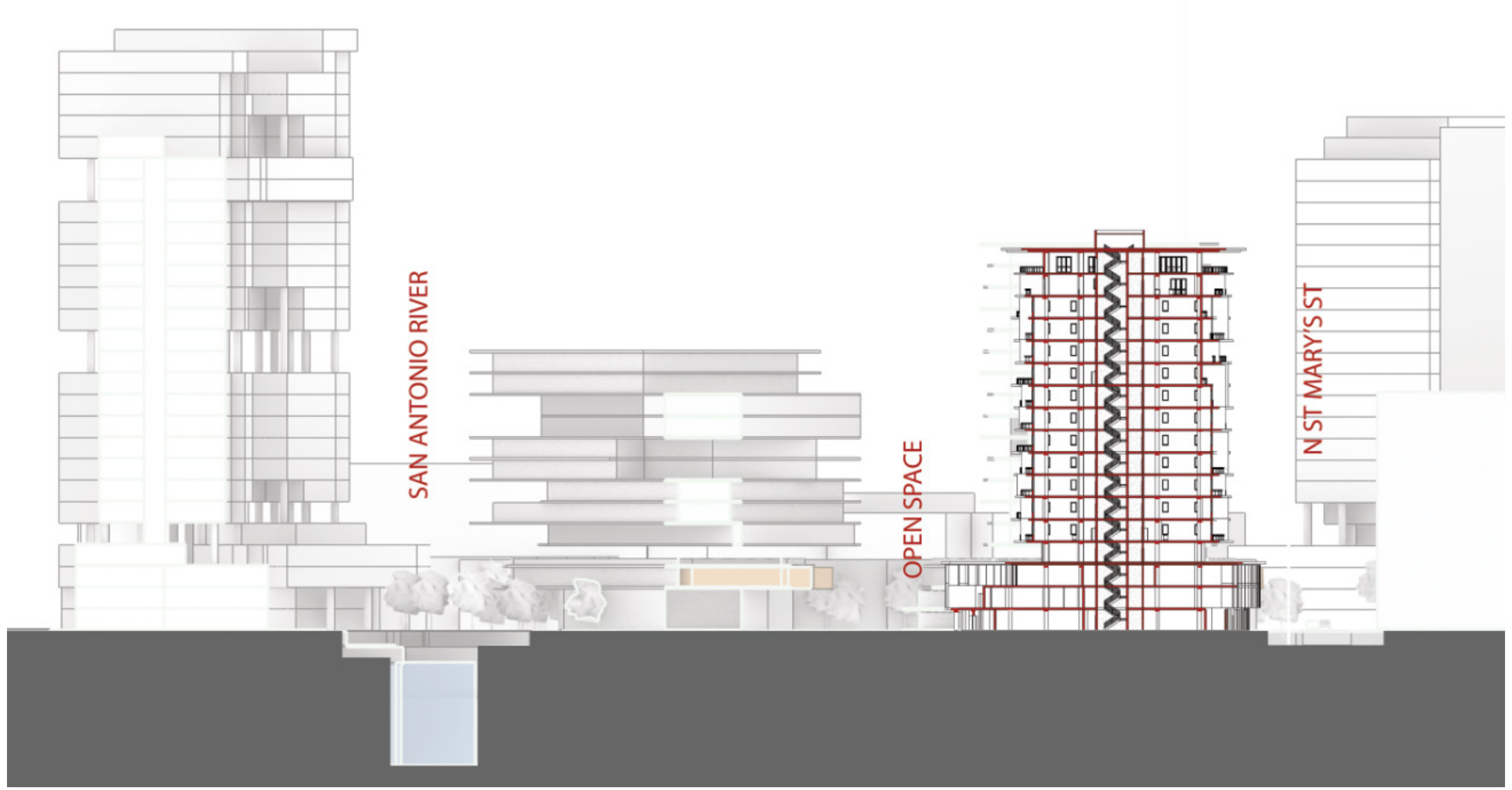
DIVERSE SAN ANTONIO - CALENDAR OF EVENTS



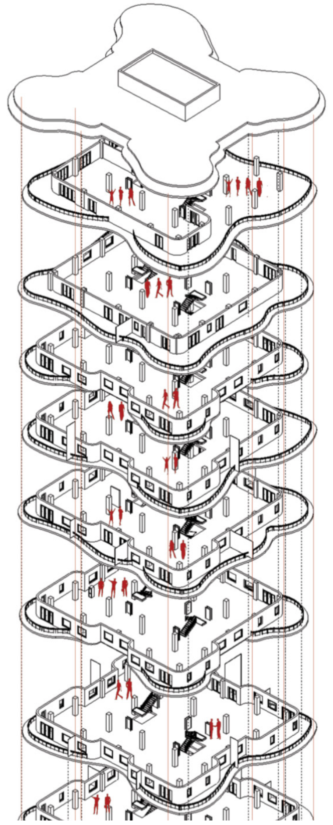
Plans / Sections / Axonometrics

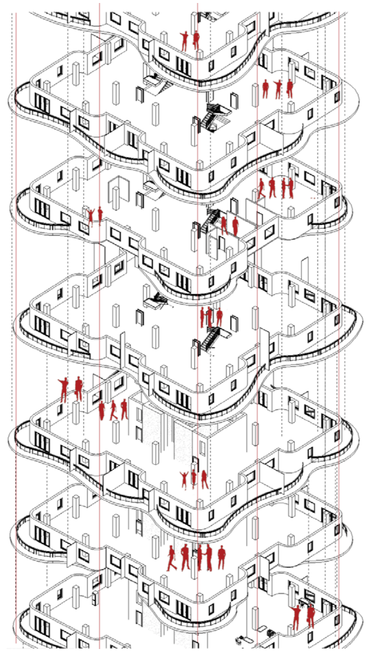


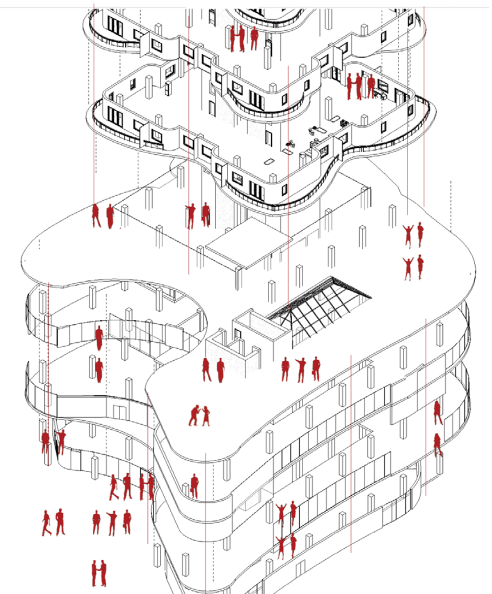


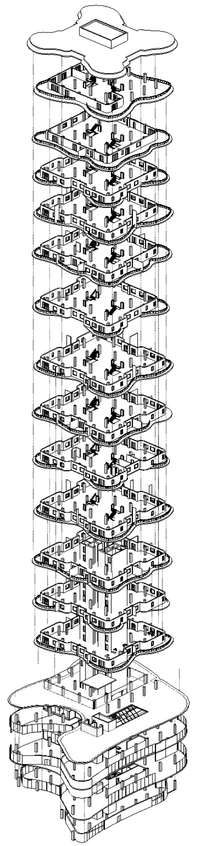


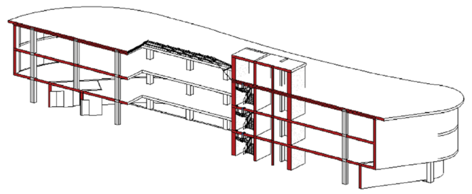
Plans / Sections / Axonometrics

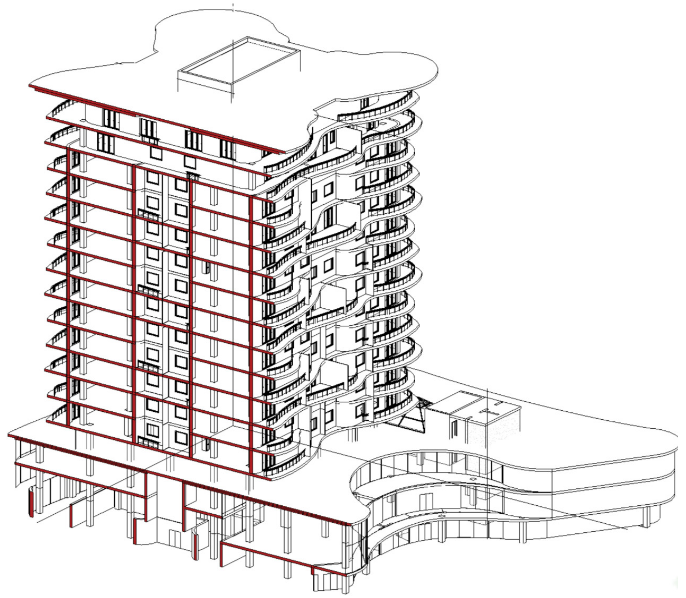


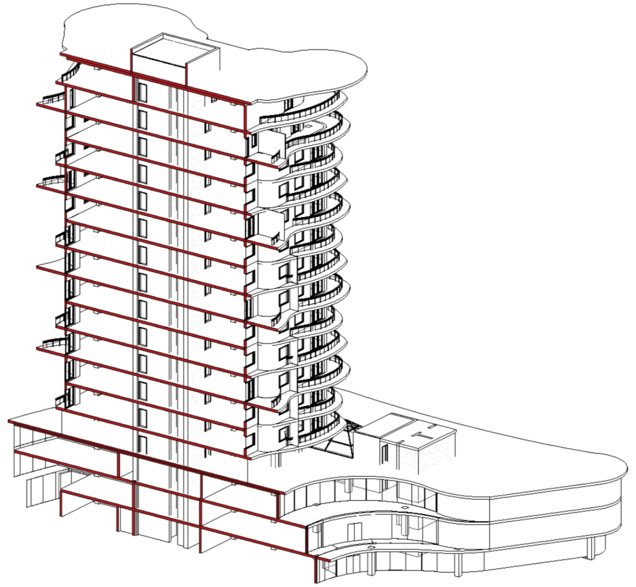


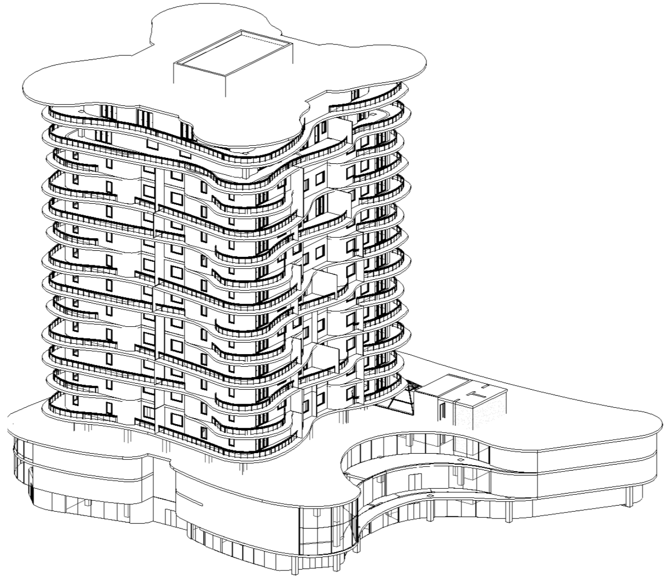




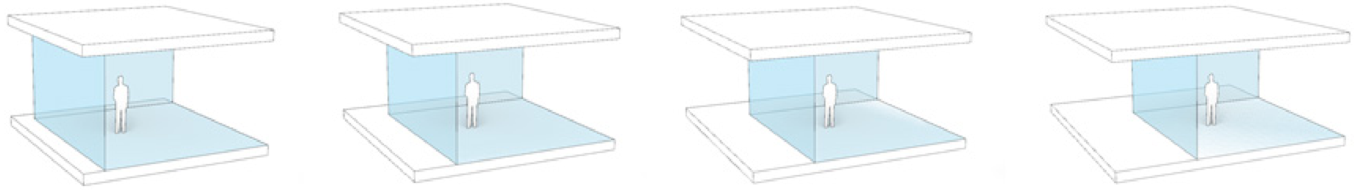




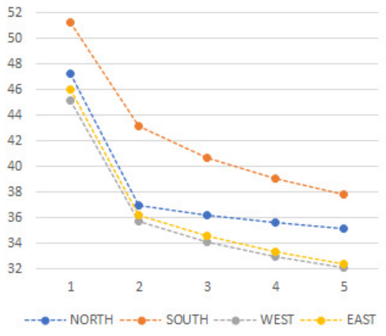




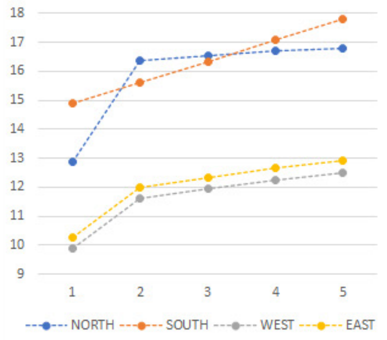
Simulation Data



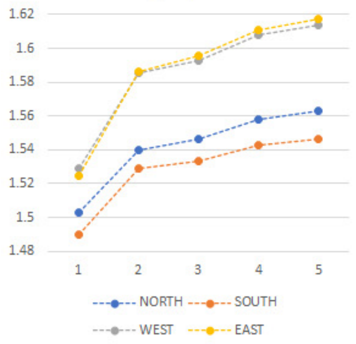
Cooling EUI



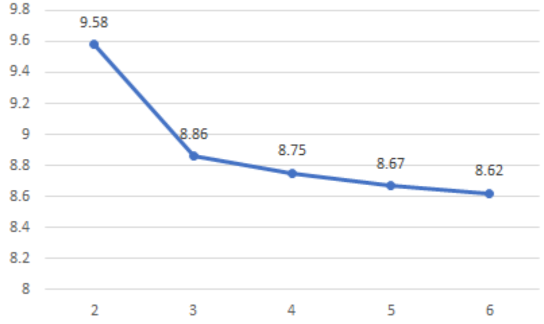
Heating EUI



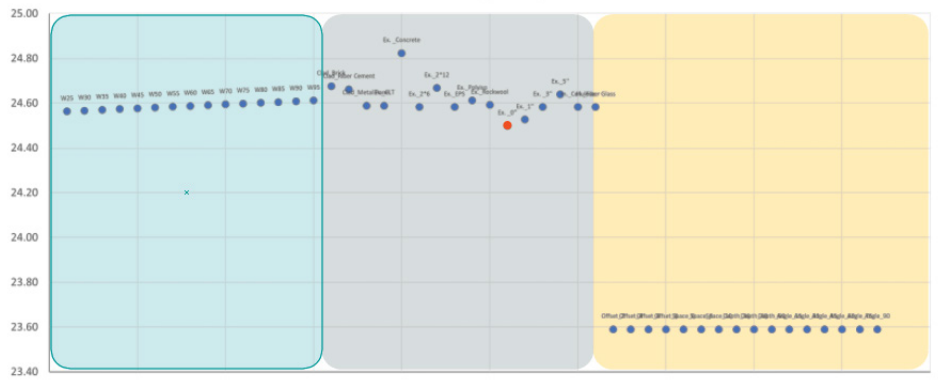
Lighting EUI



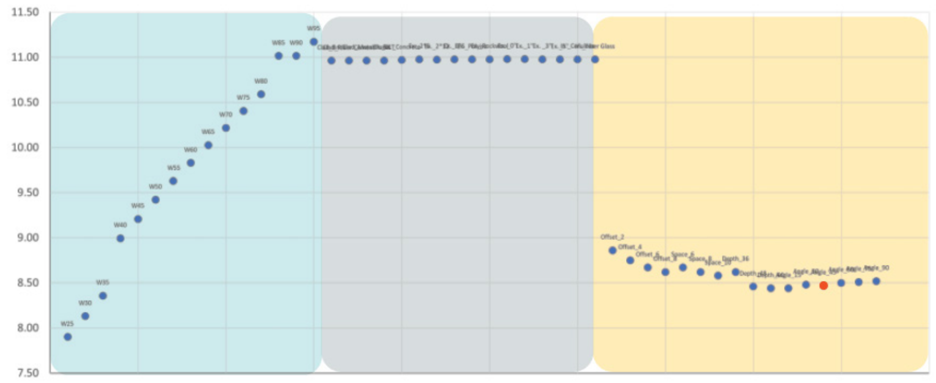
Operational kgCO2e/ft2 yr



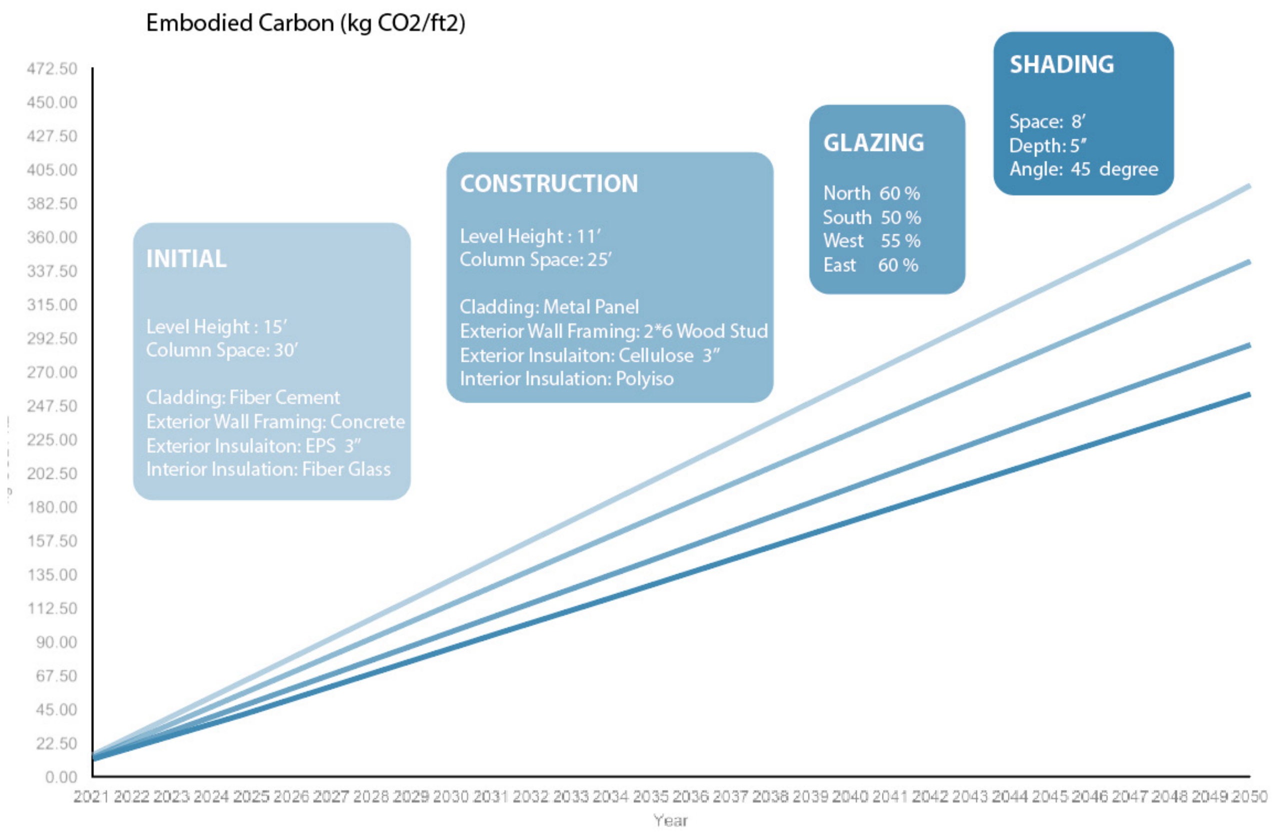
EMBODIED kg CO2e/ft2



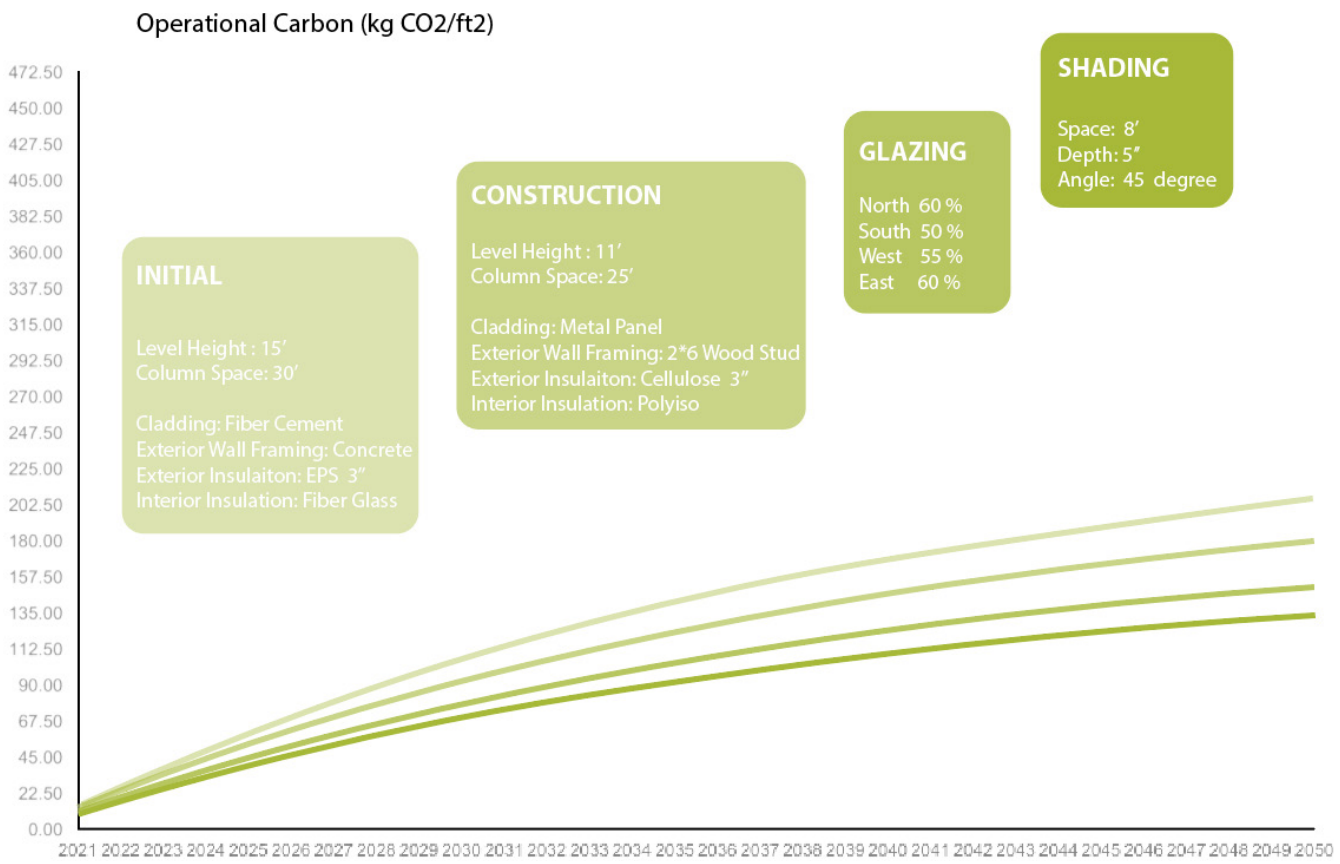
OPERATIONAL kgCO2e/ft2 yr



Results

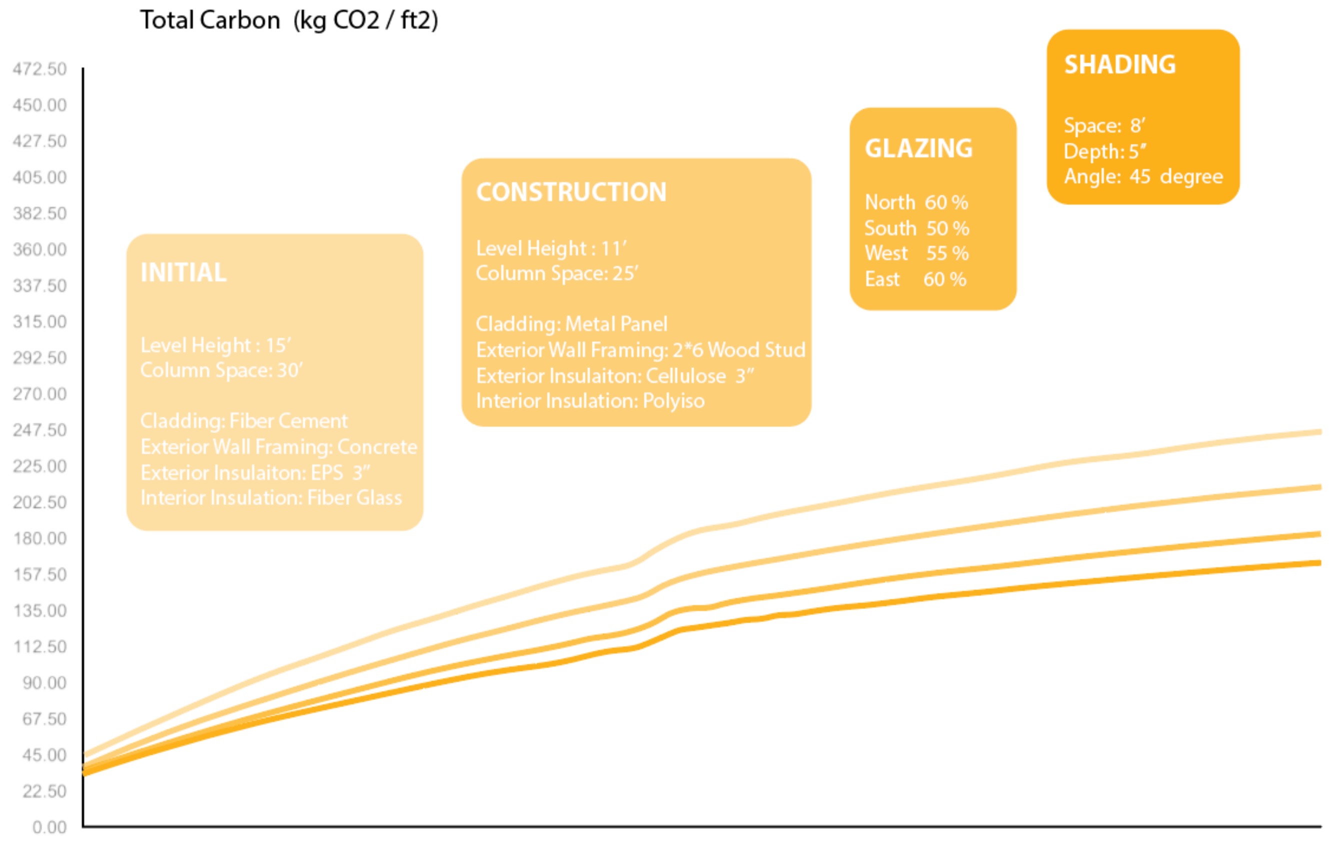


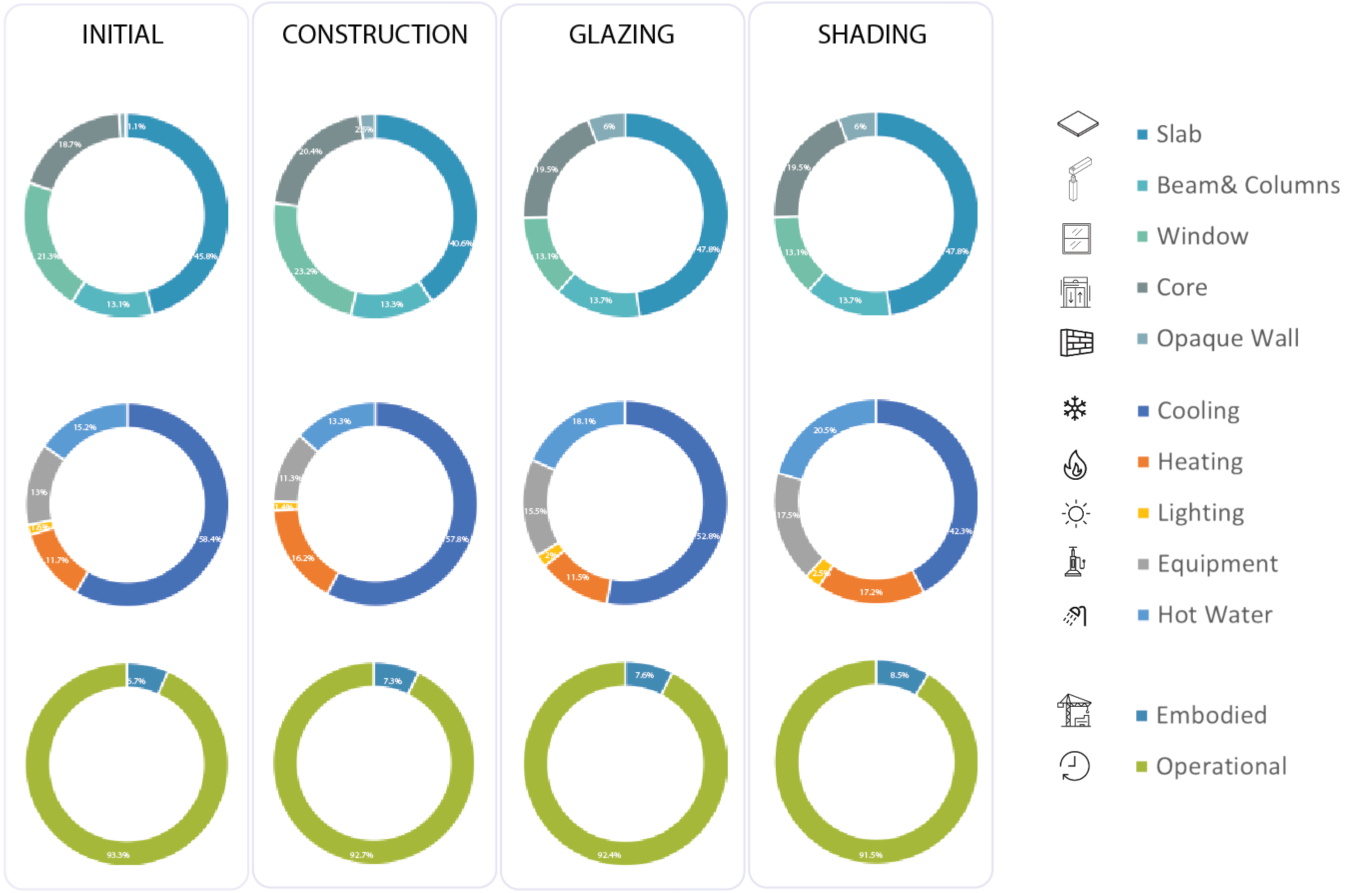
Embodied Carbon (kg CO2/ft2)
472.50
450.00
427.50
405.00
382.50
360.00
337.50
315.00
292.50
270.00
247.50
225.00
202.50
180.00
157.50
135.00
112.50
90.00
67.50
45.00
22.50
0.00
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
Year
INITIAL
Level Height : 15′
Column Space: 30′
Cladding: Fiber Cement
Exterior Wall Framing: Concrete
Exterior Insulaiton: EPS 3″
Interior Insulation: Fiber Glass
CONSTRUCTION
Level Height : 11′
Column Space: 25′
Cladding: Metal Panel
Exterior Wall Framing: 2*6 Wood Stud
Exterior Insulaiton: Cellulose 3″
Interior Insulation: Polyiso
GLAZING
North 60 %
South 50 %
West 55 %
East 60 %
SHADING
Space: 8′
Depth: 5″
Angle: 45 degree



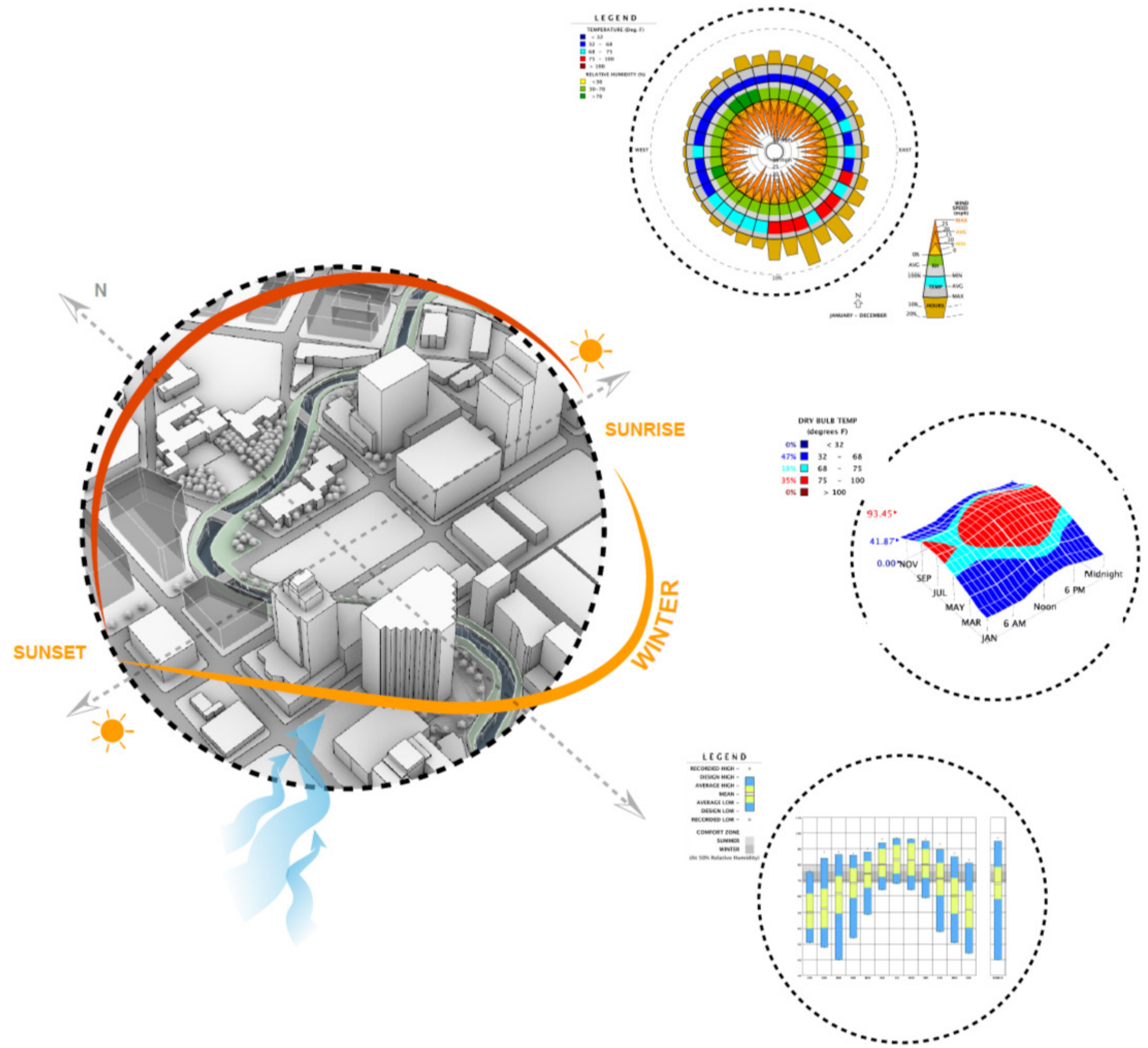
Operational Carbon (kg CO2/ft2)
472.50
450.00
427.50
405.00
382.50
360.00
337.50
315.00
292.50
270.00
247.50
225.00
202.50
180.00
157.50
135.00
112.50
90.00
67.50
45.00
22.50
0.00
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
INITIAL
Level Height : 15′
Column Space: 30′
Cladding: Fiber Cement
Exterior Wall Framing: Concrete
Exterior Insulaiton: EPS 3″
Interior Insulation: Fiber Glass
CONSTRUCTION
Level Height : 11′
Column Space: 25′
Cladding: Metal Panel
Exterior Wall Framing: 2*6 Wood Stud
Exterior Insulaiton: Cellulose 3″
Interior Insulation: Polyiso
GLAZING
North 60 %
South 50 %
West 55 %
East 60 %
SHADING
Space: 8′
Depth: 5″
Angle: 45 degree

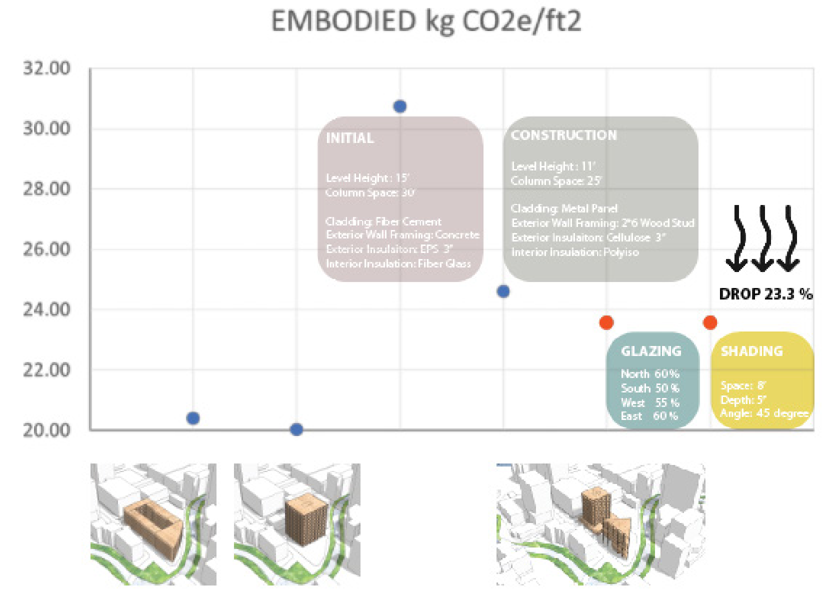
Results (cont.)

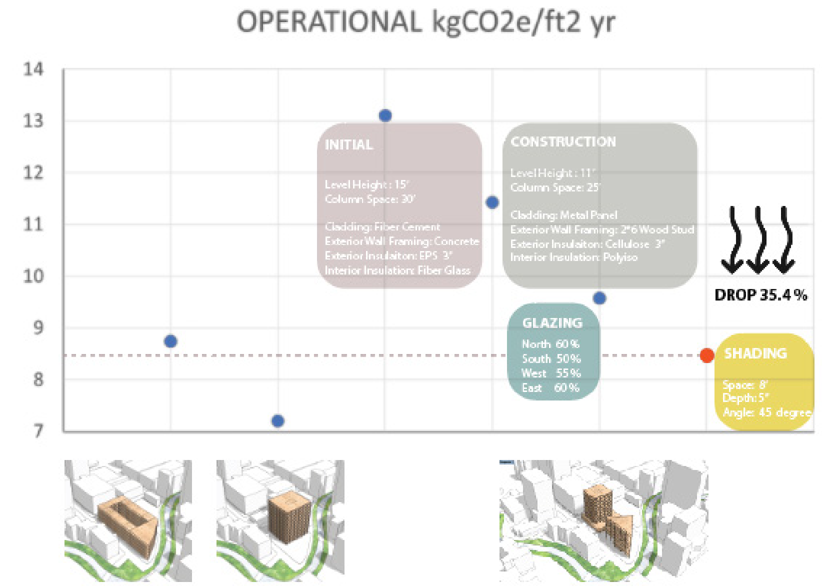


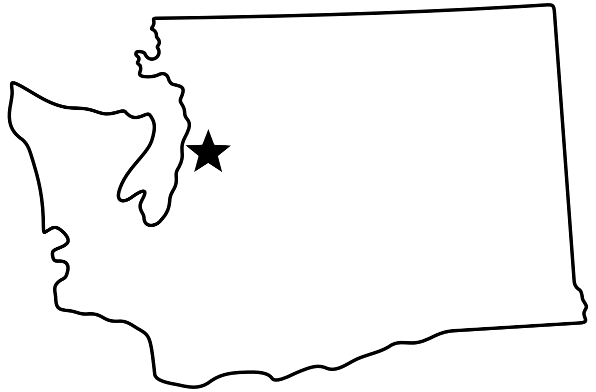


Infographics







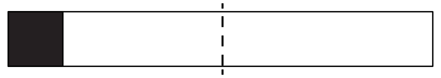


SEATTLE
WASHINGON
1300 E. Madison St.

- IECC Climate Zone 4
- IECC Moisture Regime C
- Mixed
- Marine

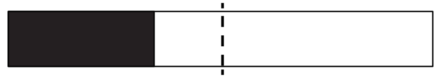
47.6136683N, 122.3160373W

Grid Carbon Intensity



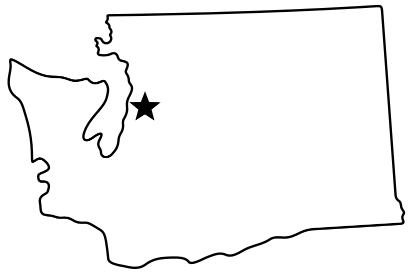
136
gCO2/kWh

CLT Supply Chain Carbon Intensity



144
kgCO2/m3

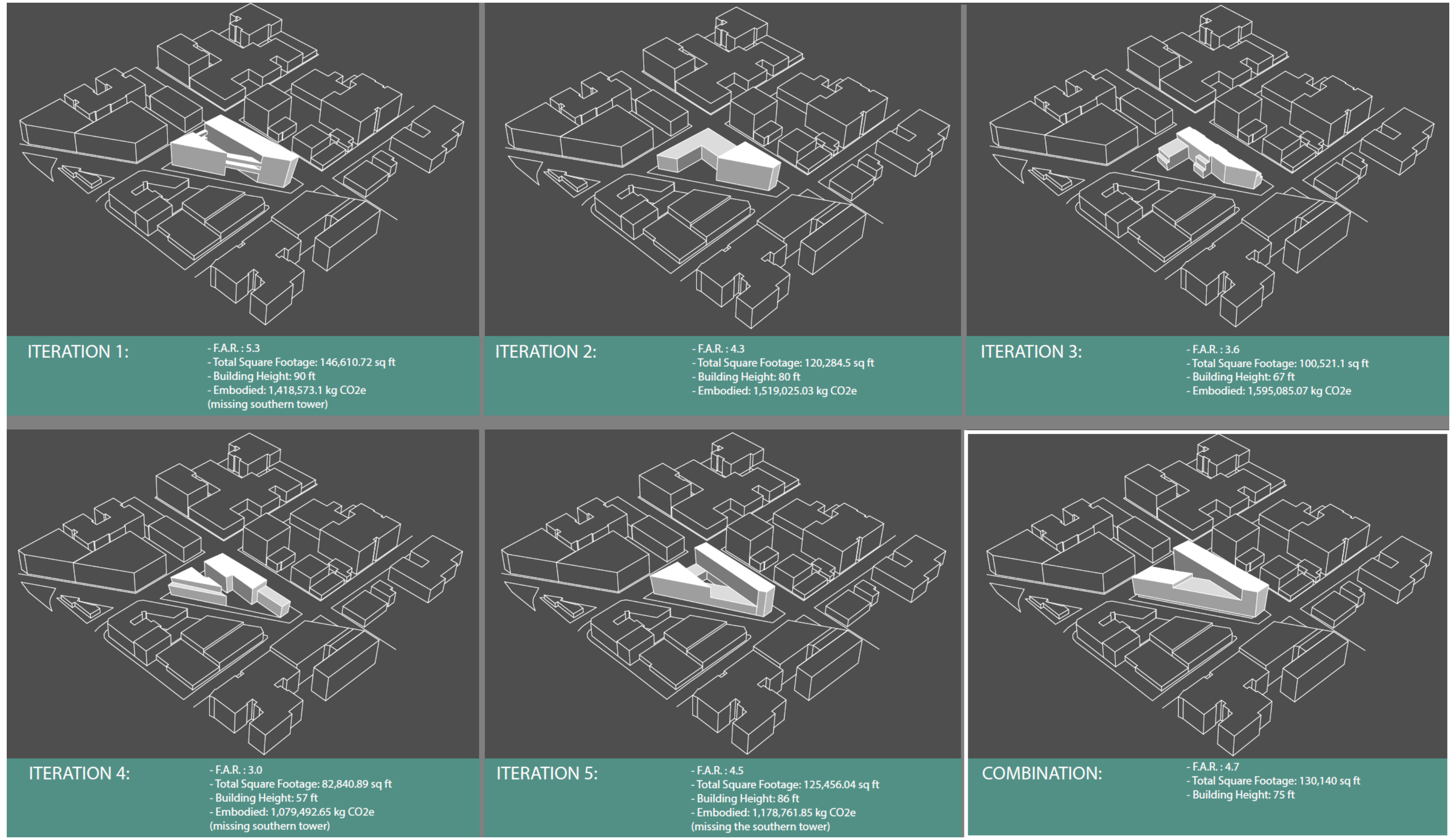
Image courtesy of Ben Dutton via https://unsplash.com/photos/insv5BSTqv0

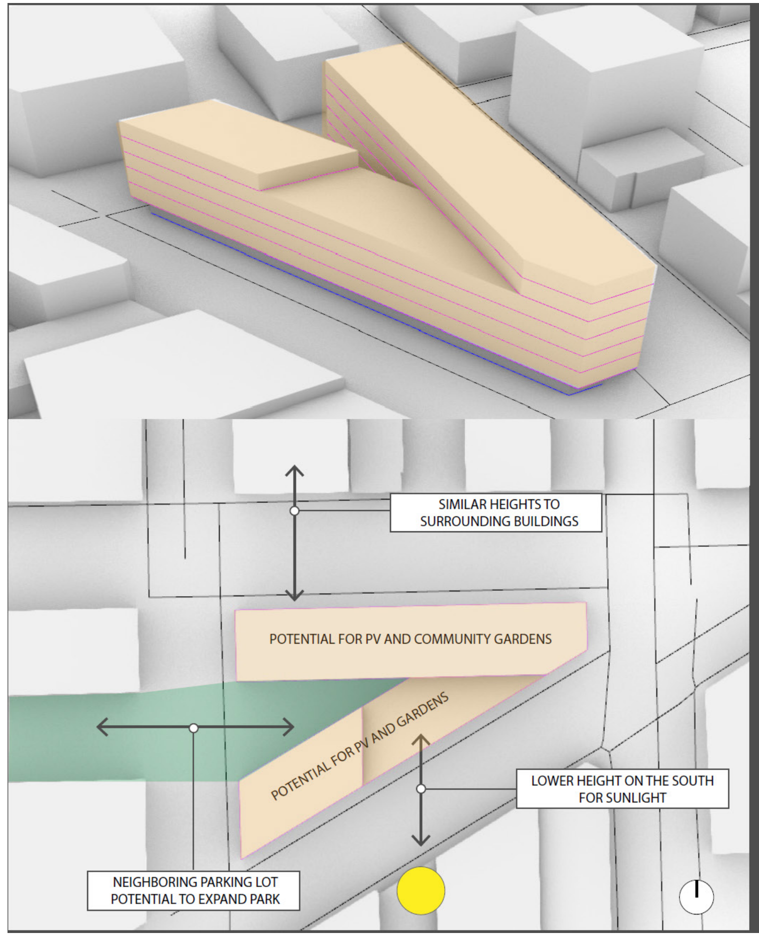


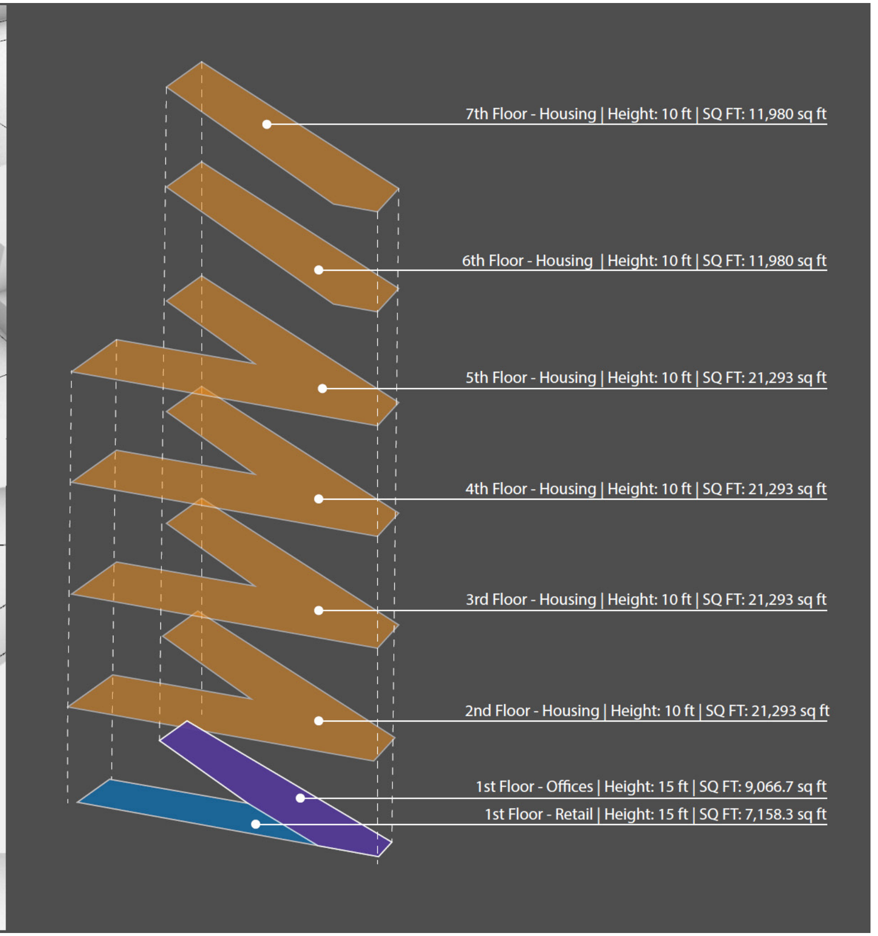
Amanda Stanton

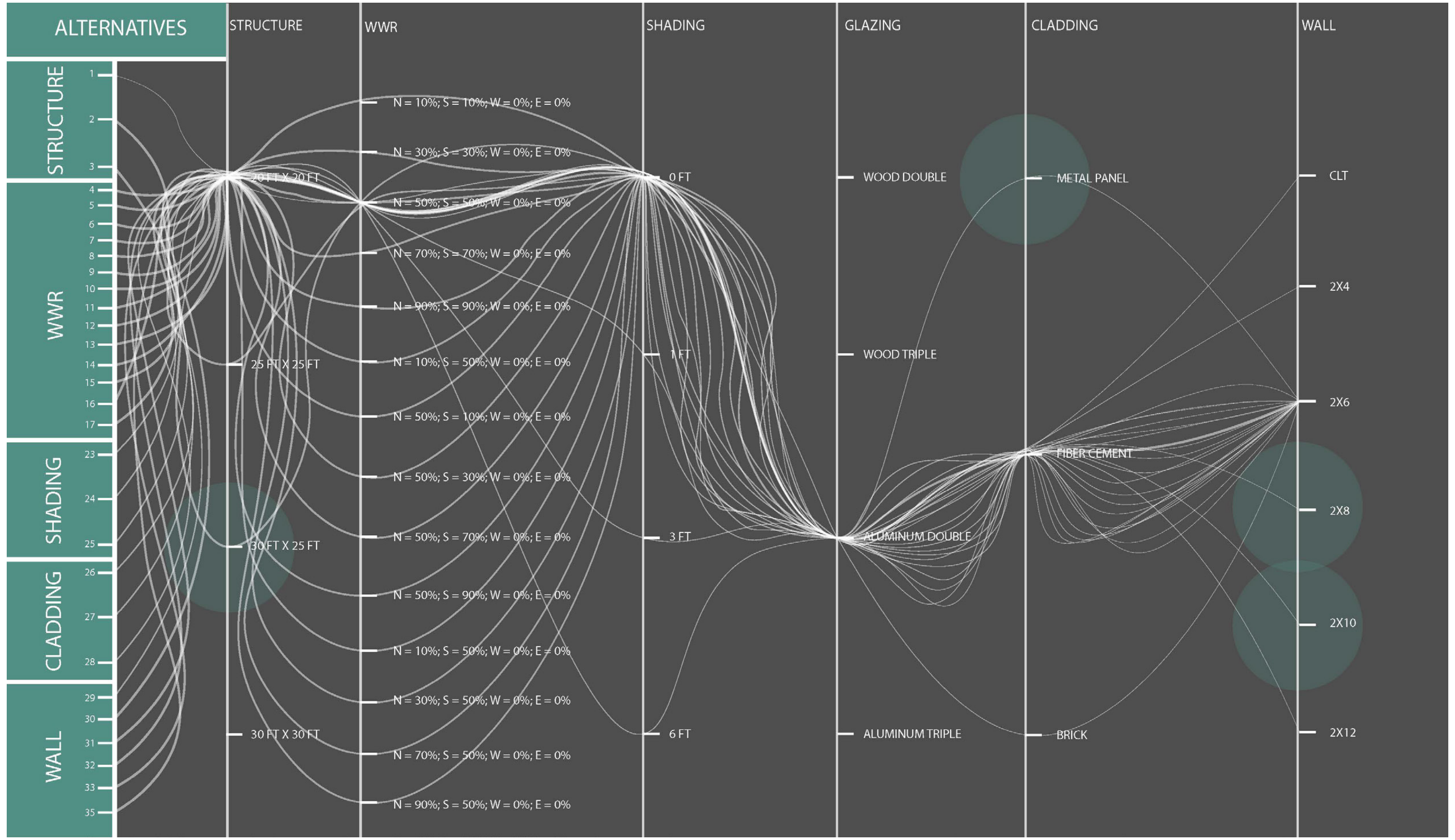
1300 E. Madison St.
Seattle, Washington

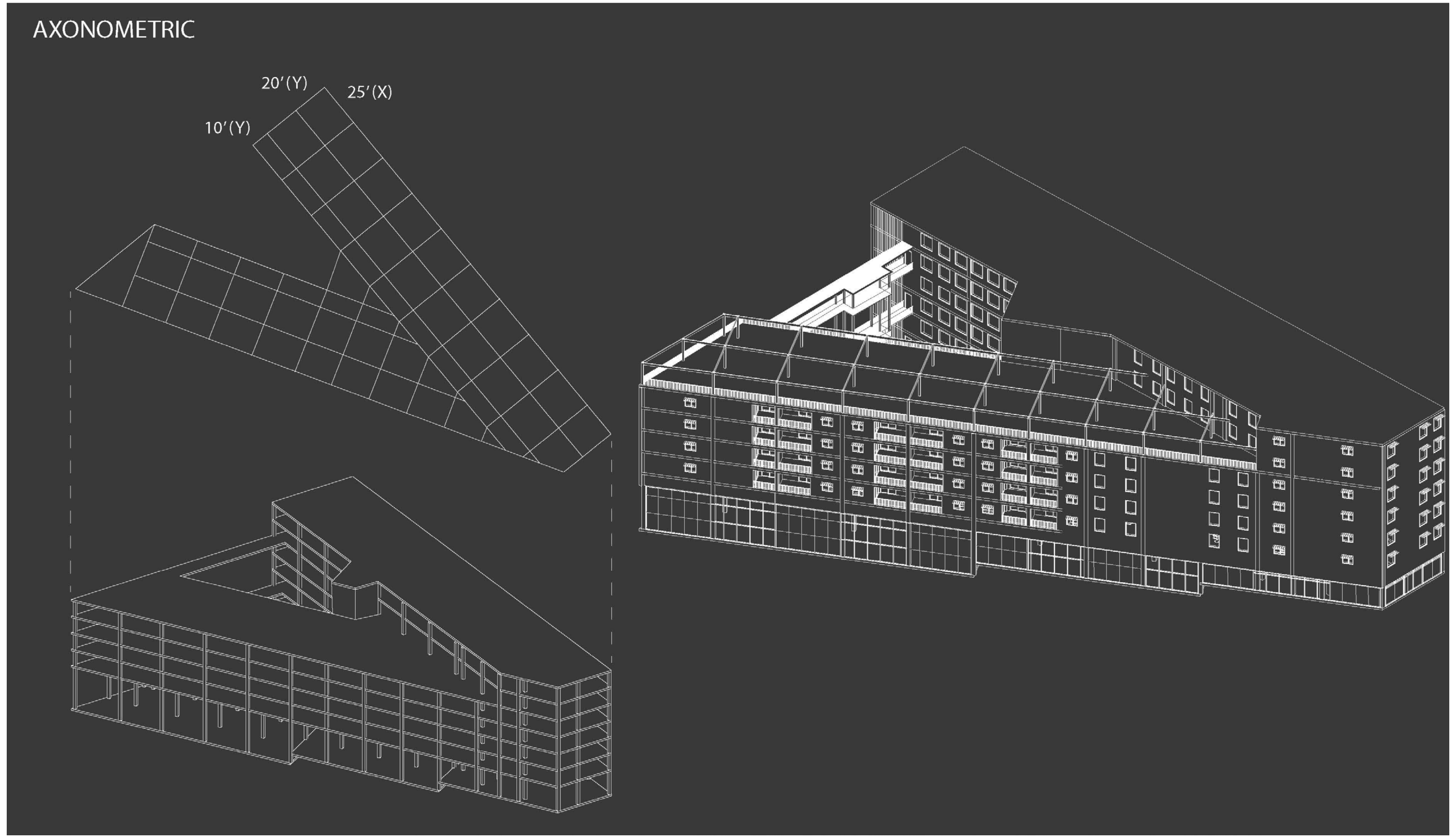
Programming / Massing



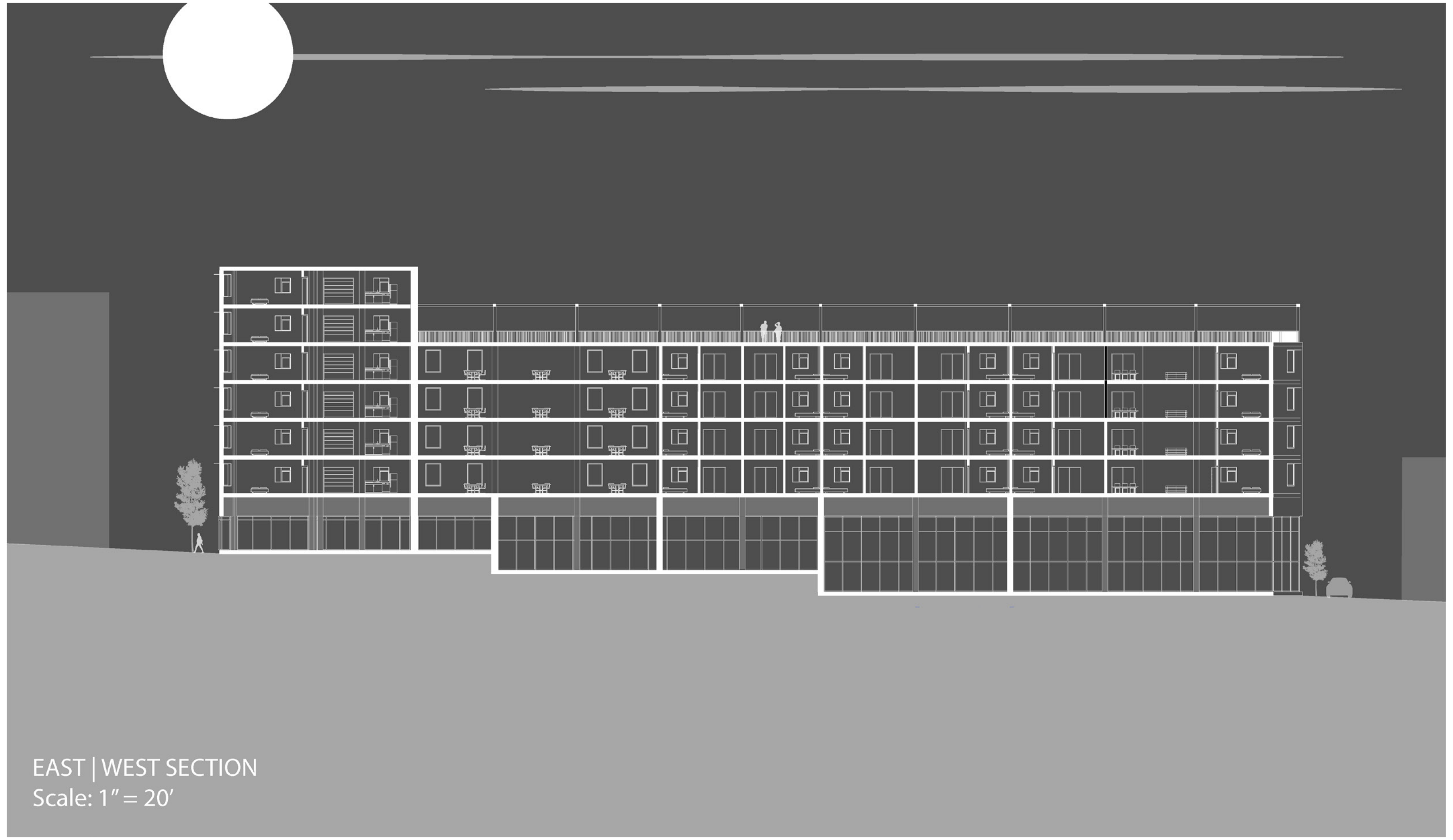




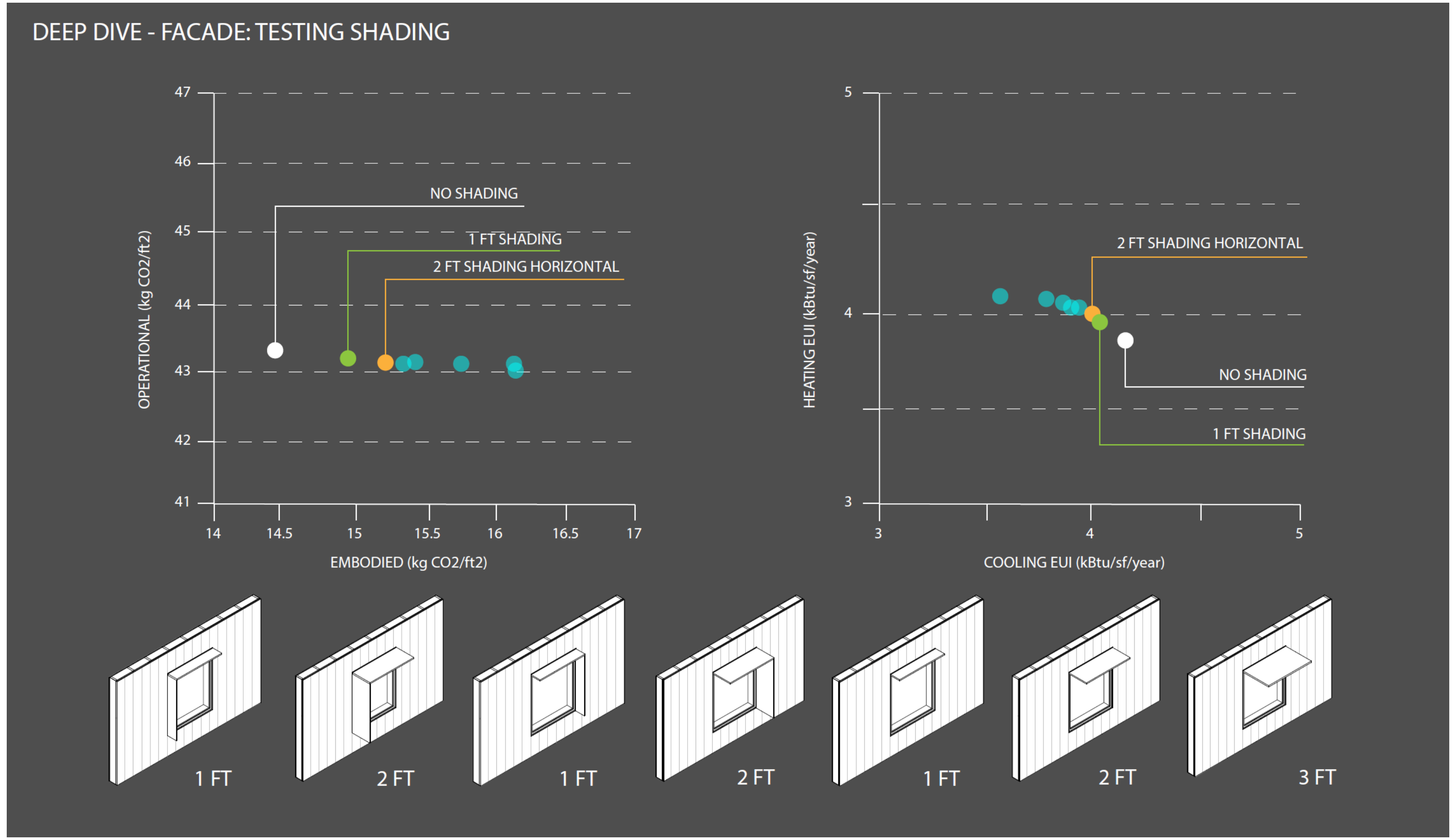

ALTERNATIVES
STRUCTURE
WWR
SHADING
CLADDING
WALL
STRUCTURE
20 FT X 20 FT
25 FT X 25 FT
30 FT X 25 FT
30 FT X 30 FT
WWR
N = 10%; S = 10%; W = 0%; E = 0%
N = 30%; S = 30%; W = 0%; E = 0%
N = 50%; S = 50%; W = 0%; E = 0%
N = 70%; S = 70%; W = 0%; E = 0%
N = 90%; S = 90%; W = 0%; E = 0%
N = 10%; S = 50%; W = 0%; E = 0%
N = 50%; S = 10%; W = 0%; E = 0%
N = 50%; S = 30%; W = 0%; E = 0%
N = 50%; S = 70%; W = 0%; E = 0%
N = 50%; S = 90%; W = 0%; E = 0%
N = 10%; S = 50%; W = 0%; E = 0%
N = 30%; S = 50%; W = 0%; E = 0%
N = 70%; S = 50%; W = 0%; E = 0%
N = 90%; S = 50%; W = 0%; E = 0%
SHADING
0 FT
1 FT
3 FT
6 FT
GLAZING
WOOD DOUBLE
WOOD TRIPLE
ALUMINUM DOUBLE
ALUMINUM TRIPLE
CLADDING
METAL PANEL
FIBER CEMENT
BRICK
WALL
CLT
2X4
2X6
2X8
2X10
2X12

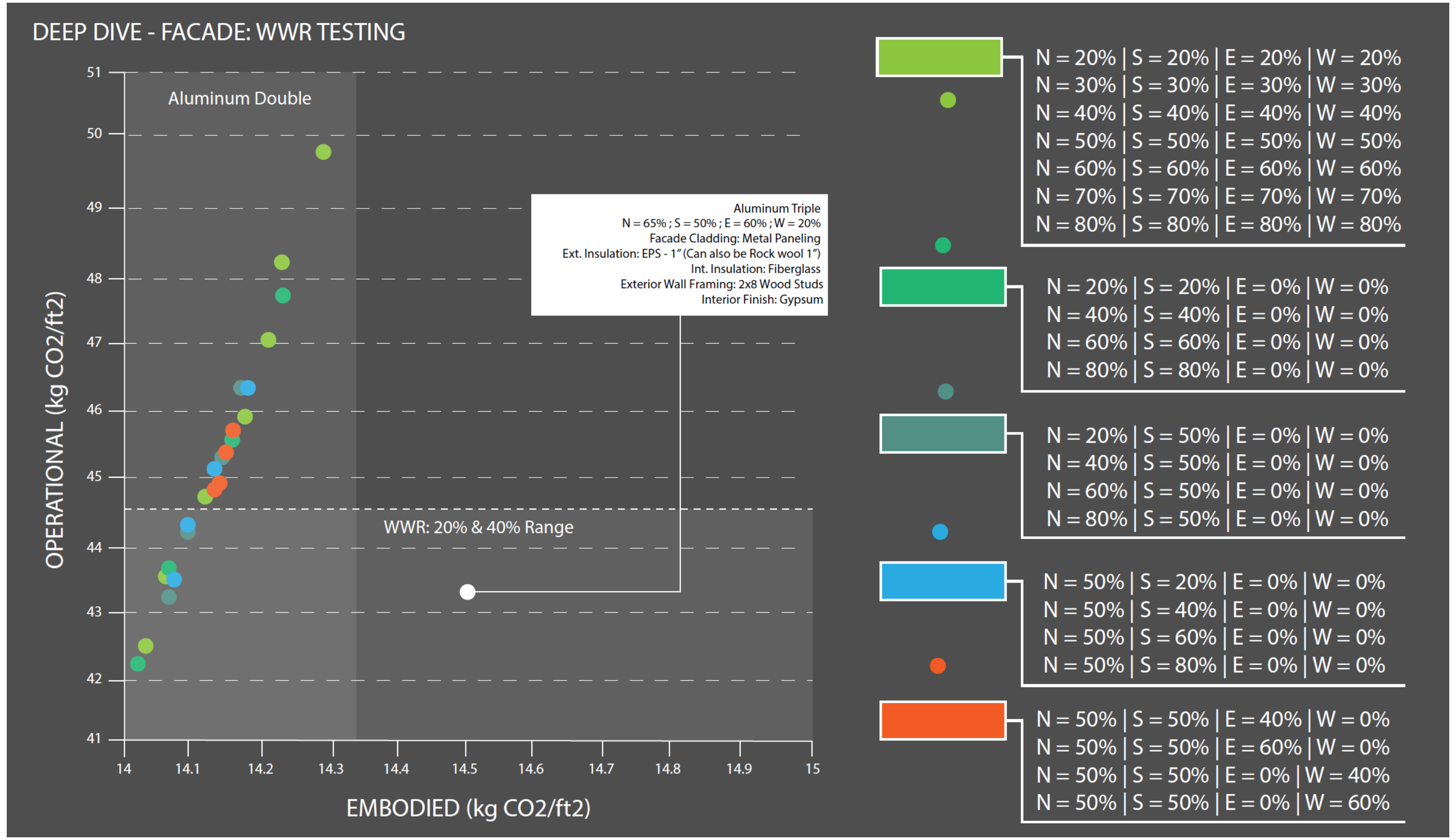

AXONOMETRIC
20′ (Y)
25′ (X)
10′ (Y)


MULTIFAMILY PLAN (2ND FLOOR TO 6TH FLOOR)
Scale: 1″=20′
E Pine St.
13th Ave
14th Ave
E Madison St

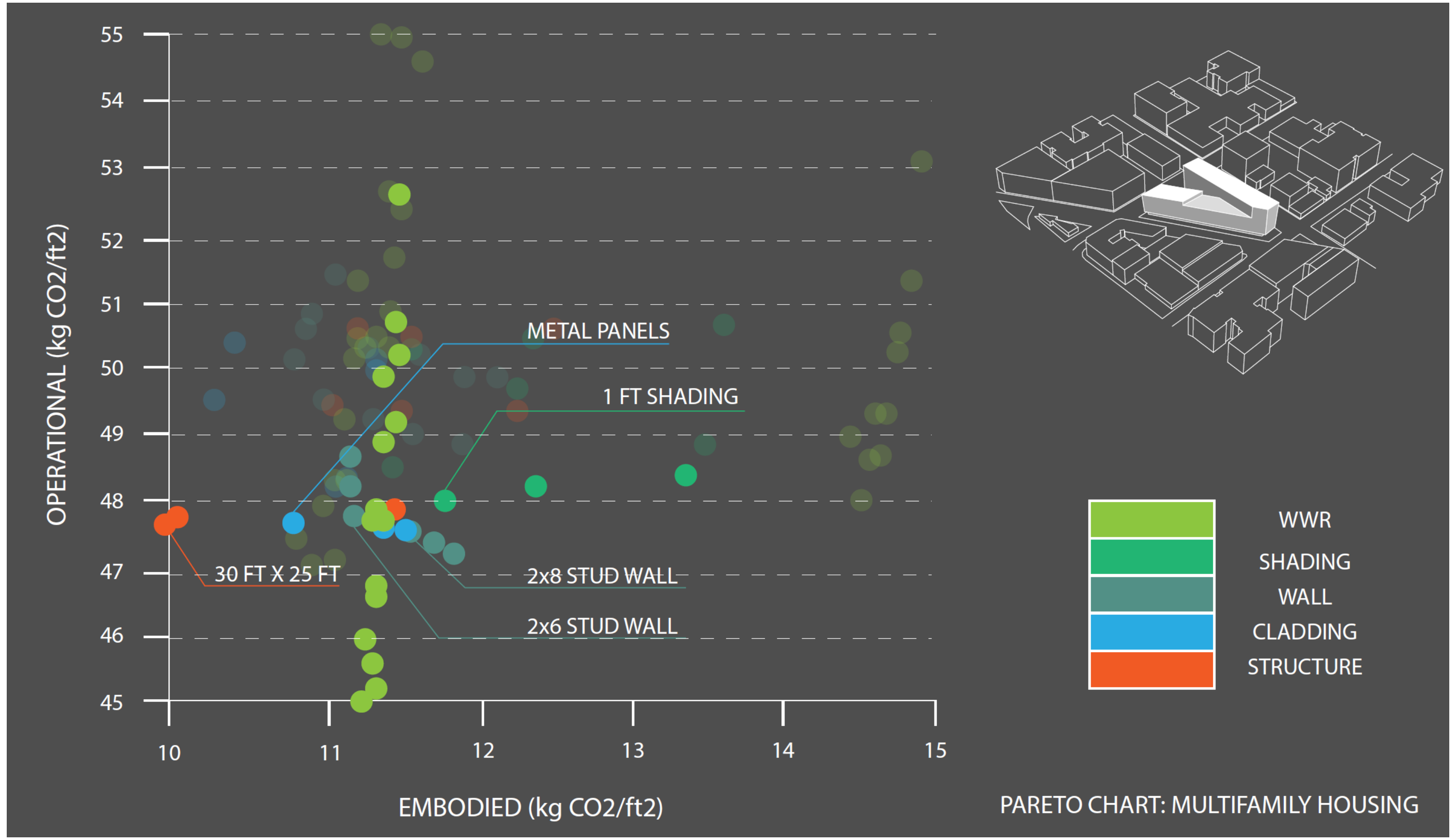

EAST | WEST SECTION
Scale: 1″ = 20′

Simulation Data

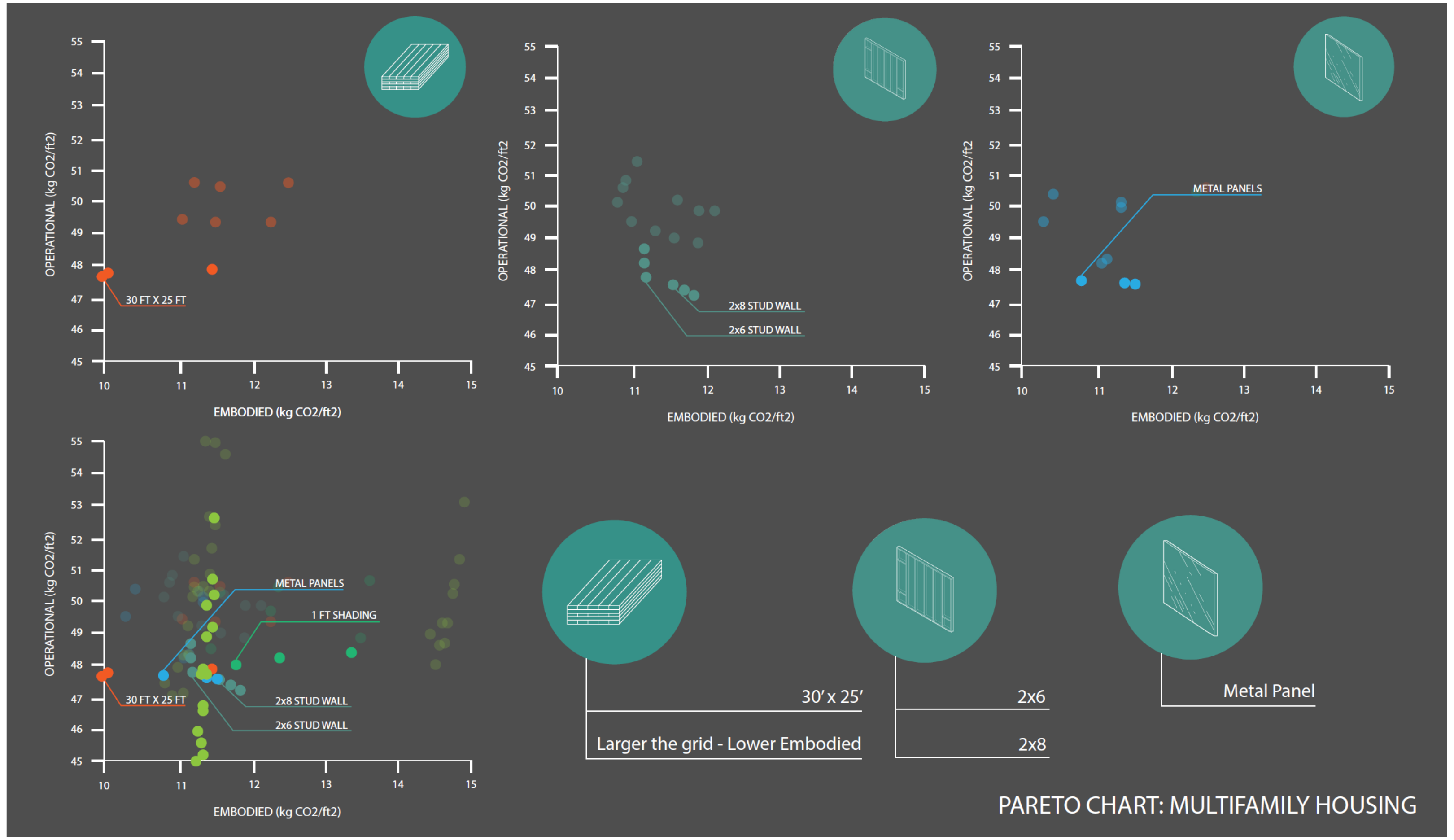


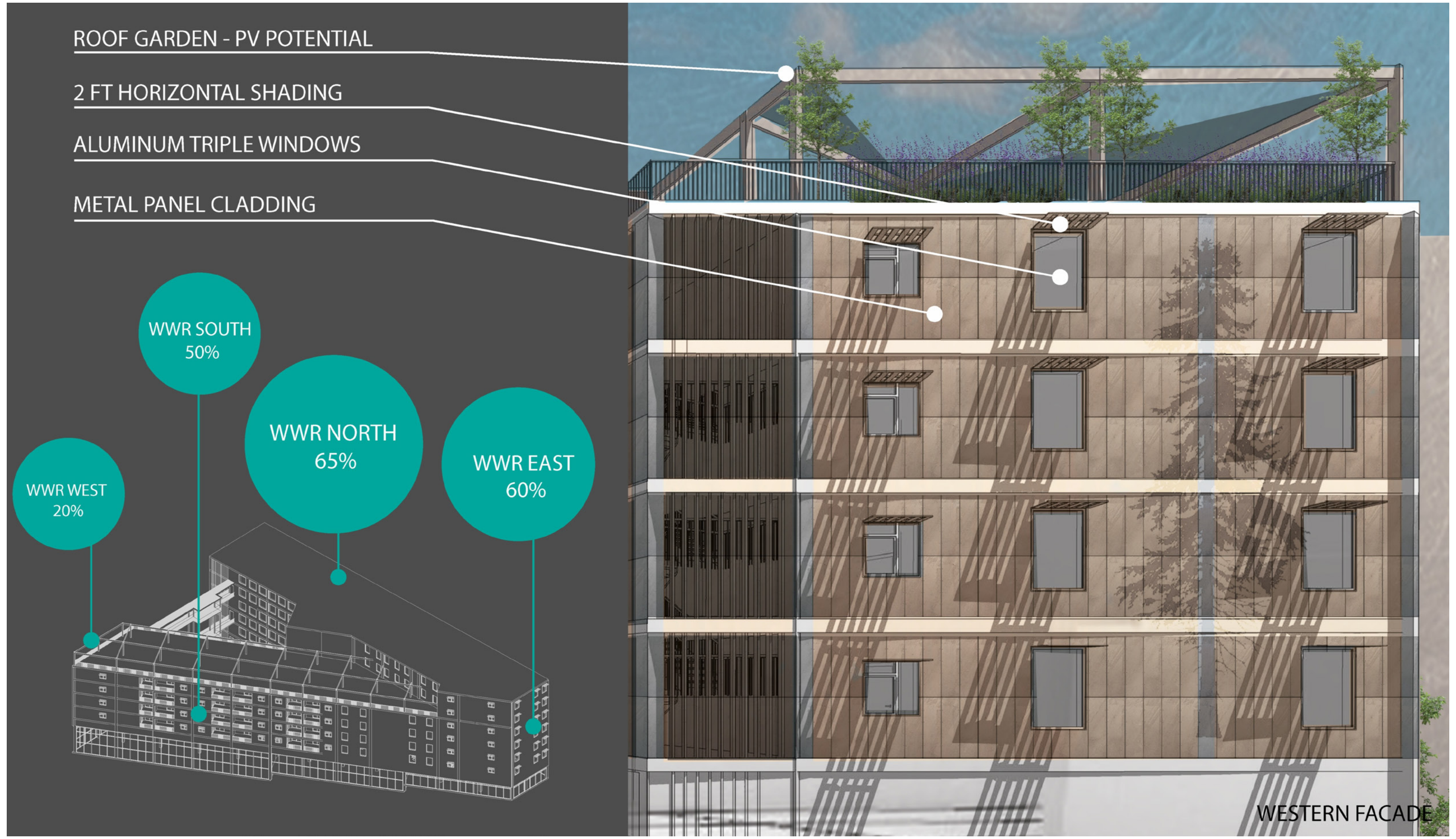


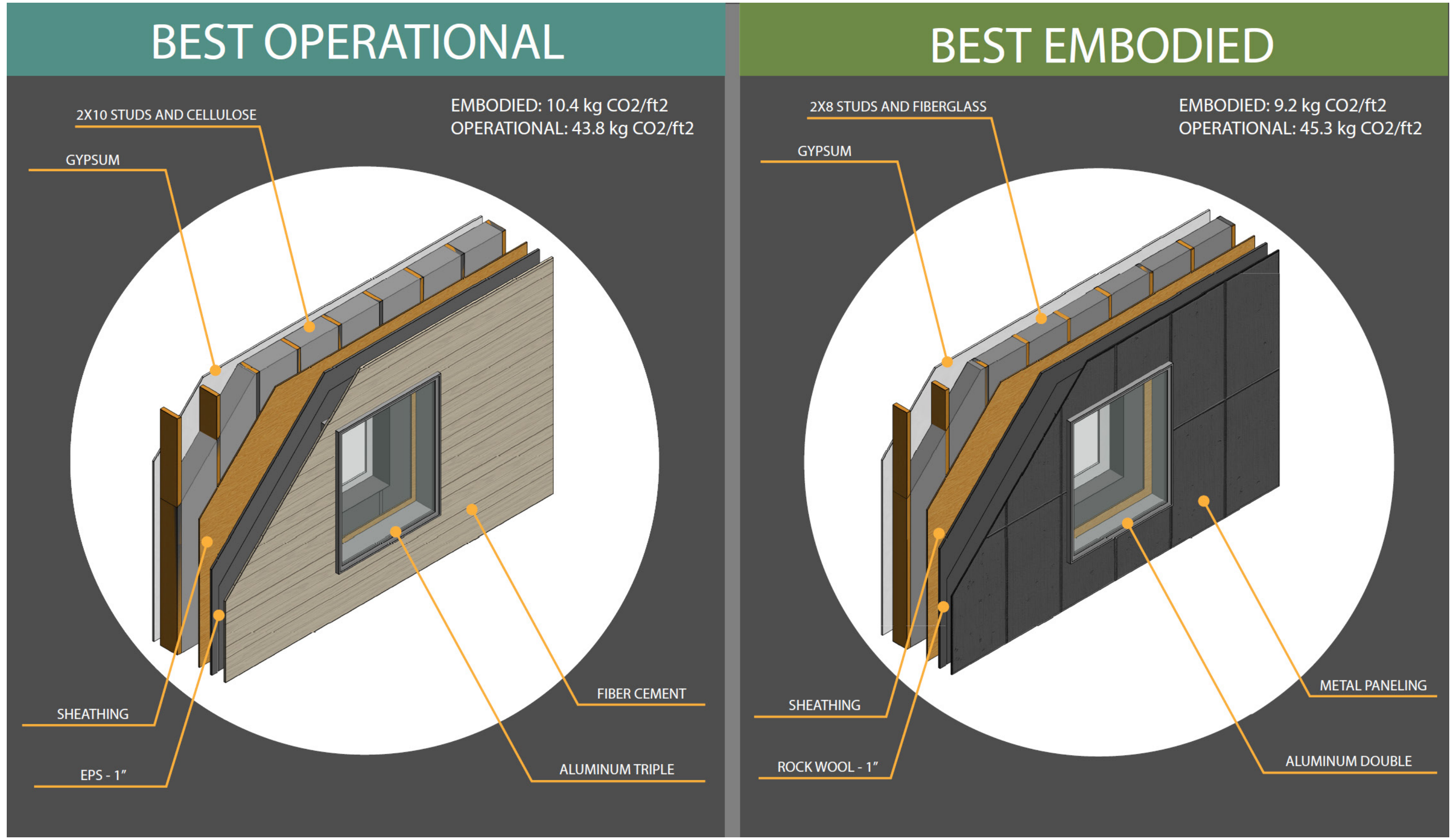

PARETO CHART: ALL DATA (RETAIL, OFFICE, AND HOUSING)
OPERATIONAL (kg CO2/ft2)
55
54
53
52
51
50
49
48
47
46
45
10
11
12
13
14
15
EMBODIED (kg CO2/ft2)
WWR
SHADING
WALL
CLADDING
STRUCTURE

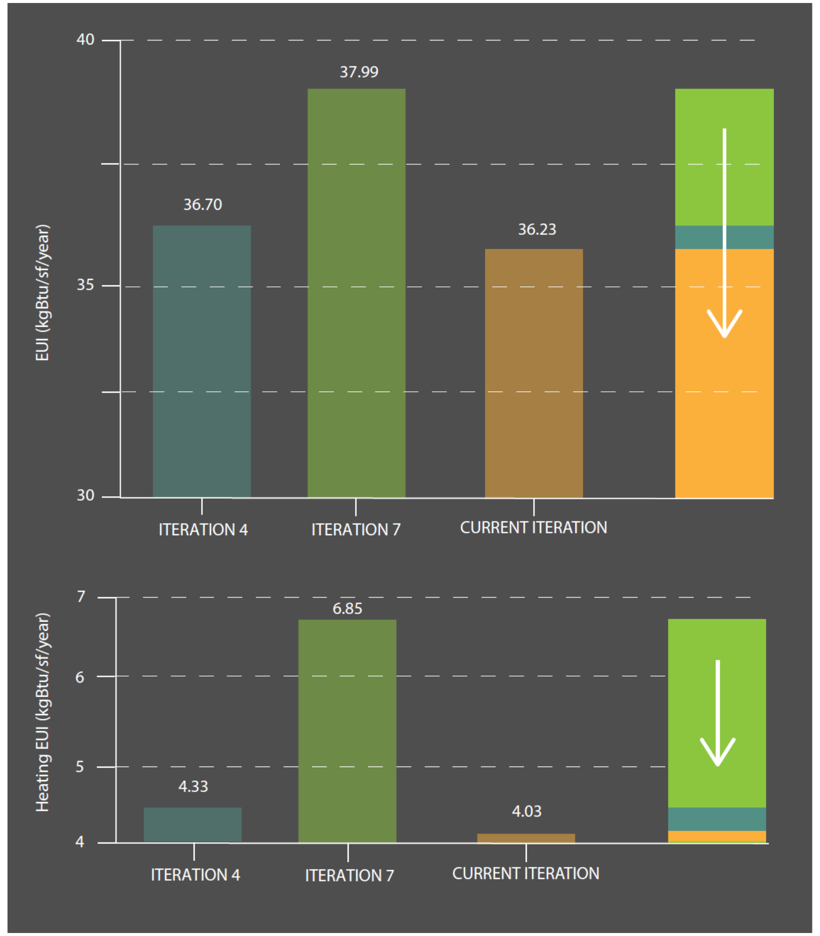

OPERATIONAL (kg CO2/ft2)
55
54
53
52
51
50
49
48
47
46
45
METAL PANELS
1 FT SHADING
30 FT X 25 FT
2x8 STUD WALL
2x6 STUD WALL
10
11
12
13
14
15
EMBODIED (kg CO2/ft2)
WWR
SHADING
WALL
CLADDING
STRUCTURE
PARETO CHART: MULTIFAMILY HOUSING

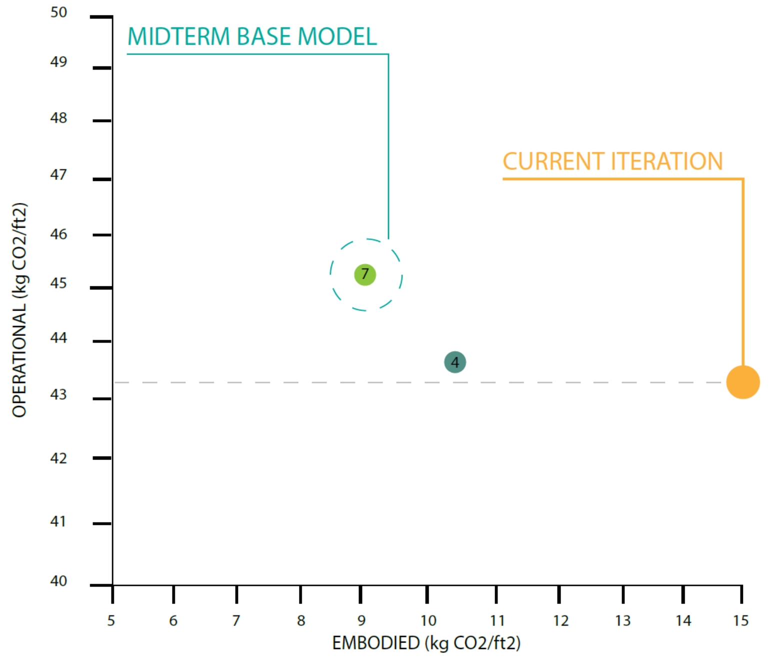
Results

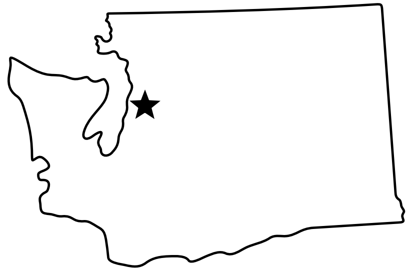

OPERATIONAL (kg CO2/ft2)
EMBODIED (kg CO2/ft2)
30 FT X 25 FT
2x8 STUD WALL
2x6 STUD WALL
METAL PANELS
1 FT SHADING
30' x 25'
Larger the grid - Lower Embodied
2x6
2x8
Metal Panel
PARETO CHART: MULTIFAMILY HOUSING


ROOF GARDEN - PV POTENTIAL
2 FT HORIZONTAL SHADING
ALUMINUM TRIPLE WINDOWS
METAL PANEL CLADDING
WWR SOUTH 50%
WWR WEST 20%
WWR NORTH 65%
WWR EAST 60%
WESTERN FACADE


BEST OPERATIONAL
2X10 STUDS AND CELLULOSE
EMBODIED: 10.4 kg CO2/ft2
OPERATIONAL: 43.8 kg CO2/ft2
GYPSUM
SHEATHING
EPS - 1"
FIBER CEMENT
ALUMINUM TRIPLE
BEST EMBODIED
2X8 STUDS AND FIBERGLASS
EMBODIED: 9.2 kg CO2/ft2
OPERATIONAL: 45.3 kg CO2/ft2
GYPSUM
SHEATHING
ROCK WOOL - 1"
METAL PANELING
ALUMINUM DOUBLE


EUI (kgBtu/sf/year)
36.70
37.99
36.23
ITERATION 4
ITERATION 7
CURRENT ITERATION
Heating EUI (kgBtu/sf/year)
4.33
6.85
4.03
ITERATION 4
ITERATION 7
CURRENT ITERATION

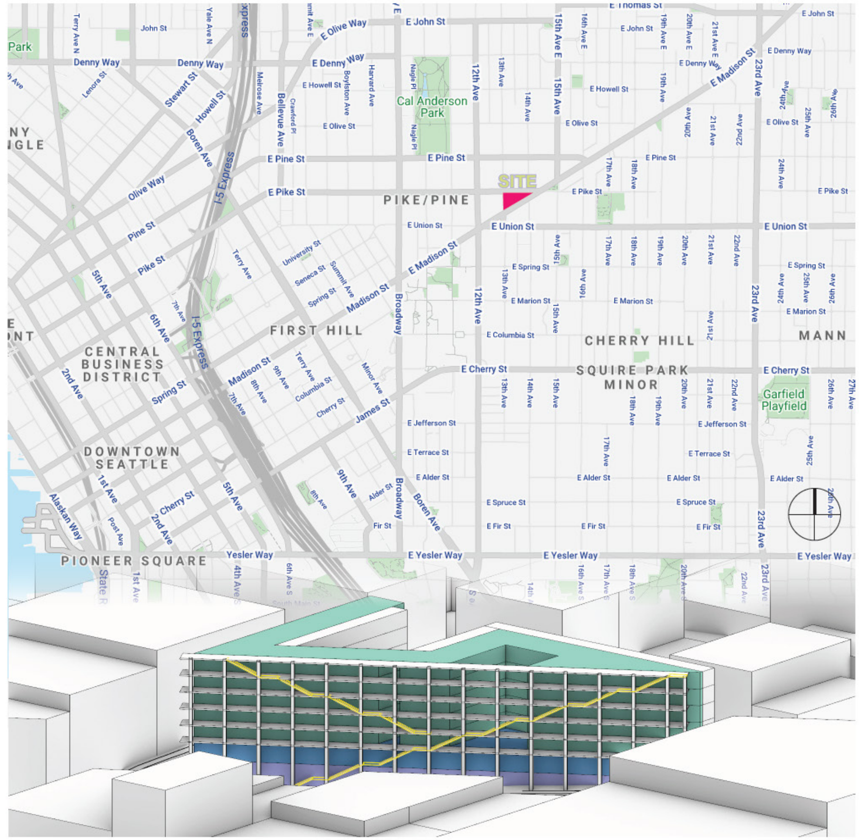

MIDTERM BASE MODEL
CURRENT ITERATION
OPERATIONAL (kg CO2/ft2)
EMBODIED (kg CO2/ft2)

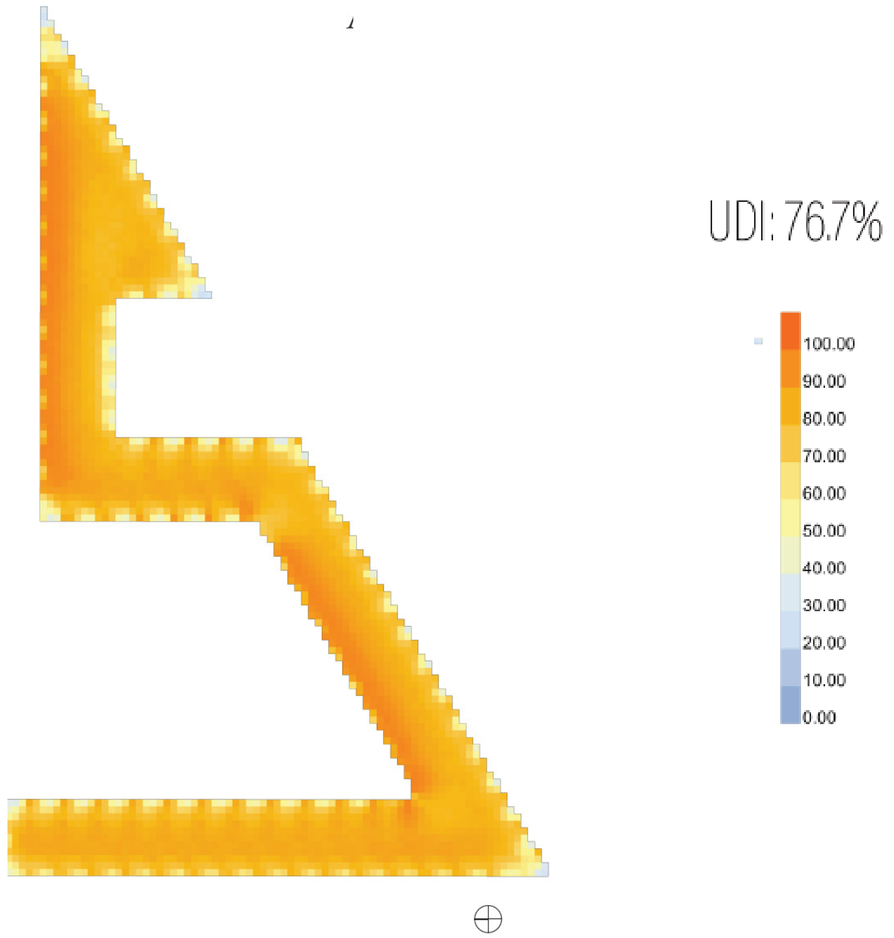


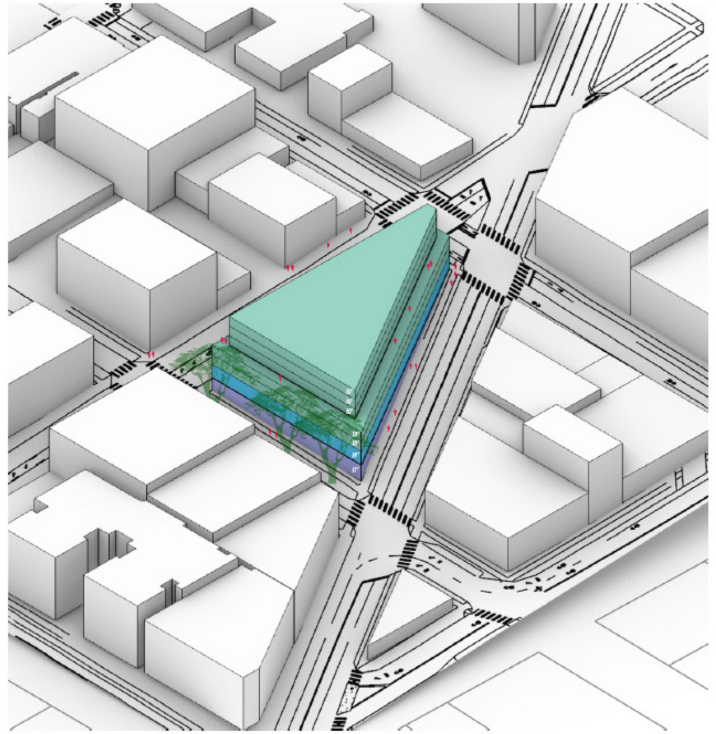
Cody Edmonds

1300 E. Madison St.
Seattle, Washington

Programming / Massing



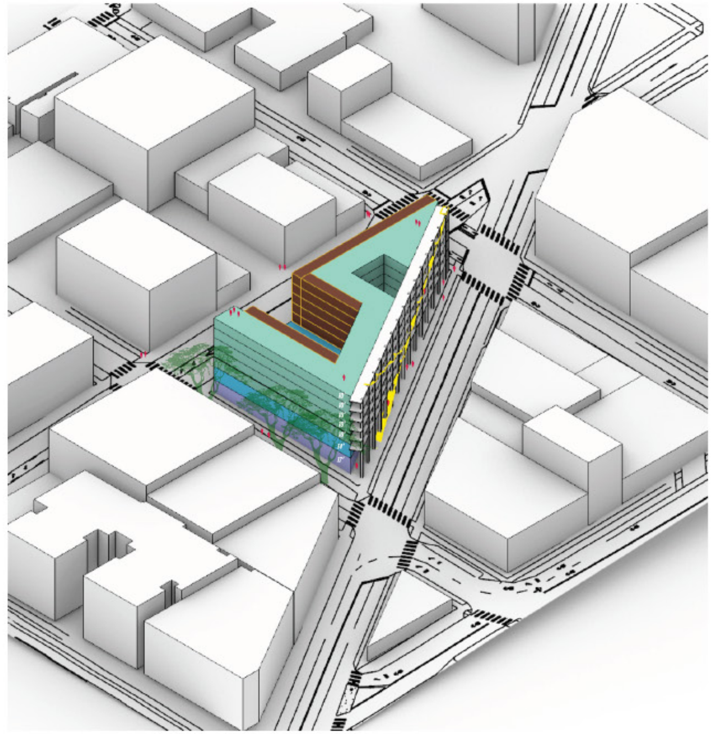




Maximum Site Development

SF	Res: 110779.82	Off: 26466.33	Retail: 26466.33
FAR	6.2	S/V Ratio:	23.14%
Units	71		

$C0_2$ eq/SF	9.61	kg CO_2 /SF/ Year	0.71

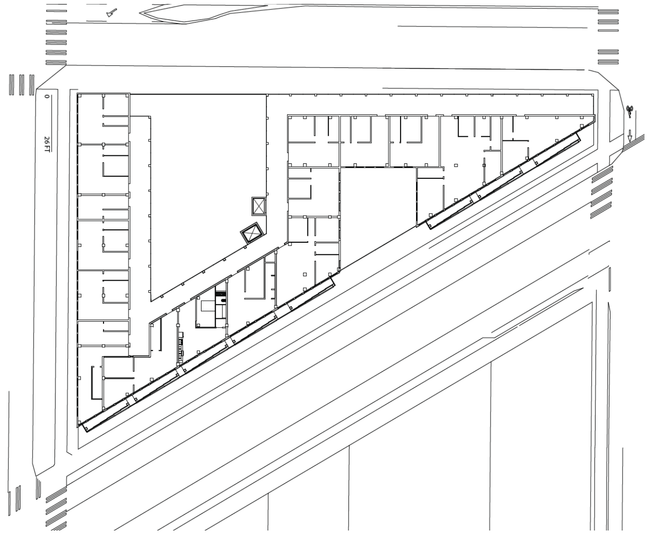


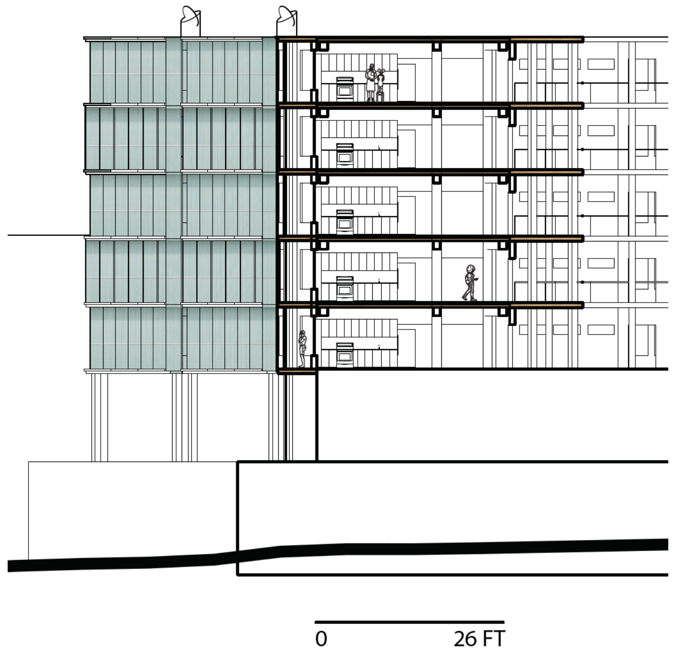
Skinny 5 Building

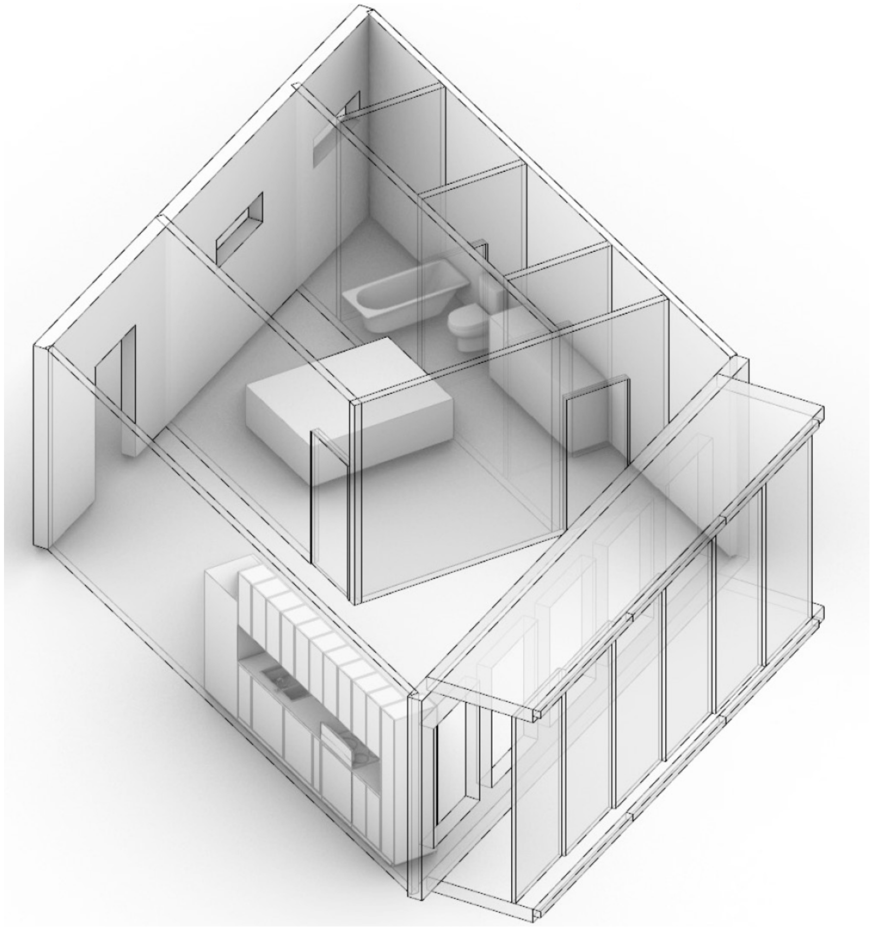
SF	Res: 129552.85	Off: 22741.13	Retail: 22741.13
FAR	6.6	S/V Ratio:	28.4%
Units	85		

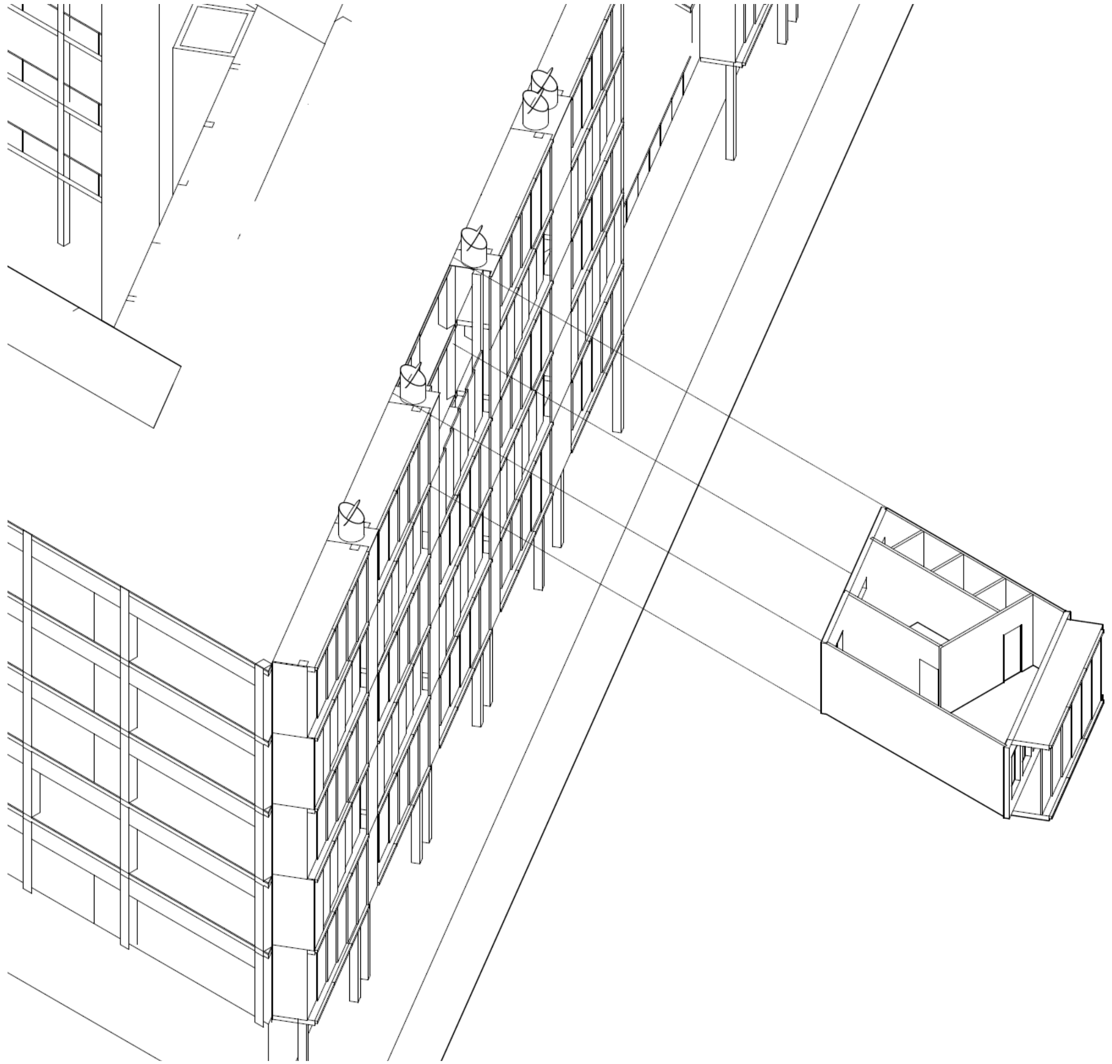
$C0_2$ eq/SF	9.91	kBtu/SF/ Year	0.93

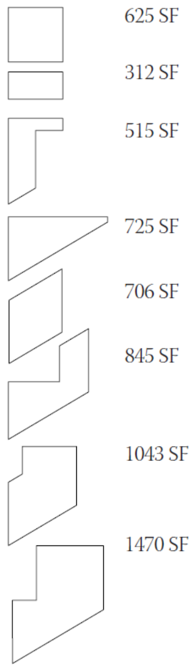
Plans / Sections / Axonometrics



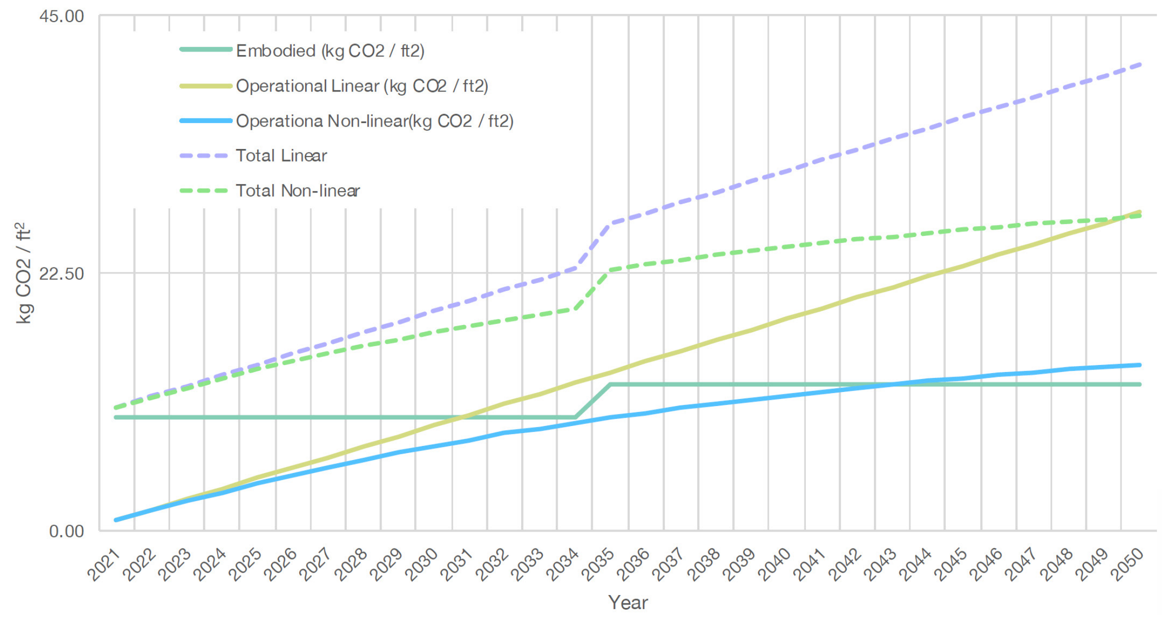


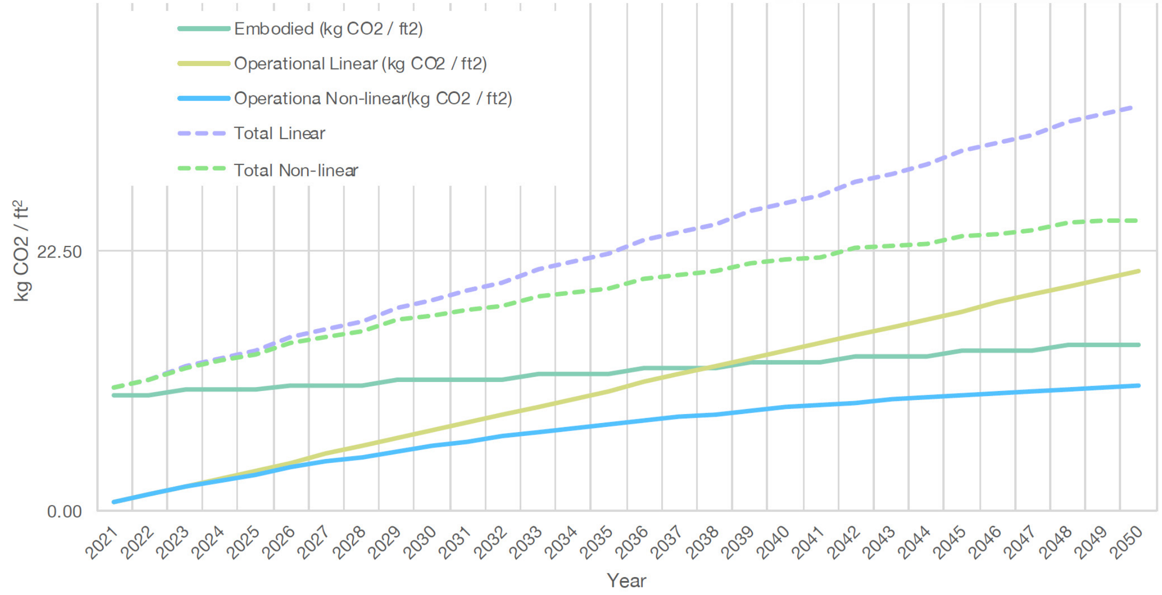


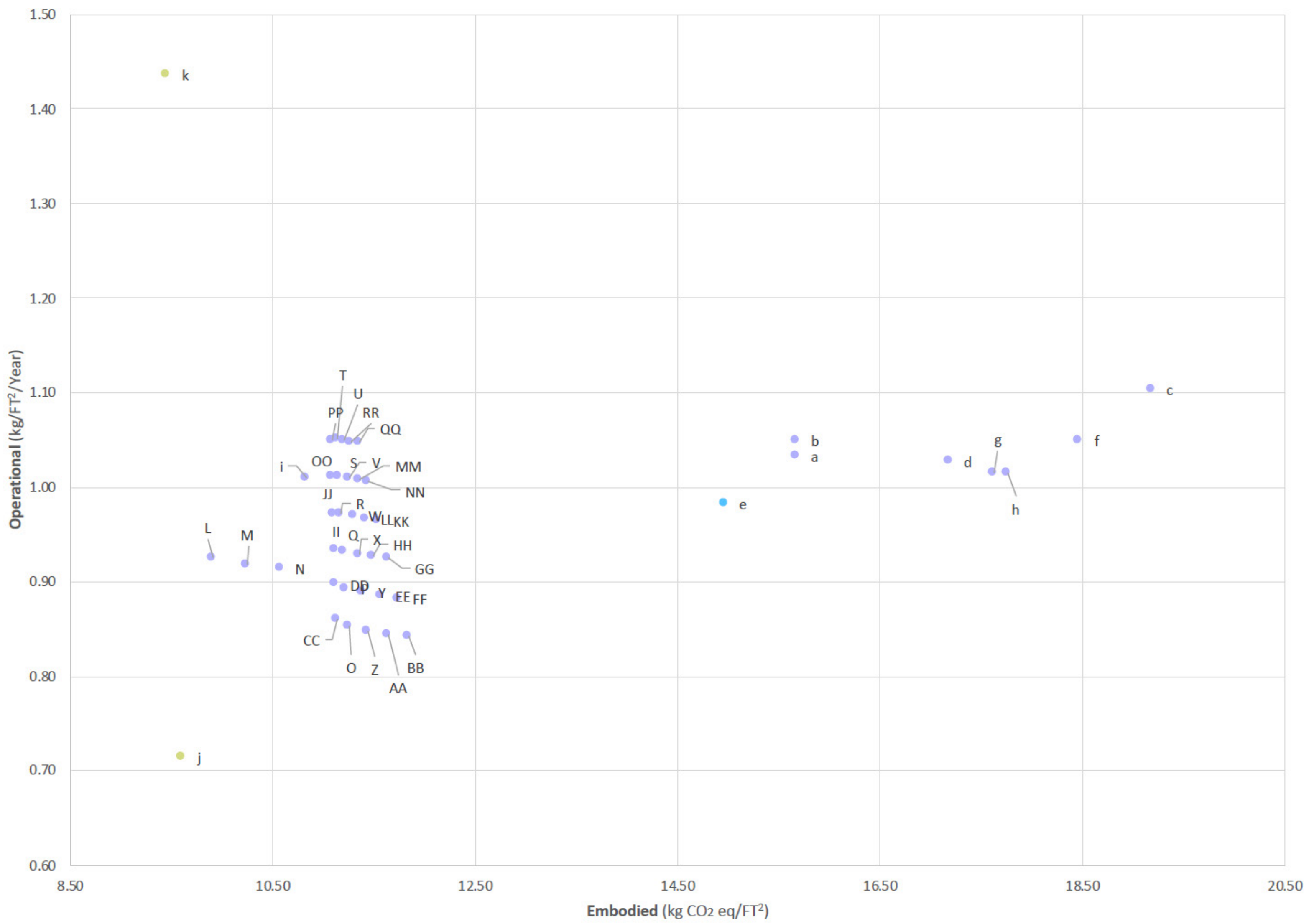


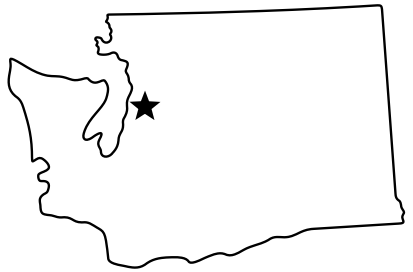


Simulation Data + Results



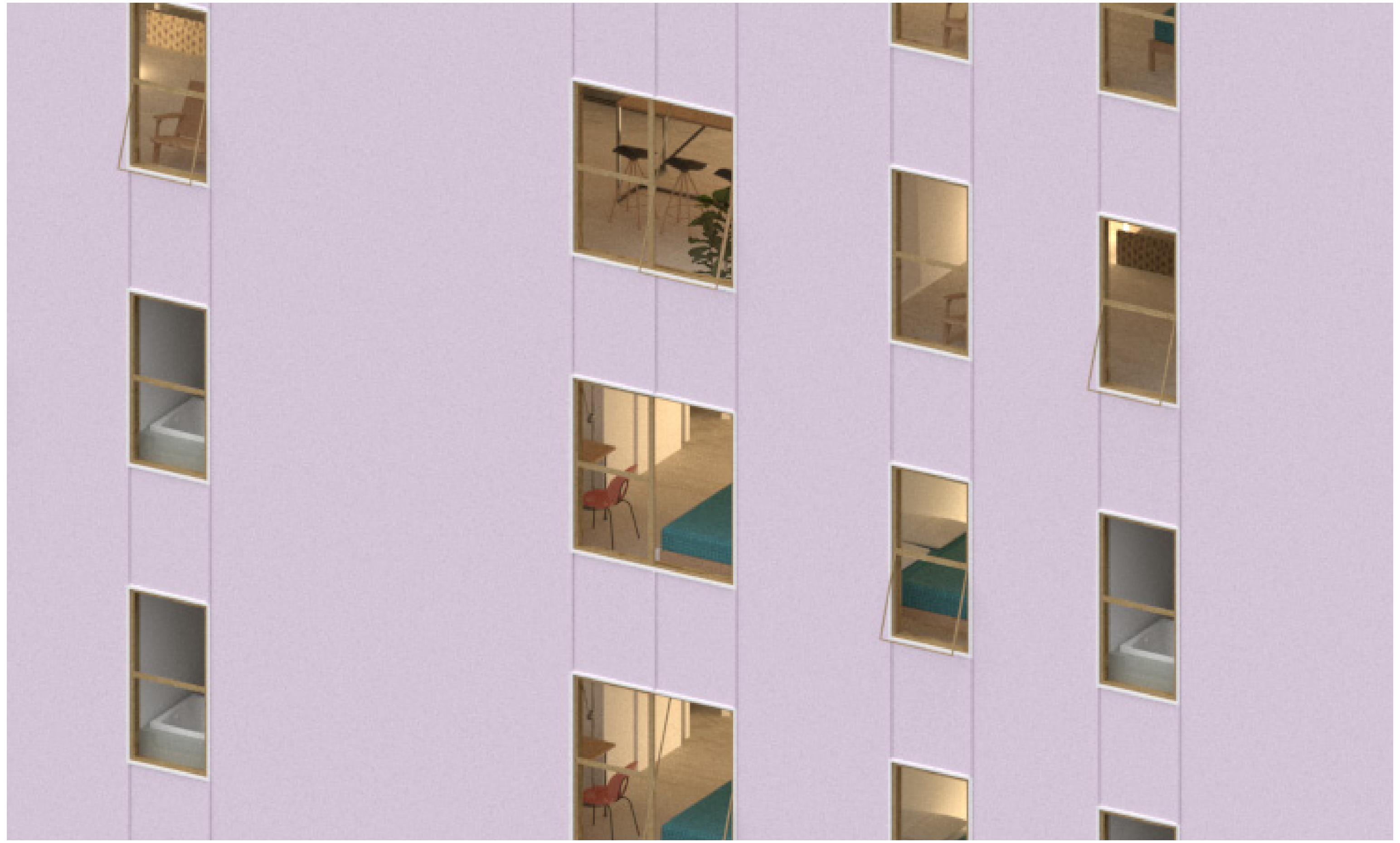




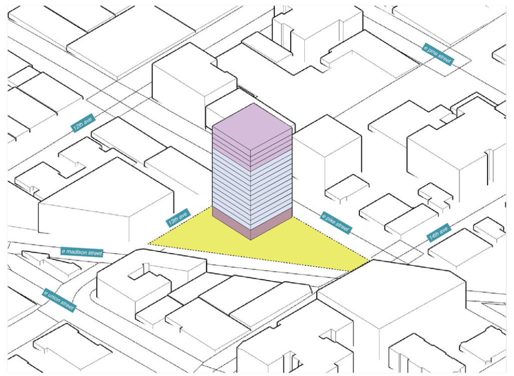


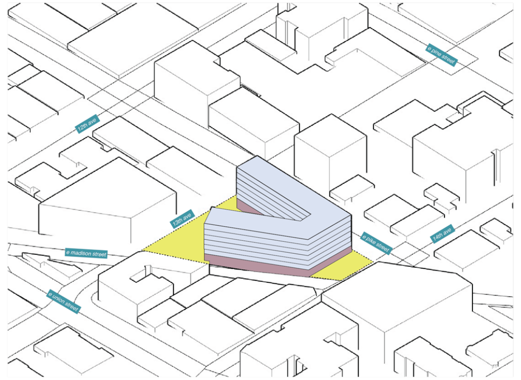
Emily Crichlow
+
Claire Sullivan

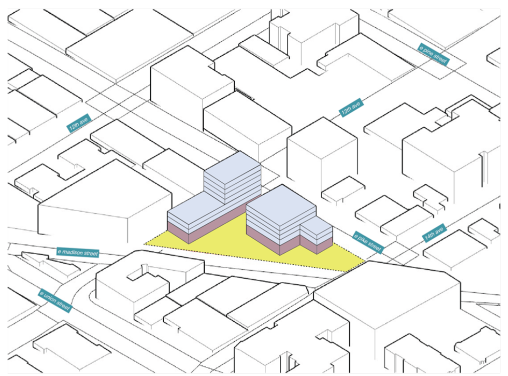
1300 E. Madison St.
Seattle, Washington



Programming / Massing







concept 01:

- 145,800ft²
- 18-story tower
- maximizing housing density on site
- office space on upper floors
- remainder of site available for other uses

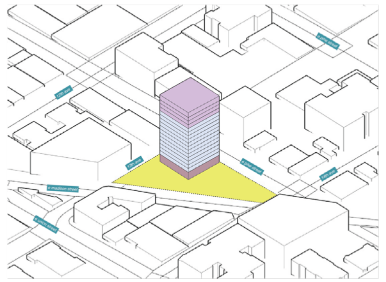
concept 02:

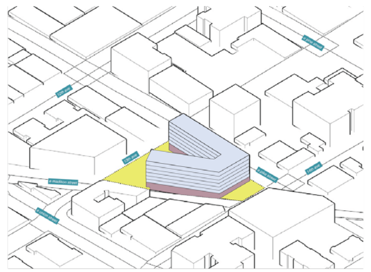
- 147,039ft²
- total ground floor: 18,396ft²
- u-shape to border street edge and create interior private courtyard
- maximizing SW daylight
- 8-story, code compliant
- all multi-family residential units

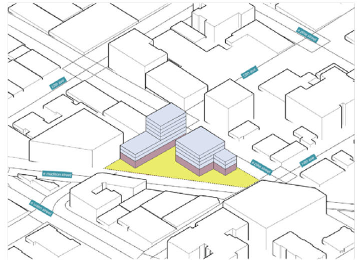
concept 03:

- 92,062ft²
- combination of building levels
- terracing to optimize daylighting
-

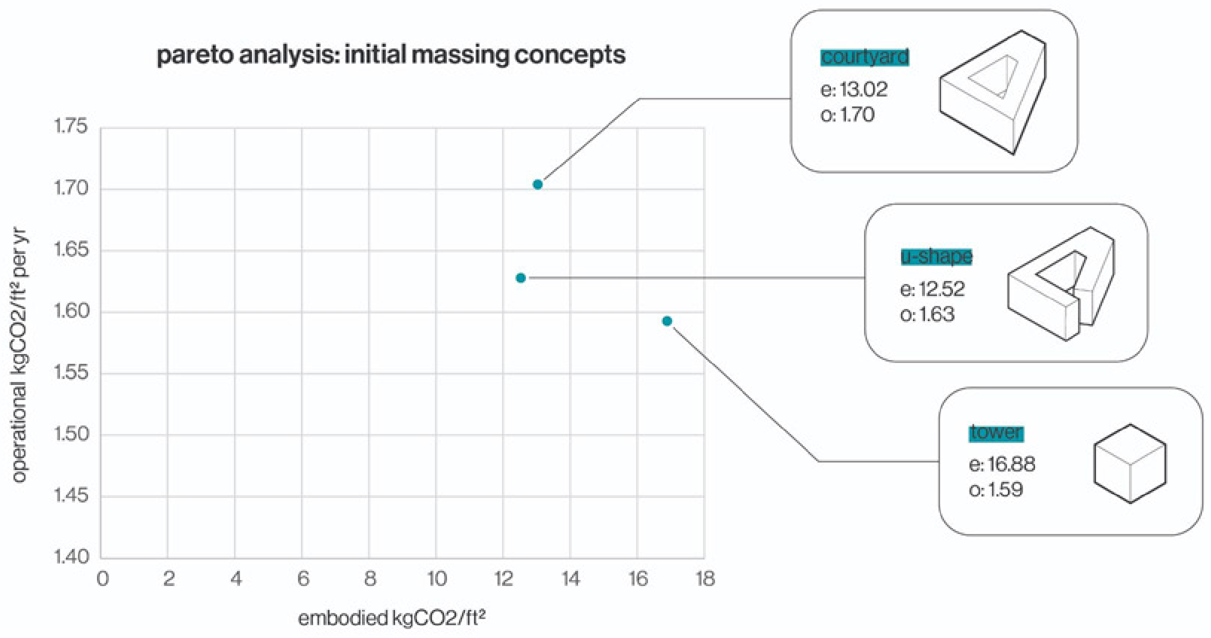
concept 03:
92,062ft2
combination of
building levels
terracing to opti-
mize daylighting



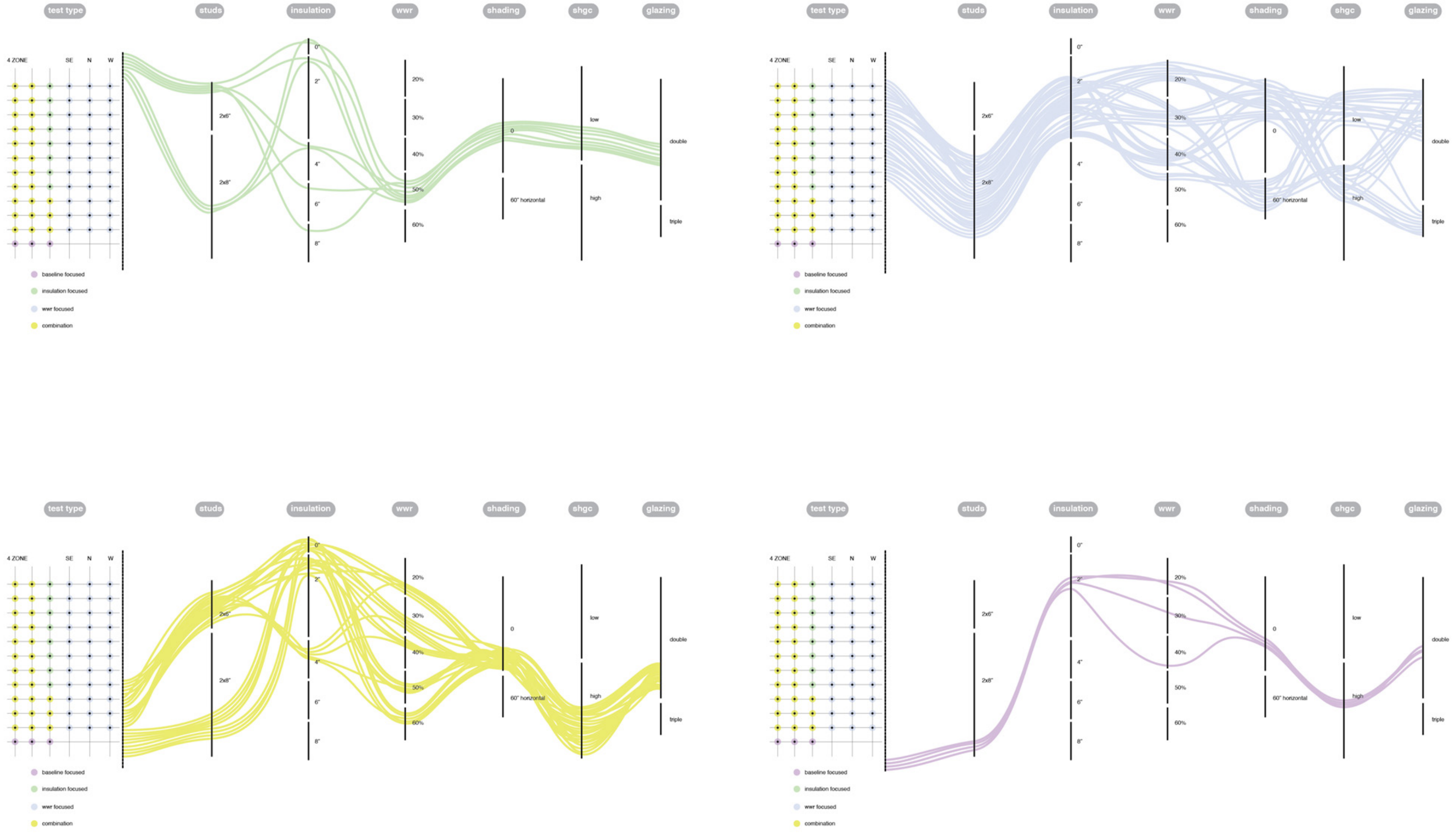


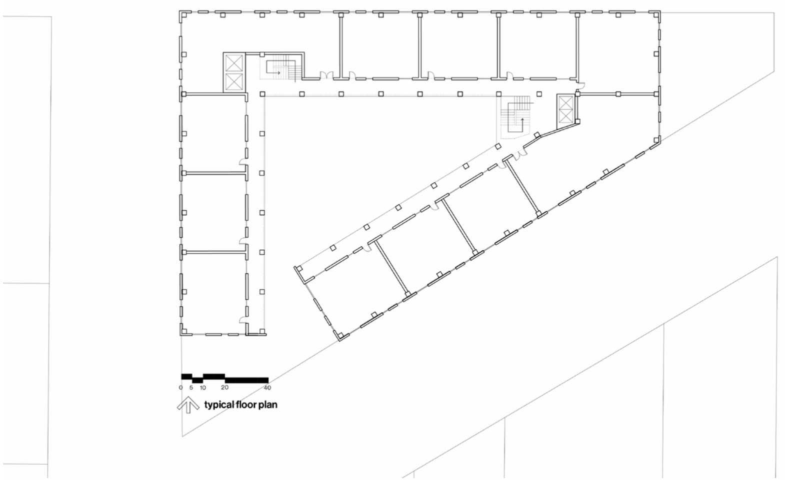


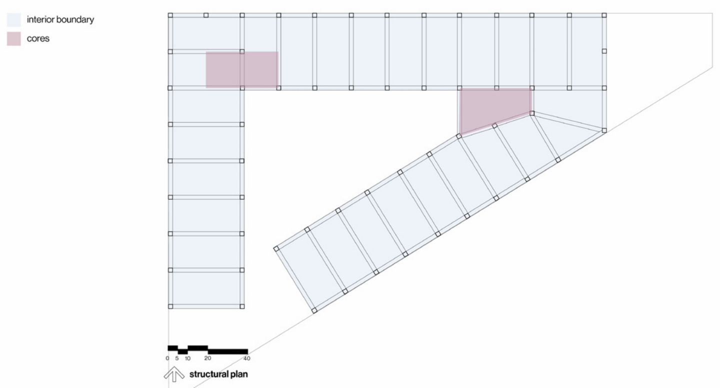
embodied carbon	45,543	336,299	374,682
operational carbon (kg CO2e/yr)	332,705	321,233	338,441
Benchmark EUI		299.096 lb/MWh	299.096 lb/MWh
Target EUI	299.096 lb/MWh	46.7 kBtu/ft²-yr	47.1 kBtu/ft²-yr
carbon intensity of site electricity:	42.2 kBtu/ft²-yr	9.0 kBtu/ft²-yr	12.6 kBtu/ft²-yr
total site renewable energy potential:	4.0 kBtu/ft²-yr	325 kW	325 kW
solar potential :	143 kW		

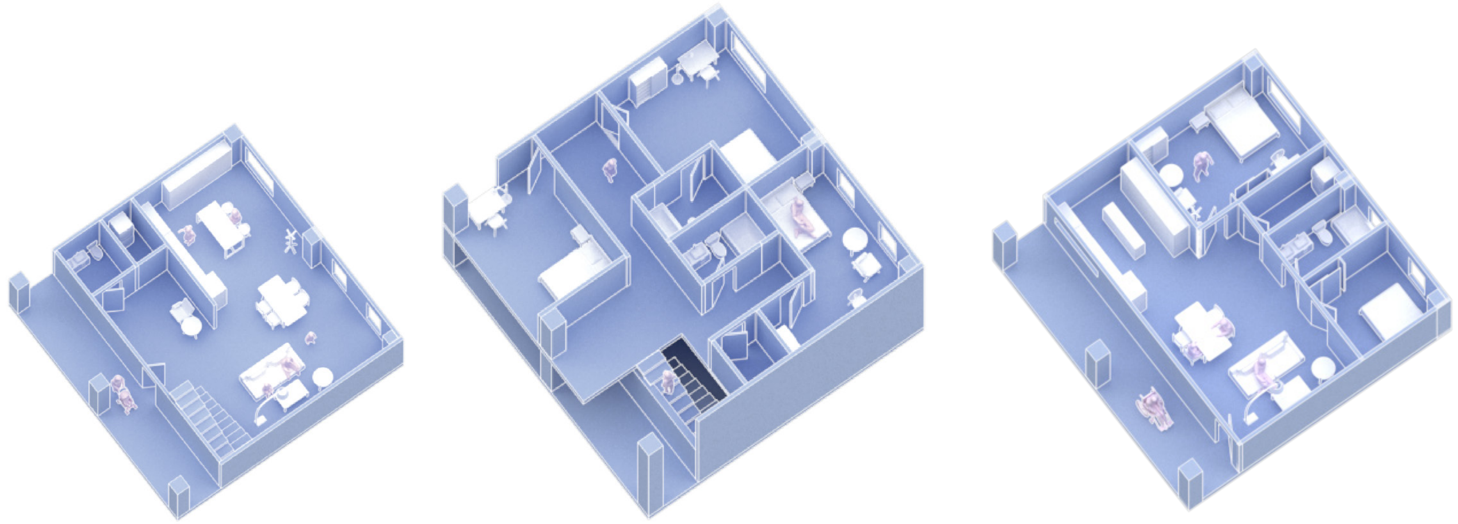


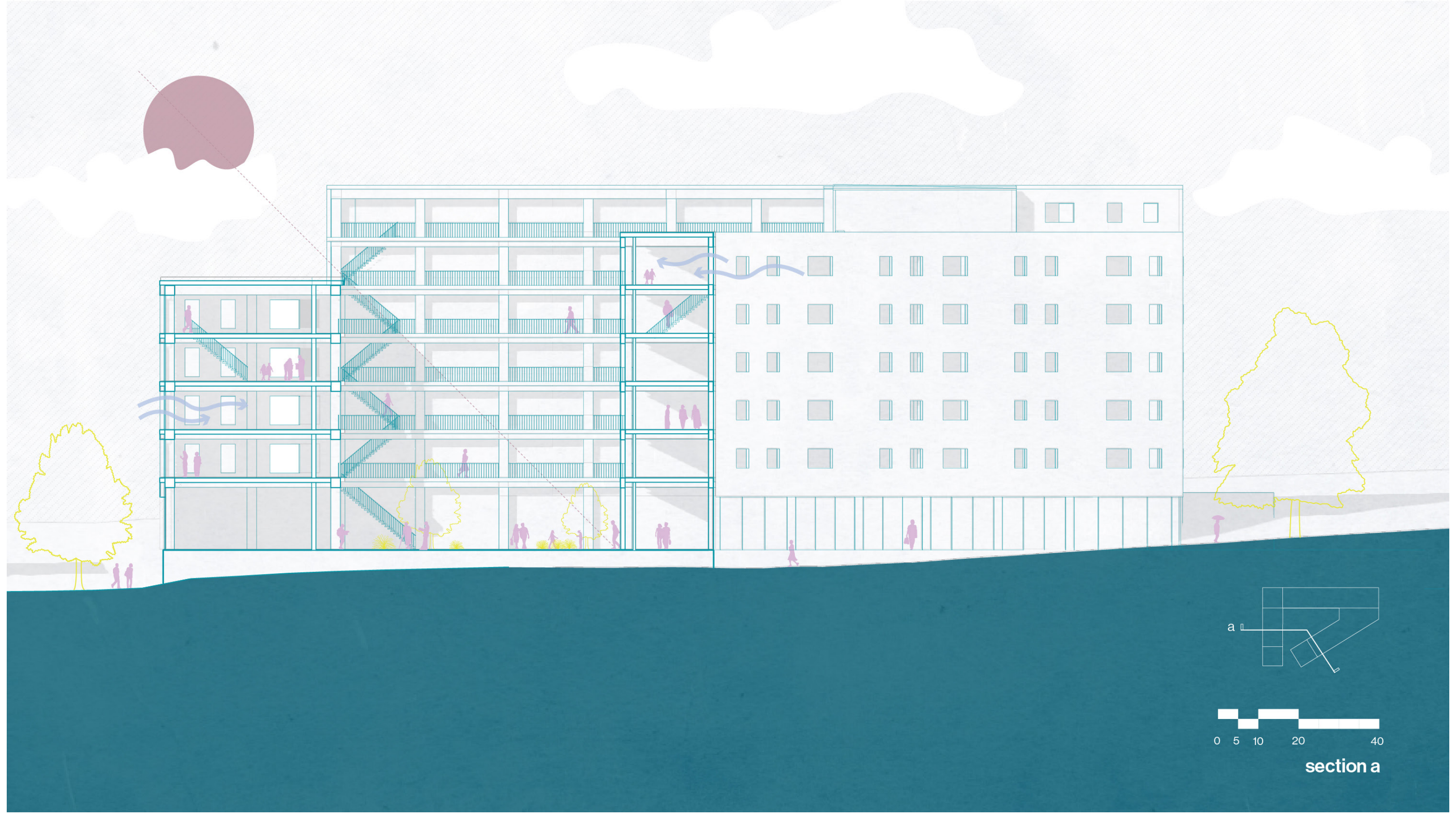
pareto analysis: initial massing concepts
operational kgCO2/ft² per yr
embodied kgCO2/ft²
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
0
2
4
6
8
10
12
14
16
18
courtyard
e: 13.02
o: 1.70
u-shape
e: 12.52
o: 1.63
tower
e: 16.88
o: 1.59



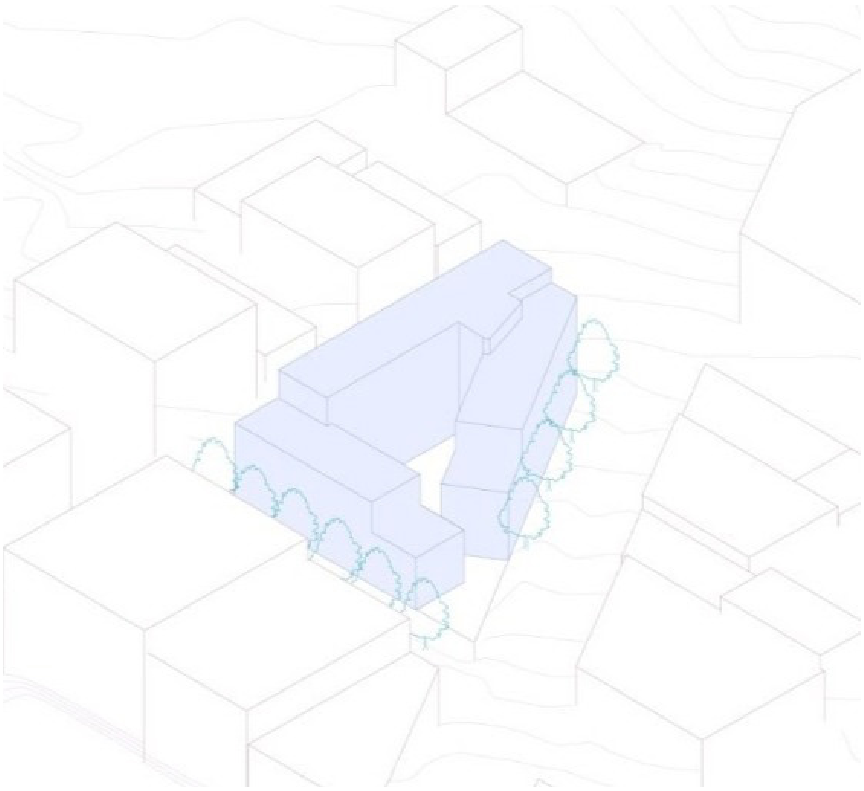

typical floor plan

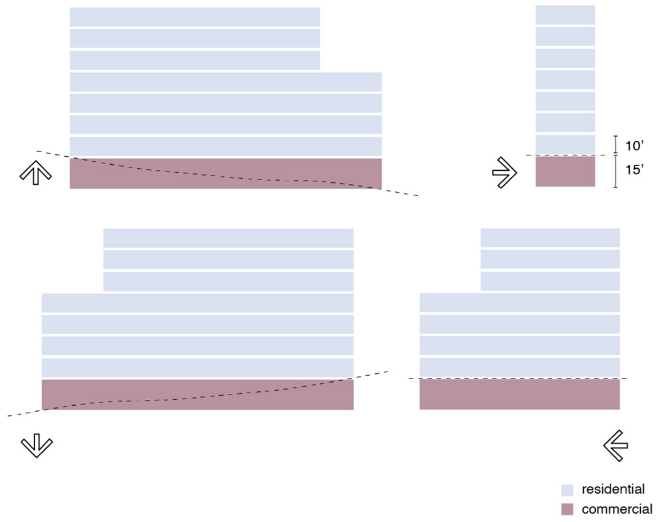

interior boundary
cores
structural plan

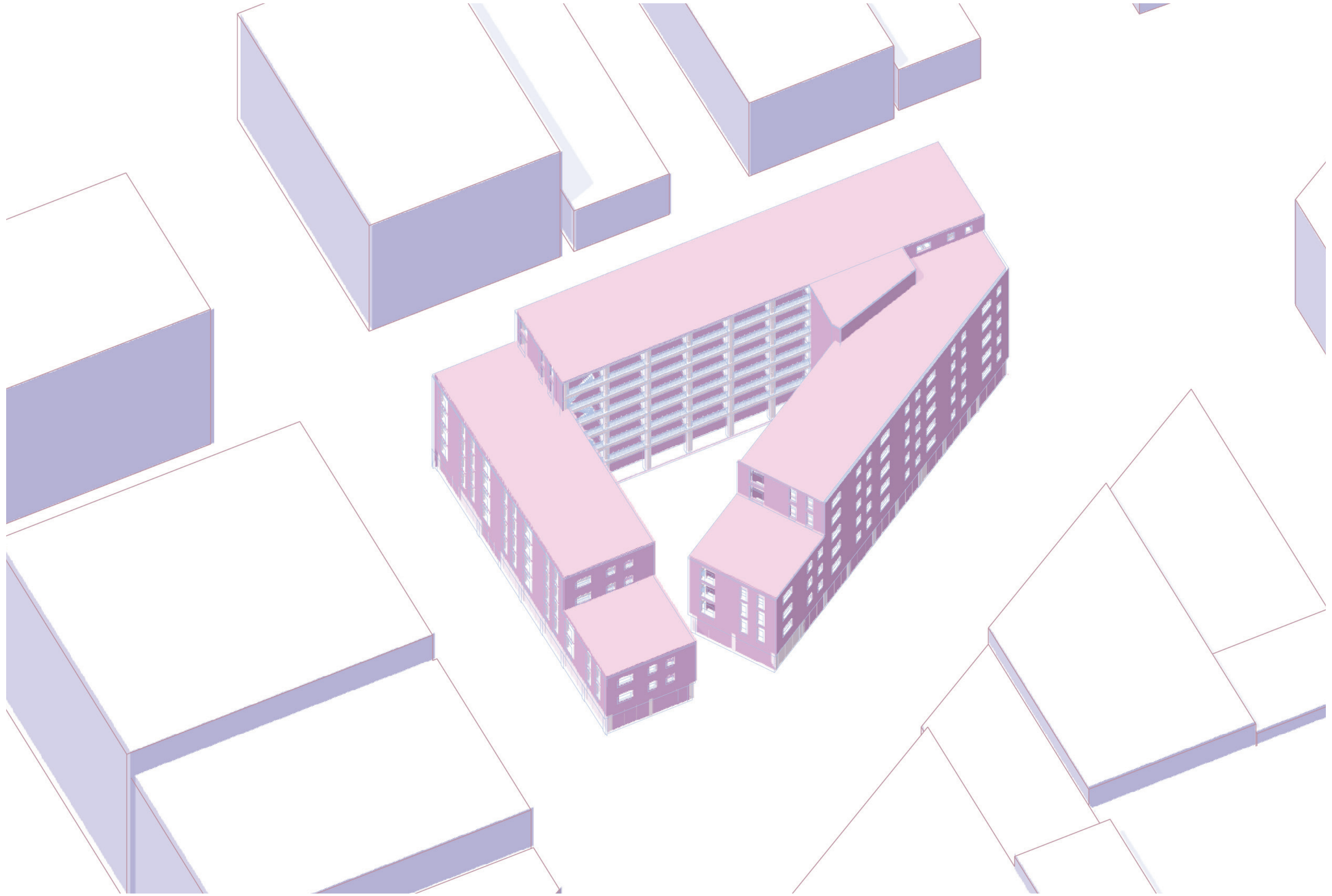



a
0 5 10 20 40
section a

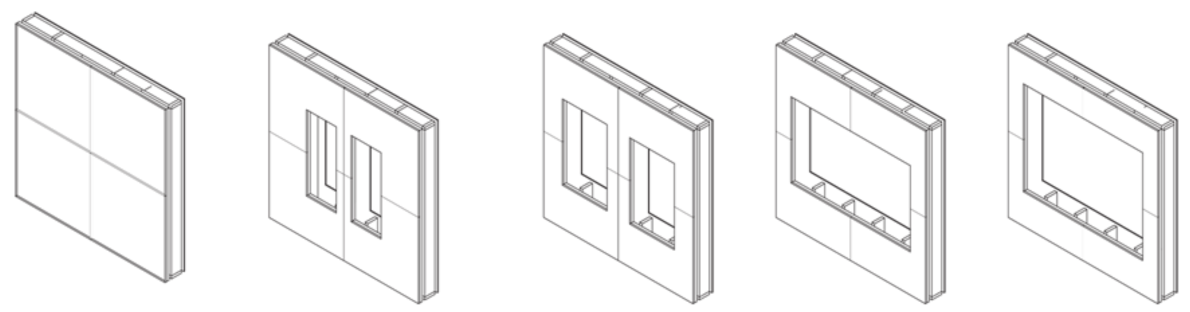
Plans / Sections / Axonometrics (cont.)

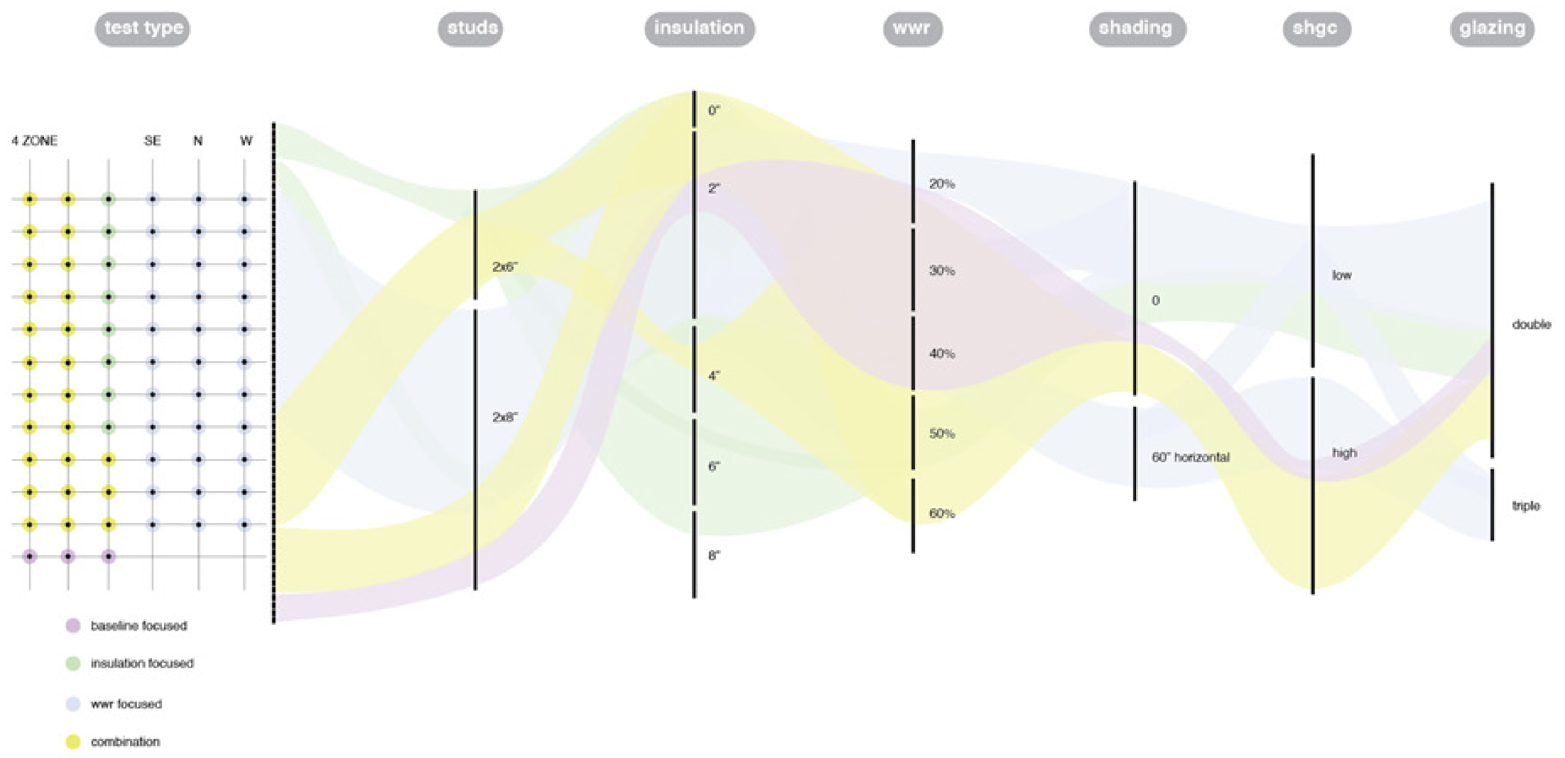


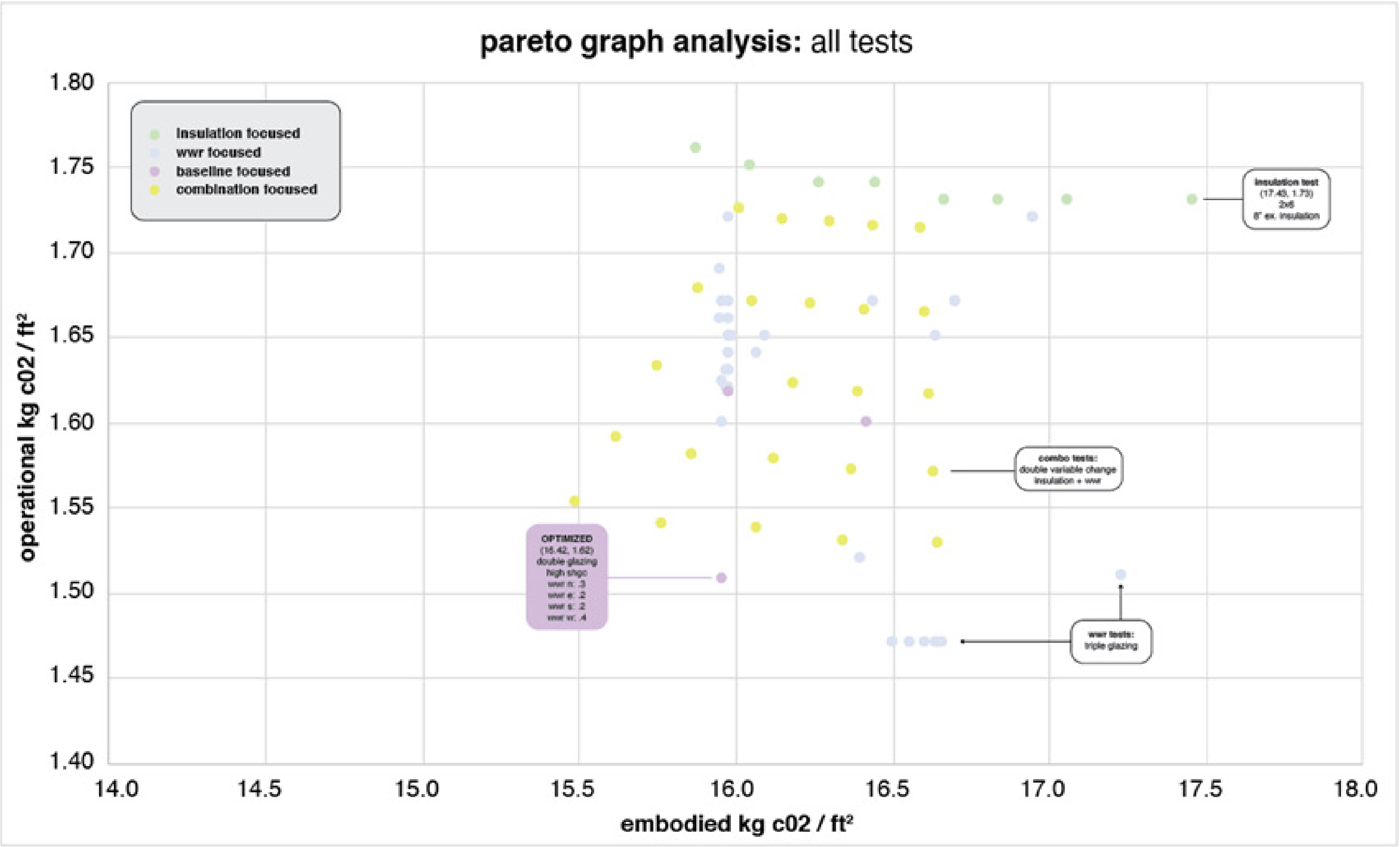




Simulation Data

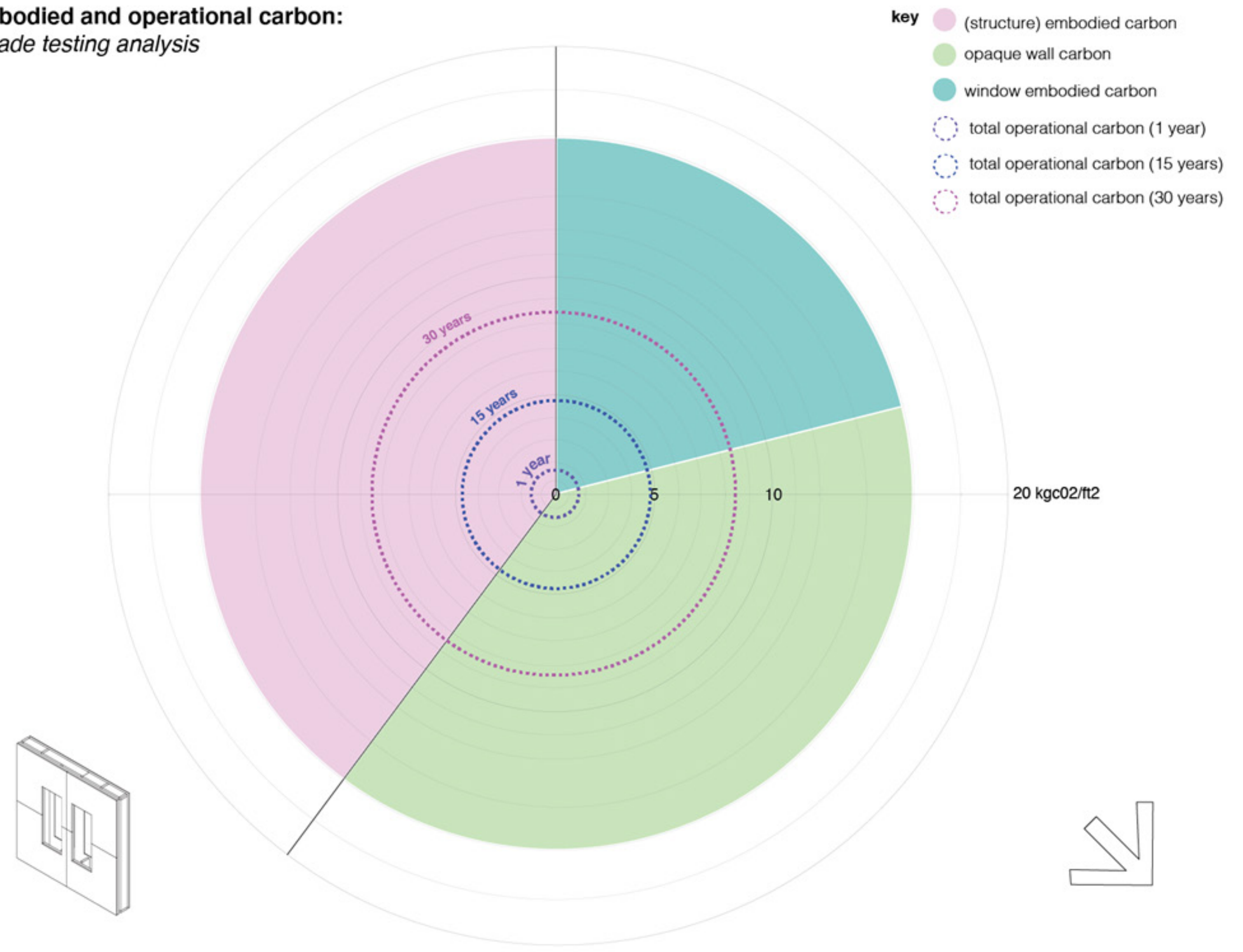




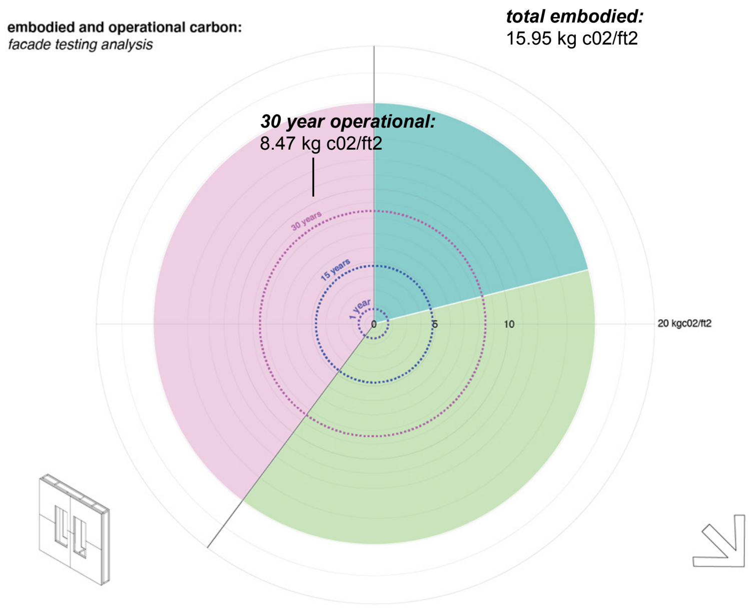


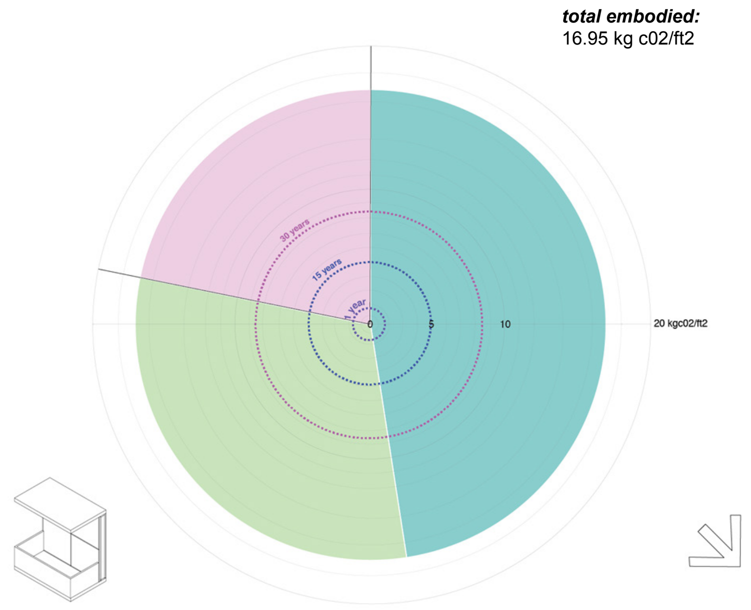
Results

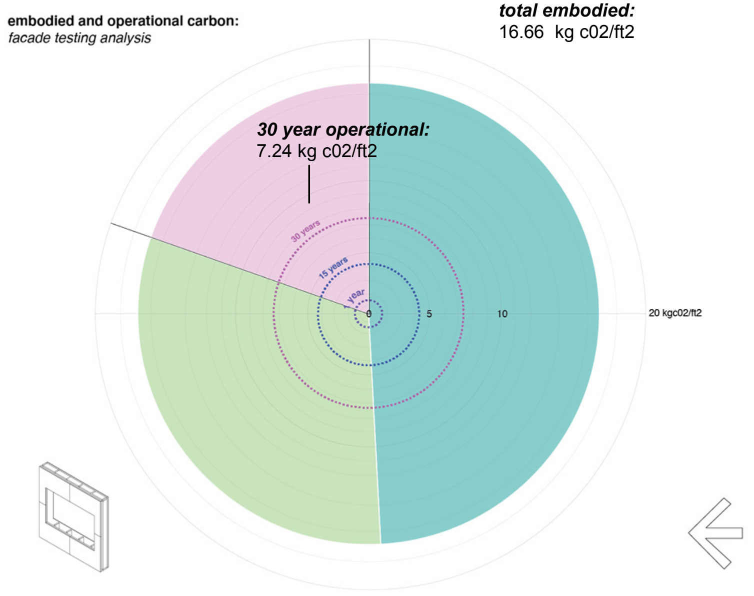
embodied and operational carbon:
facade testing analysis

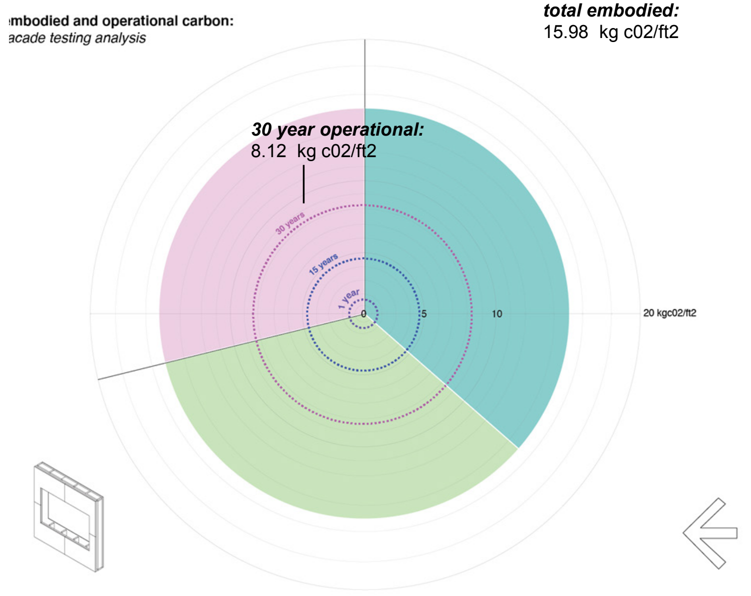


+1 kg c02/ft2



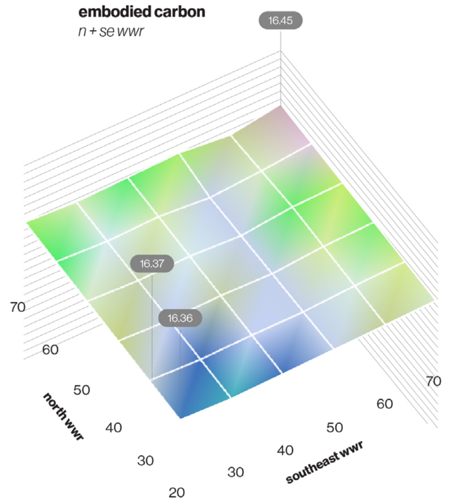


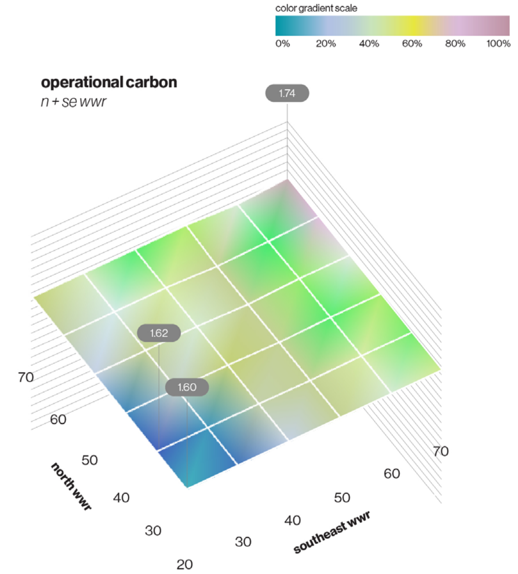


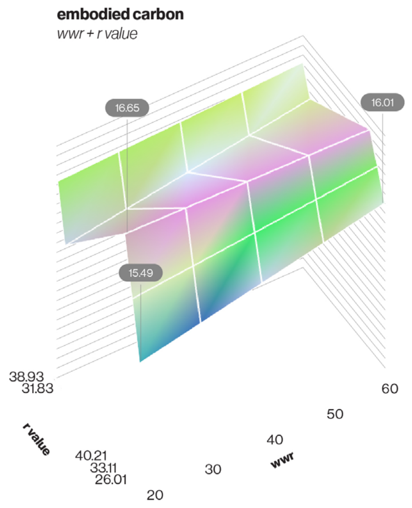


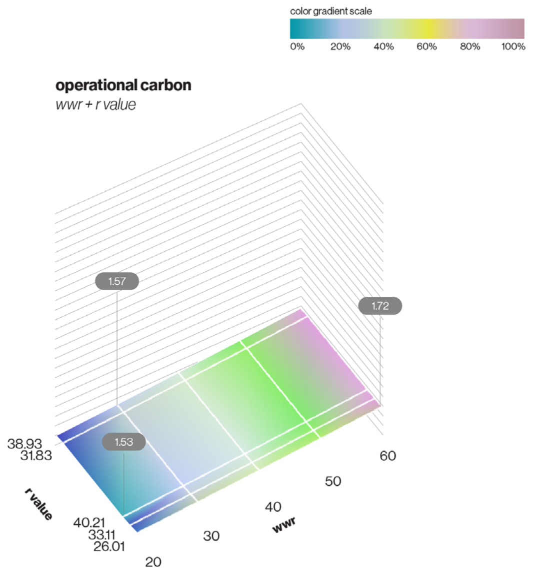
+triple glazing

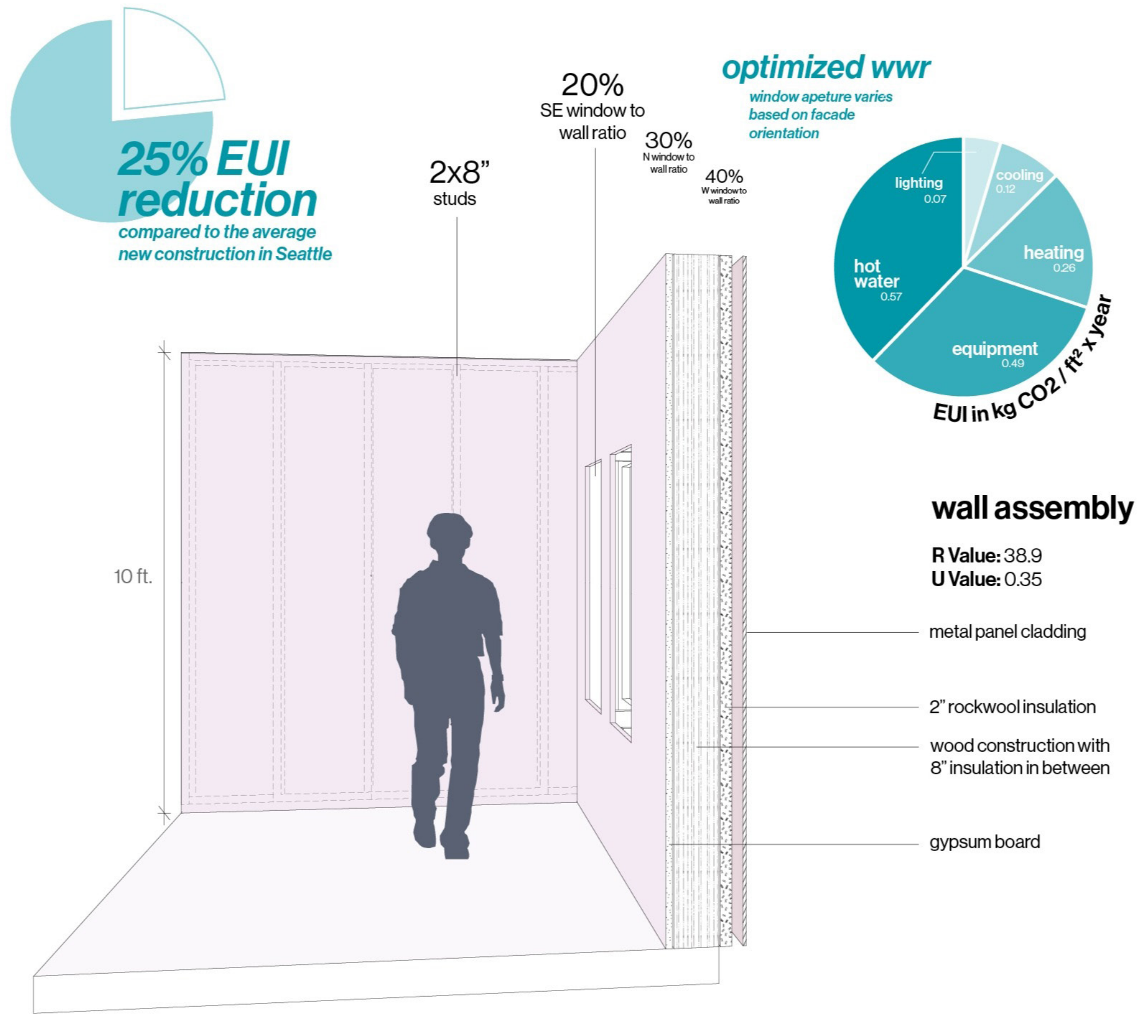
Infographics

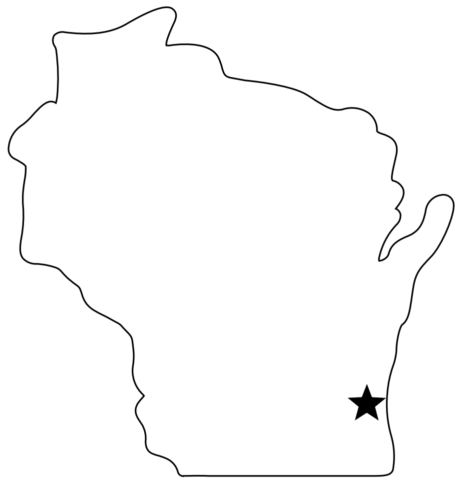












MILWAUKEE

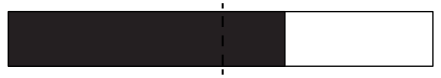
WISCONSIN

310 W. Freshwater Way

- IECC Climate Zone 6
- IECC Moisture Regime A
- Cold
- Humid

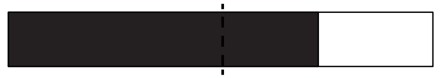
43.0296397N, 87.9151256W

Grid Carbon Intensity



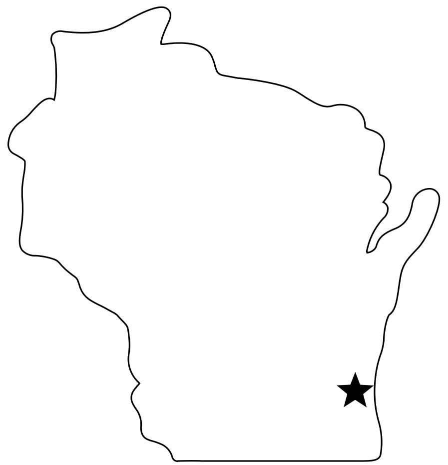
559
gCO2/kWh

CLT Supply Chain Carbon Intensity



227
kgCO2/m3

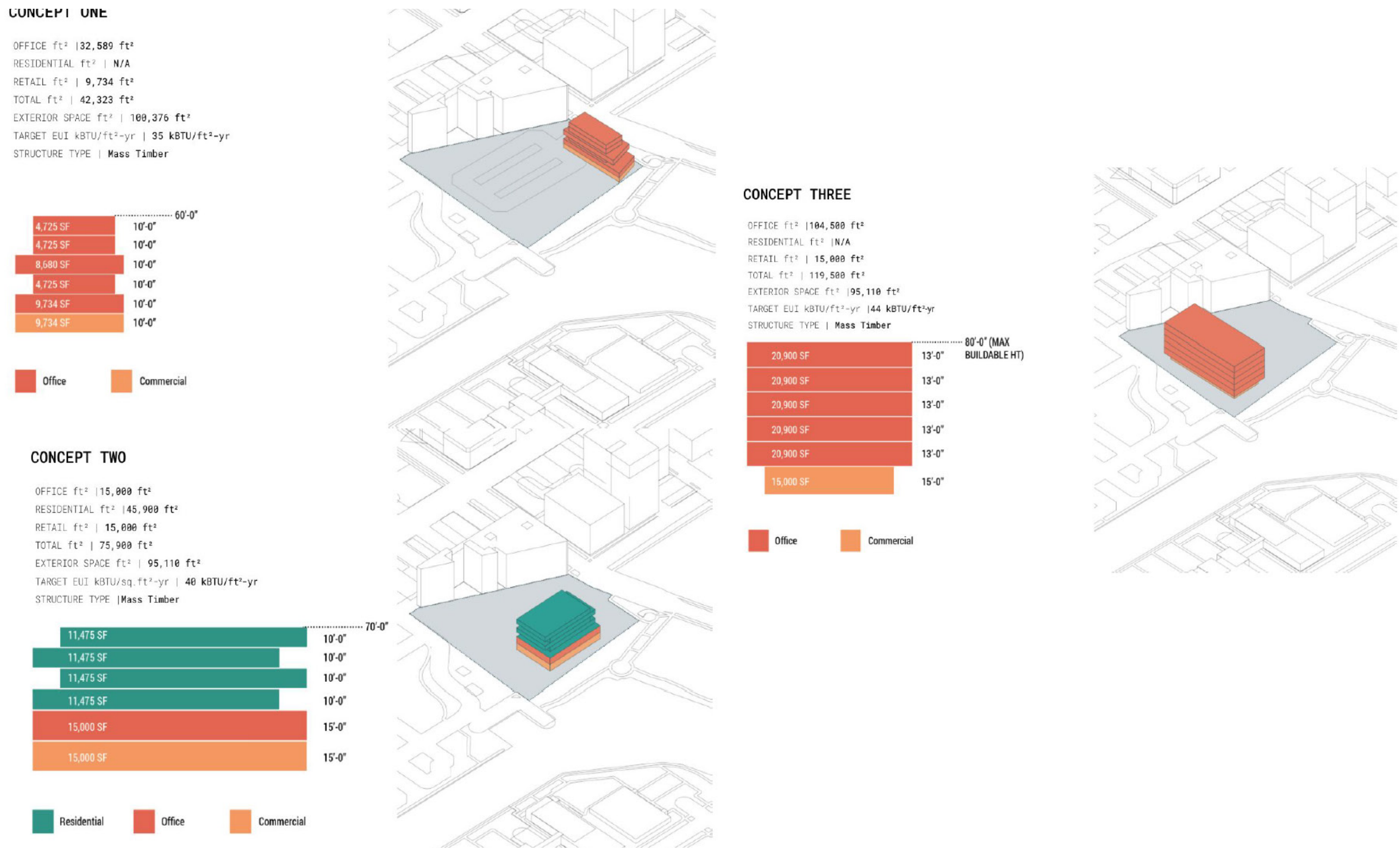
Image courtesy of Wei Zeng via https://unsplash.com/photos/6KffRaLsClk

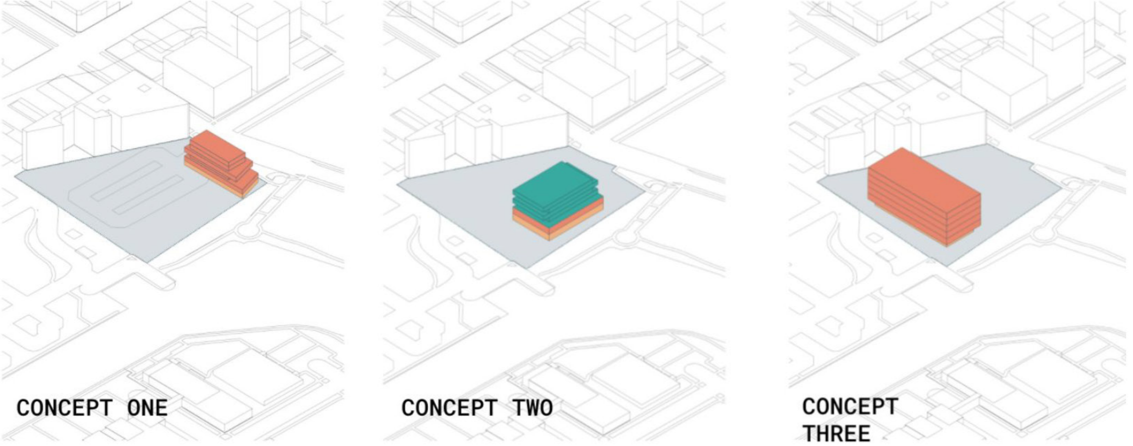


Halina Eve Murphy
+
Rebecca Isnardi
+
Anna Marie Murphy

310 W. Freshwater Way
Milwaukee, Wisconsin

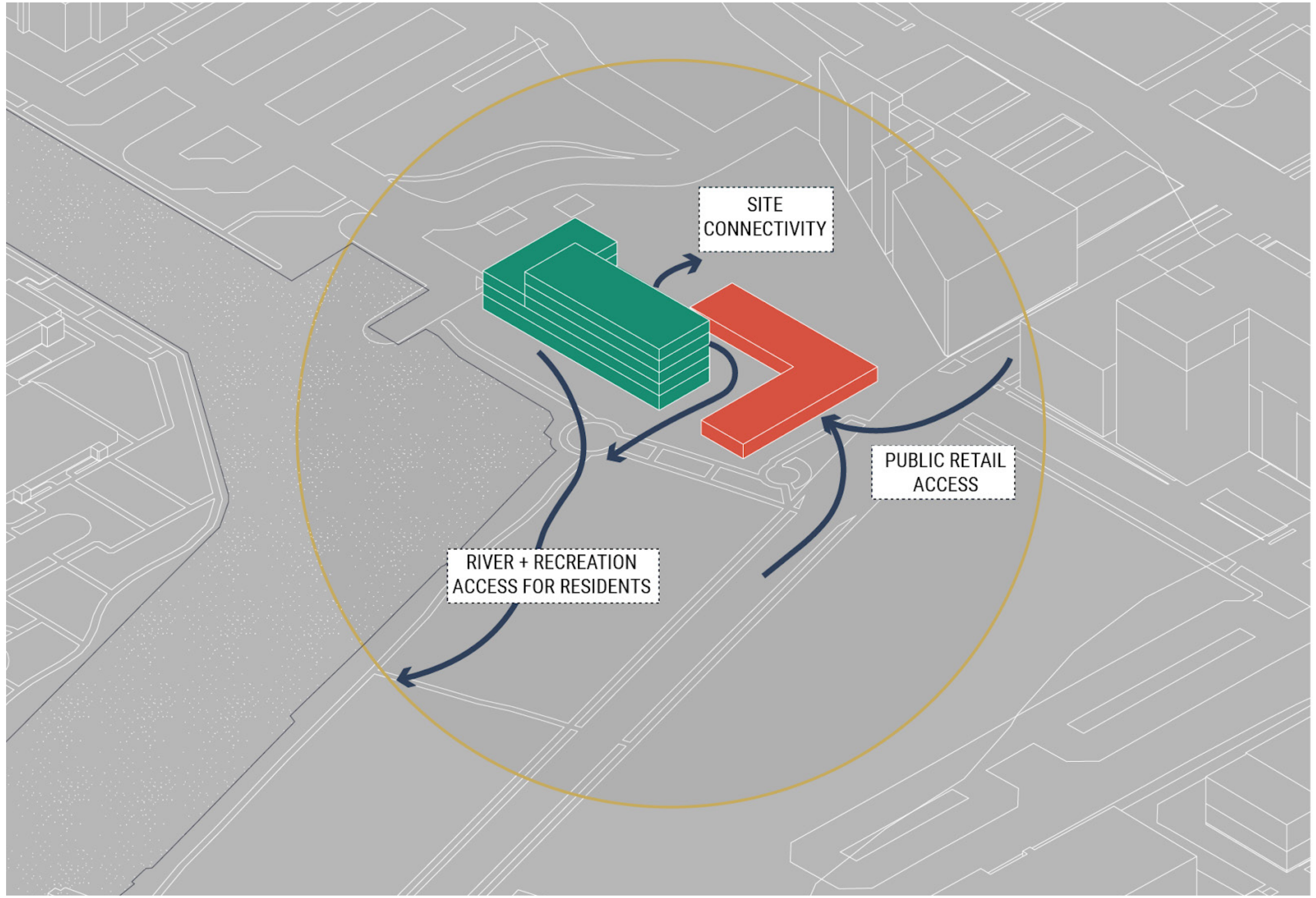
Programming / Massing

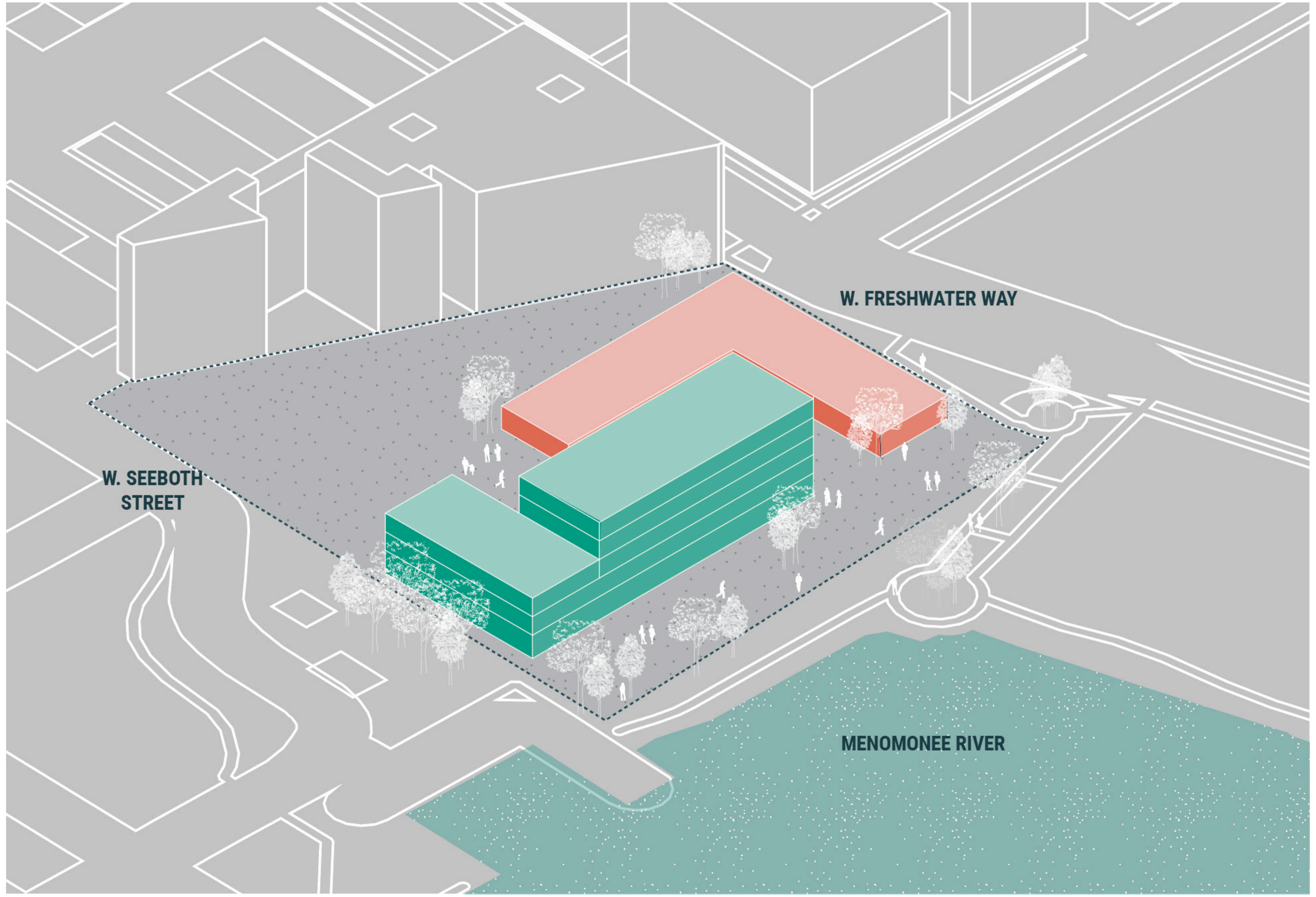


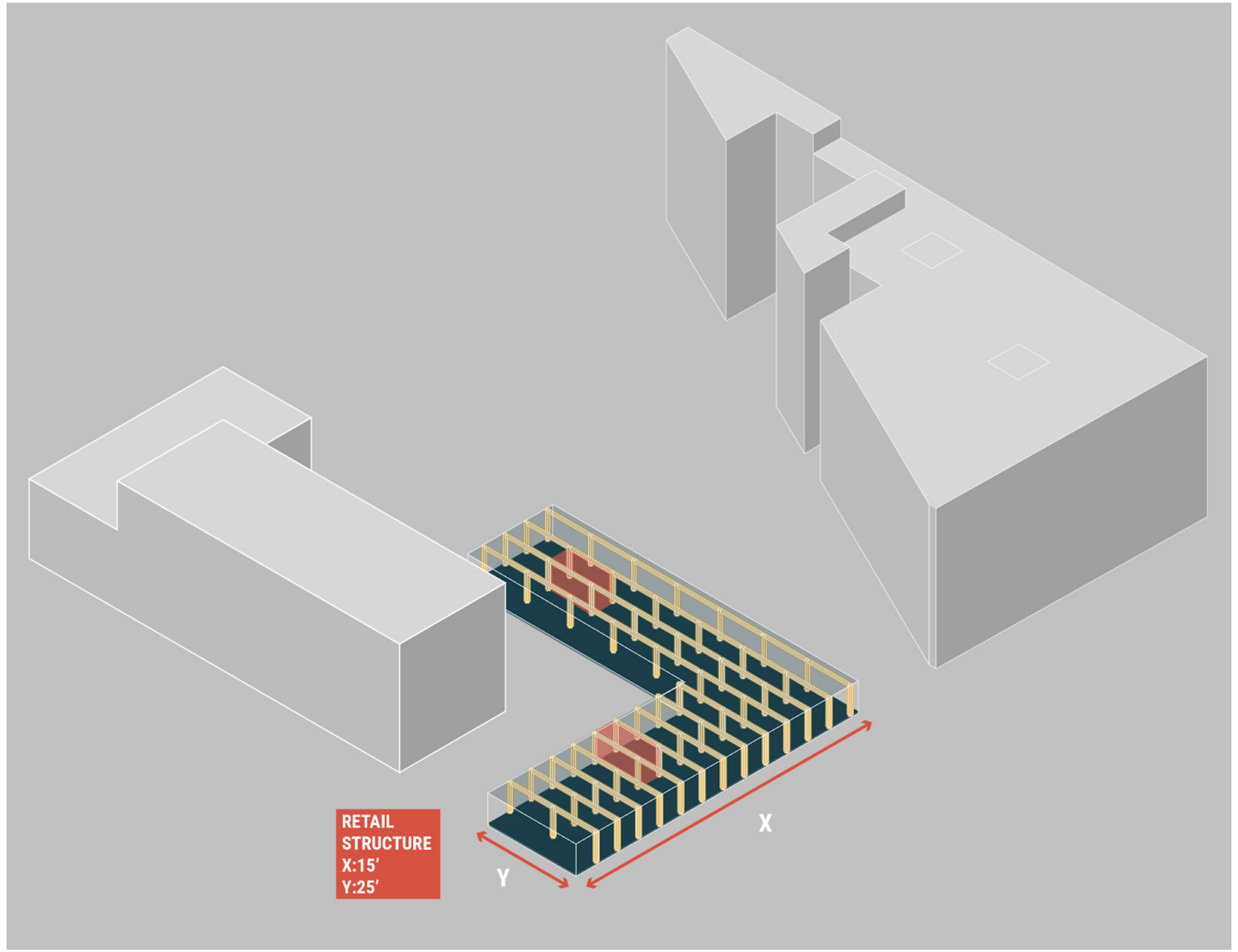


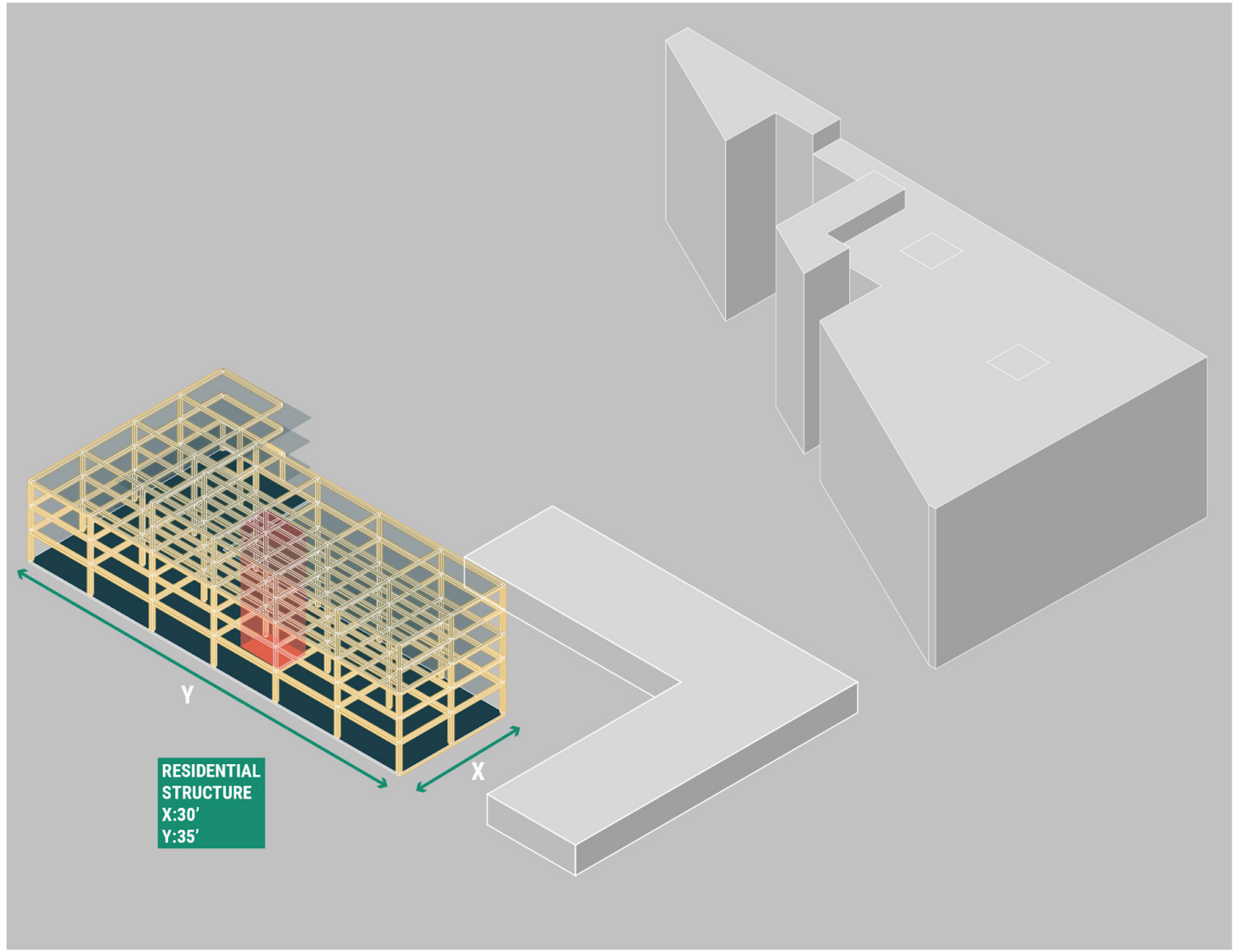
	CONCEPT ONE	CONCEPT TWO	CONCEPT THREE
Embodied carbon	710,146 kg C02e/ft²-yr	1,112,728.34 kg C02e/ft²-yr	1,734,941.55 kg C02e/ft²-yr
Operational carbon	810,946 kg C02e/ft²-yr	492,406 kg C02e/ft²-yr	852,791 kg C02e/ft²-yr
Carbon intensity of site electricity	1232.987 lb/MWh	1232.987 lb/MWh	1232.987 lb/MWh
Total site renewable energy potential	25.8 kBtu/ft²-yr	43.1 kBtu/ft²-yr	32.3 kBtu/ft²-yr
Solar potential	8.6 kBtu/ft²-yr	11.0 kBtu/ft²-yr	12.7 kBtu/ft²-yr
Total Square Footage	42,323 ft²	75,900 ft²	119,500 ft²

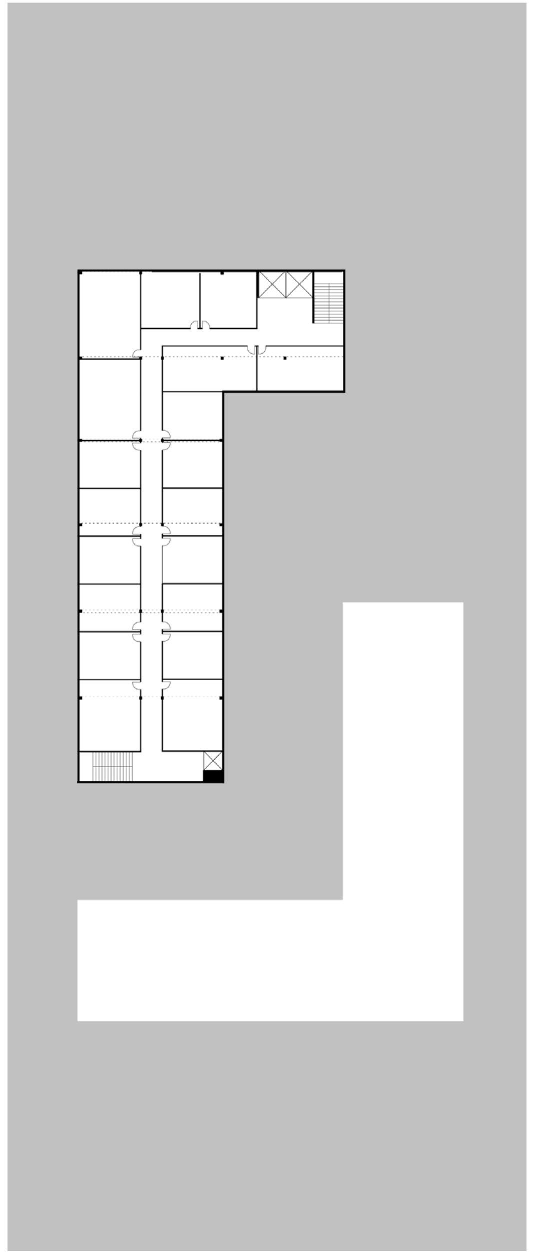
6

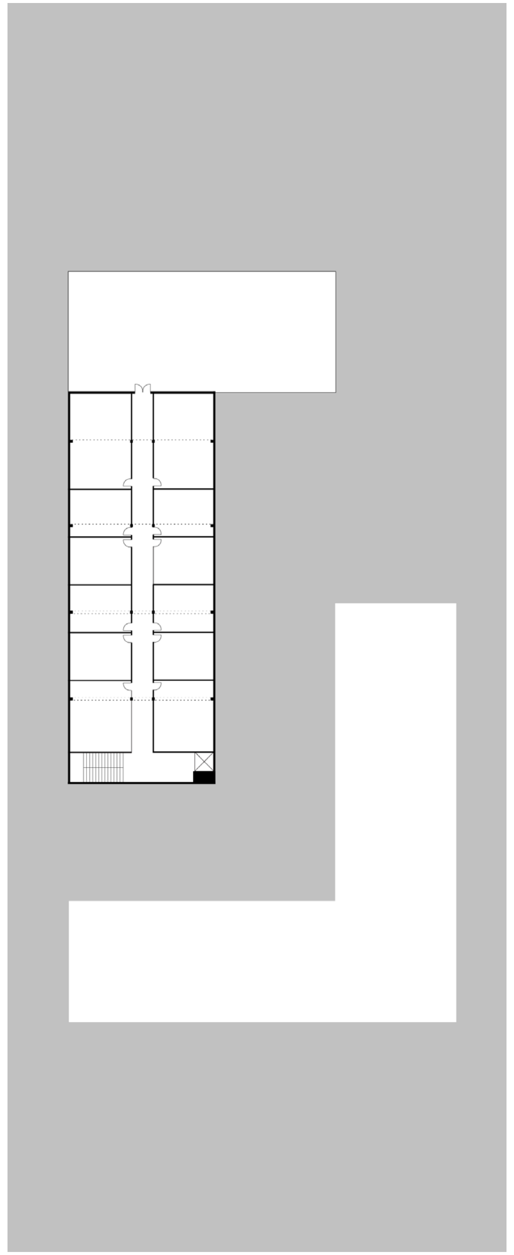

SITE
CONNECTIVITY
PUBLIC RETAIL
ACCESS
RIVER + RECREATION
ACCESS FOR RESIDENTS

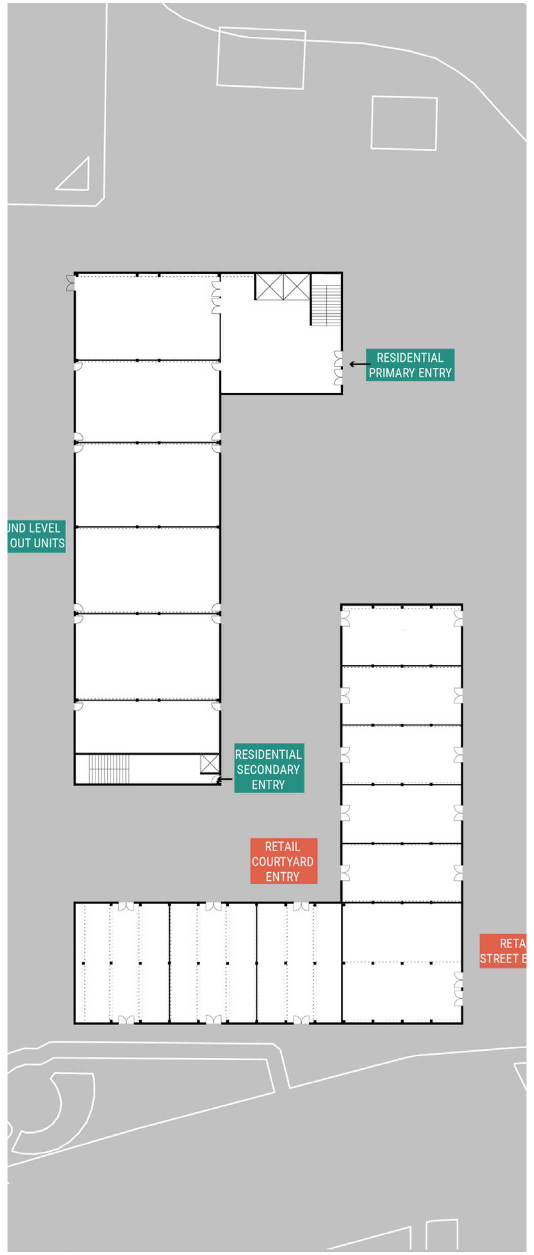

W. FRESHWATER WAY
W. SEEBOTH
STREET
MENOMONEE RIVER


RETAIL
STRUCTURE
X:15'
Y:25'
Y
X


Y
X
RESIDENTIAL
STRUCTURE
X:30'
Y:35'

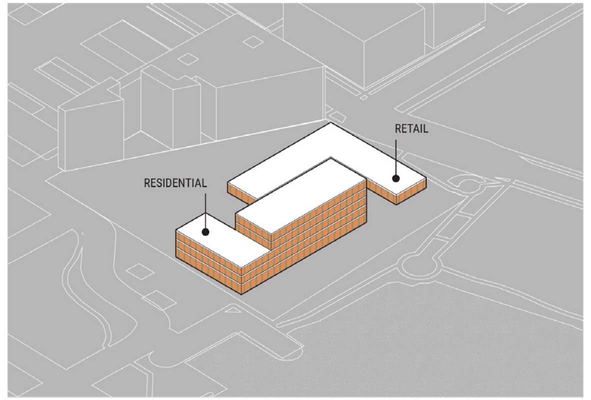


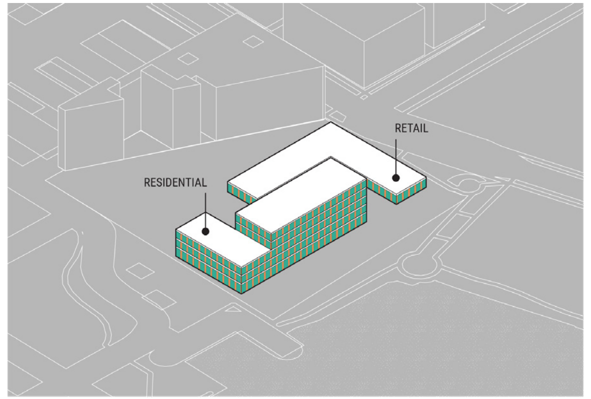



RESIDENTIAL
PRIMARY ENTRY
RESIDENTIAL
SECONDARY
ENTRY
RETAIL
COURTYARD
ENTRY

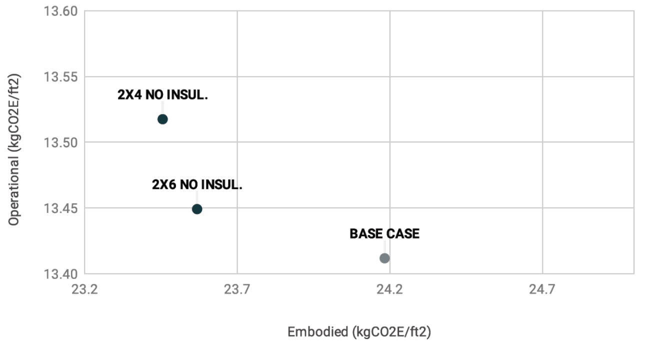

#1
#2
EAST + WEST SITE SECTION
NORTH + SOUTH SITE SECTION

Simulation Data

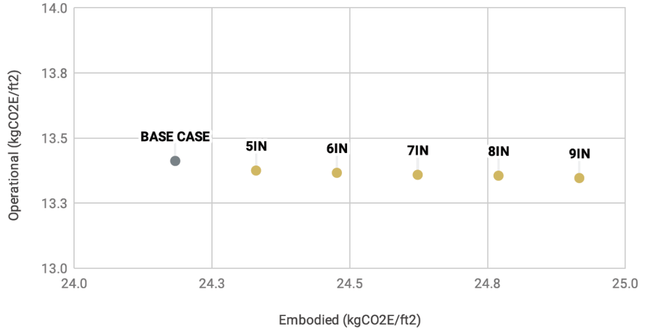




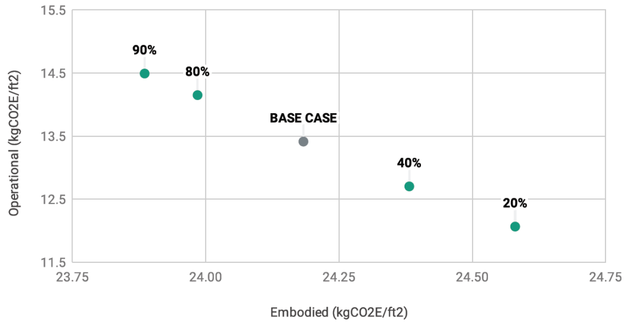
RESIDENTIAL - No Insulation



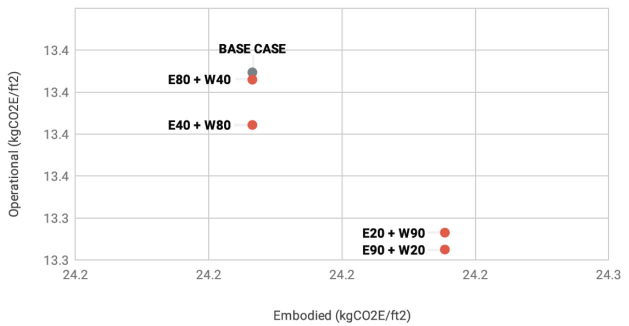
RESIDENTIAL - Insulation



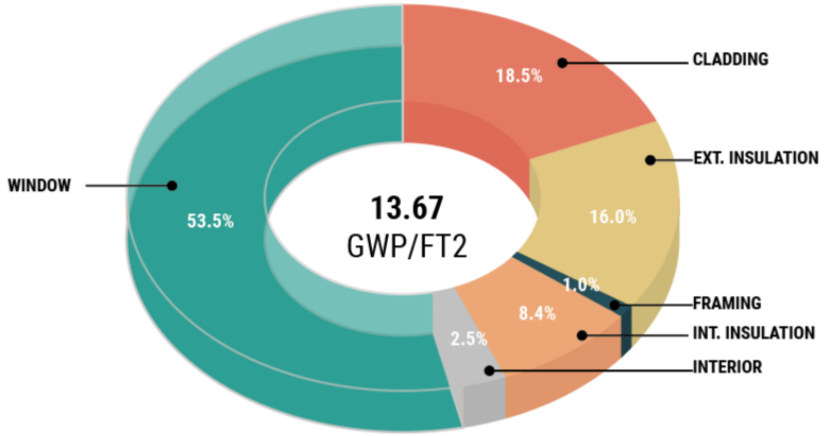
RESIDENTIAL- WWR

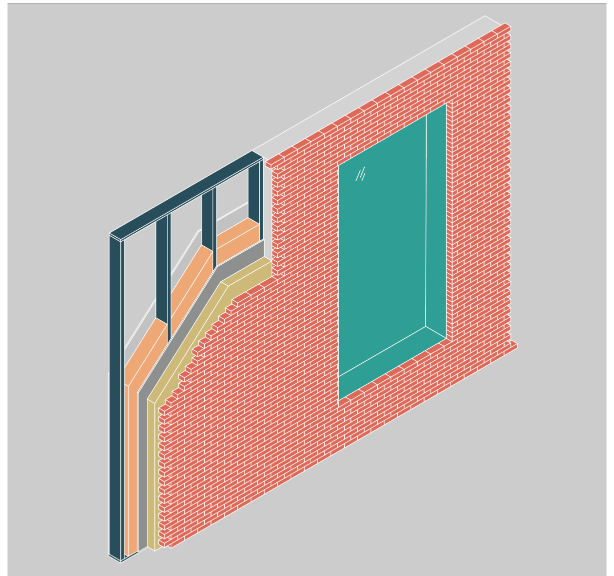


RESIDENTIAL - E+W WWR

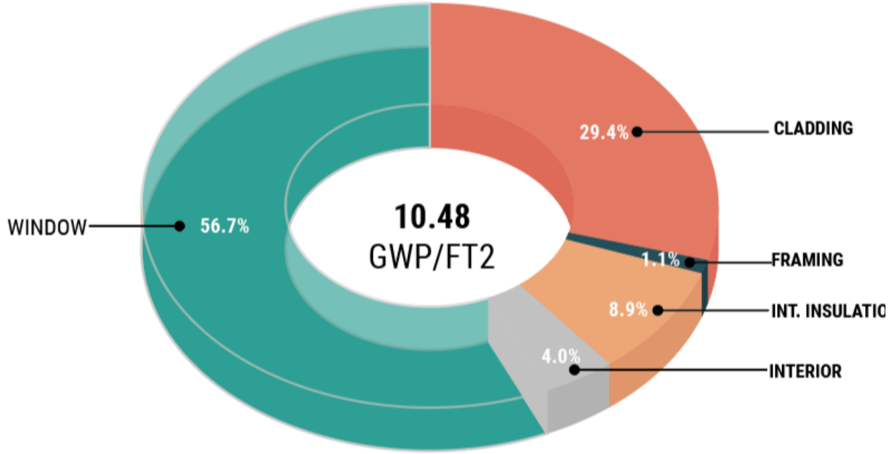


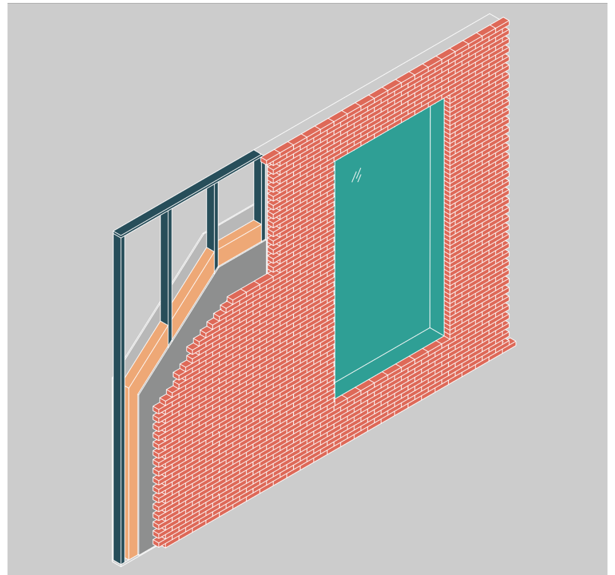
EMBODIED (CO2e)
BASE CASE
2X6 STUDS
4" EXT. INSULATION





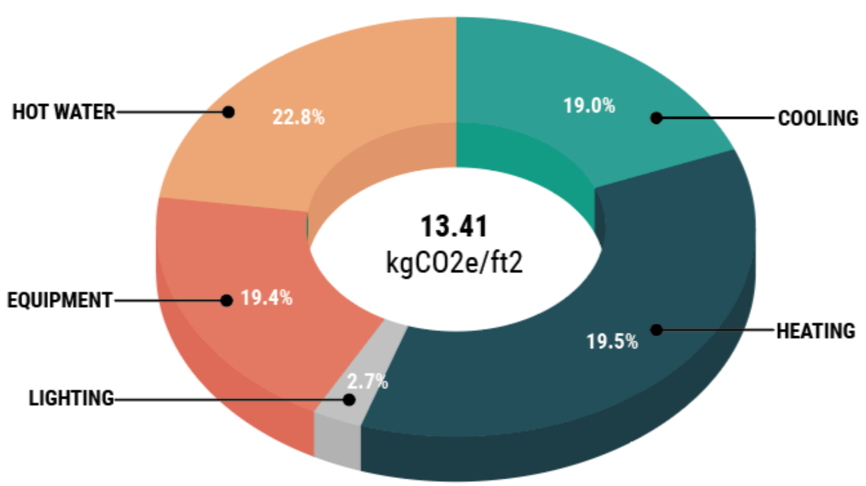
EMBODIED (CO2e)
2x4 WOOD STUD
NO EXT. INSULATION



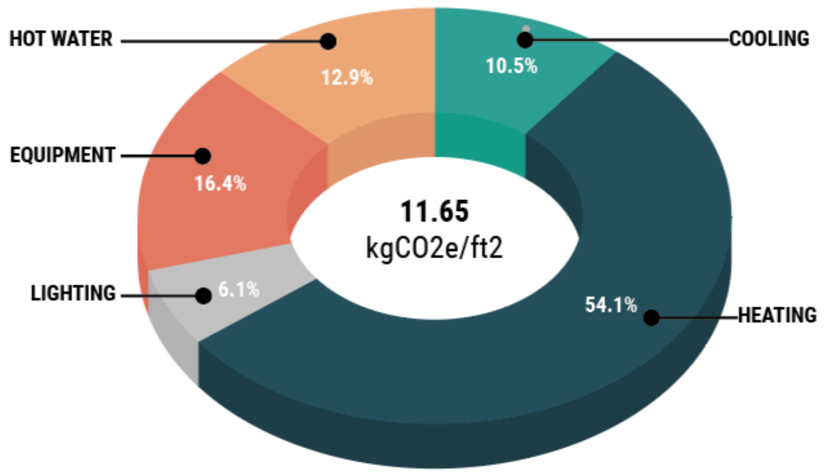


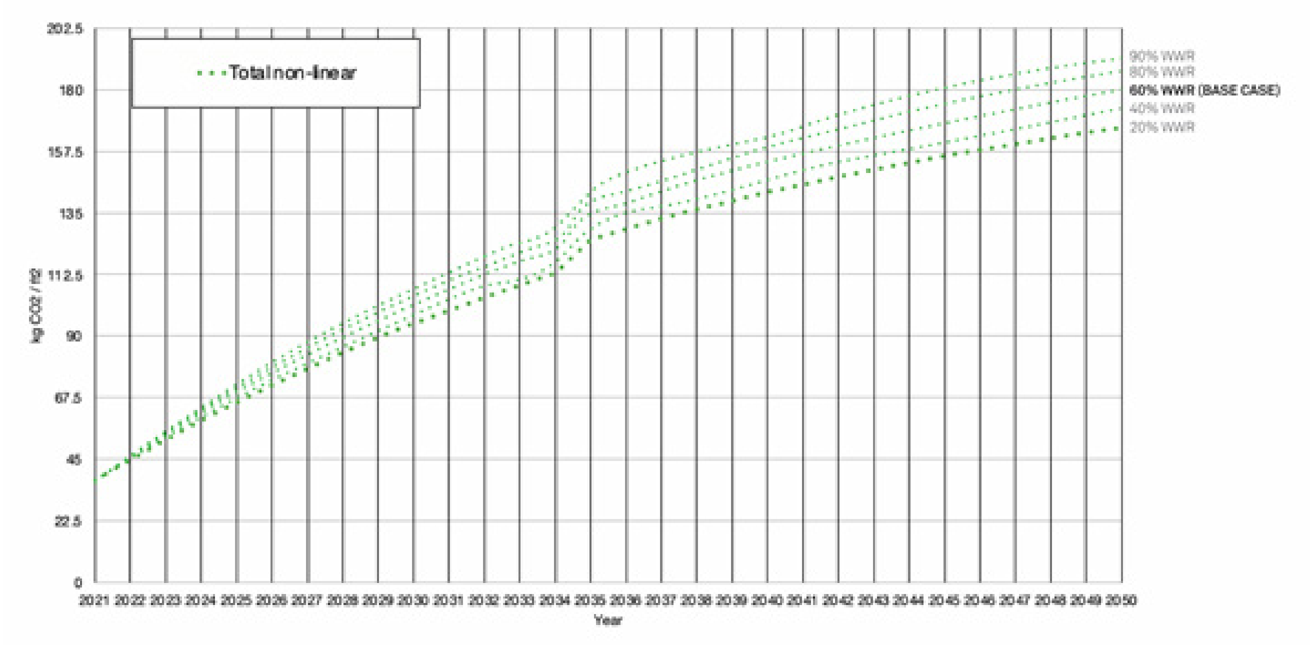
Results

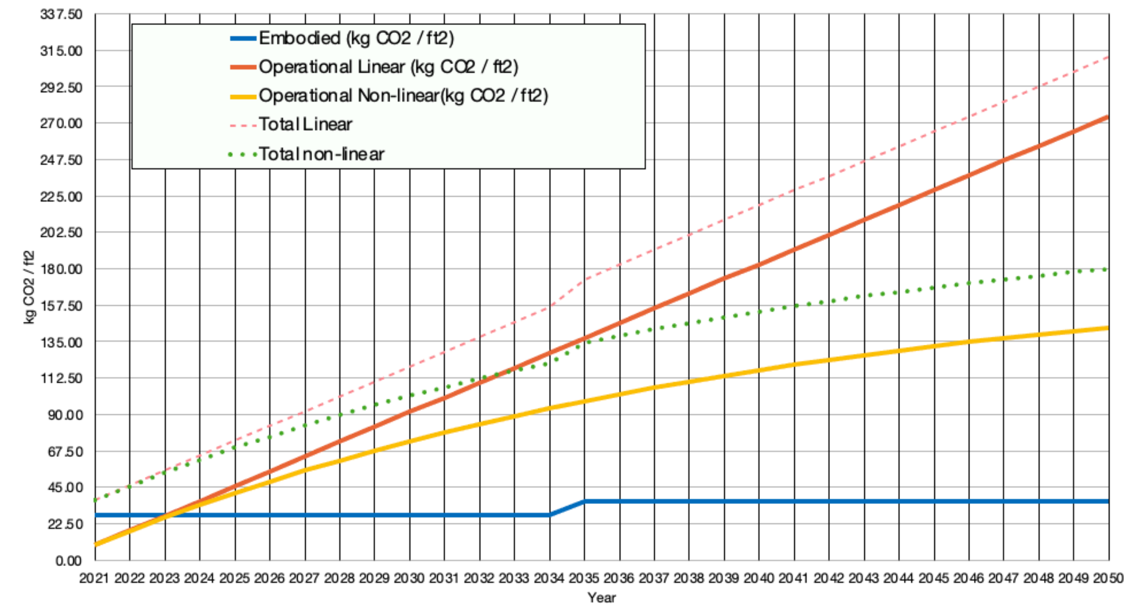
RESIDENTIAL | OPERATIONAL CARBON kBtu/sf/yr



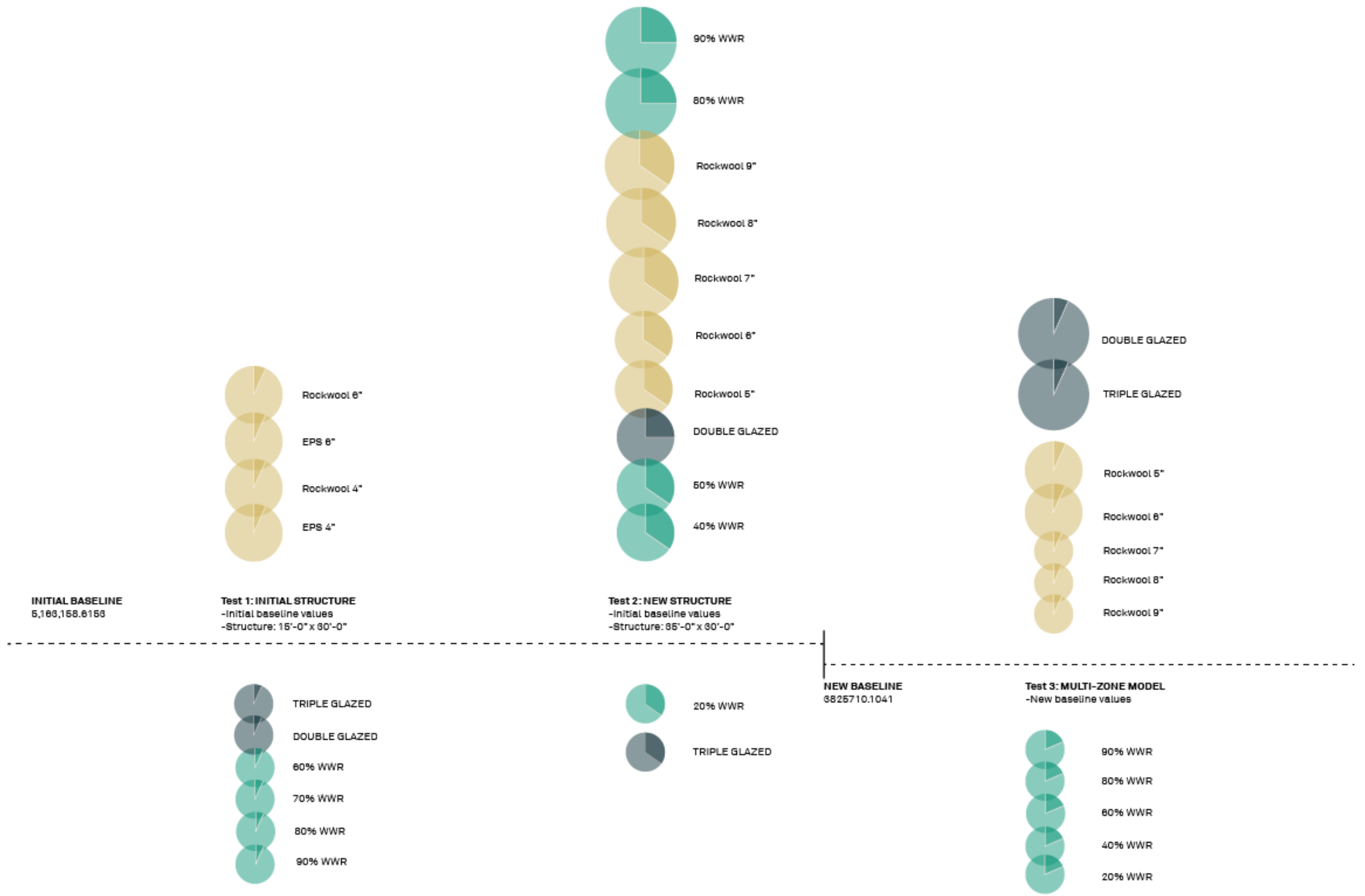
RETAIL | OPERATIONAL CARBON kBtu/sf/yr

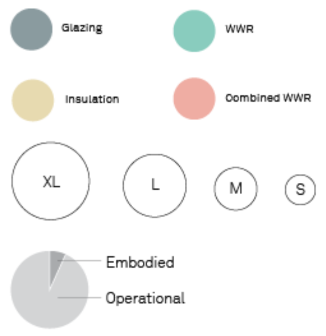


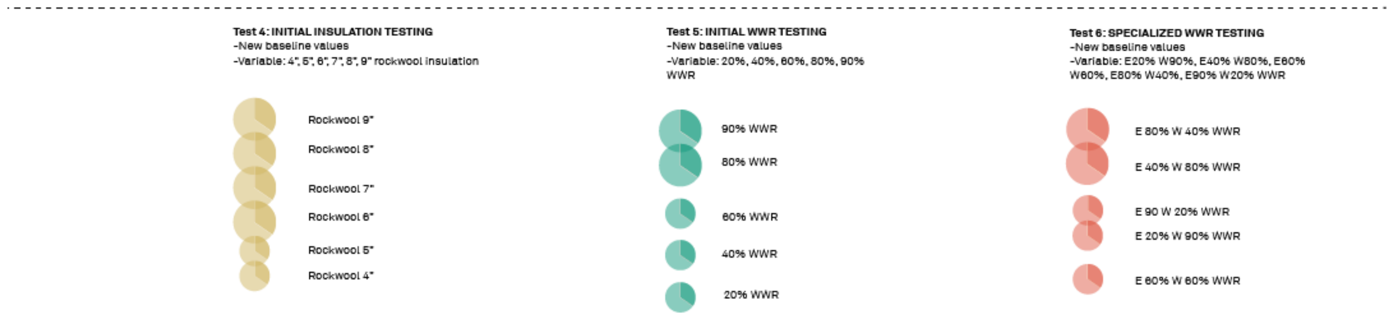


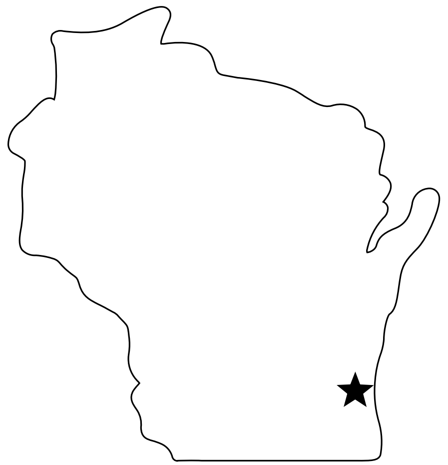


Infographics









Skyler Johnson
+
Alaena Gavins

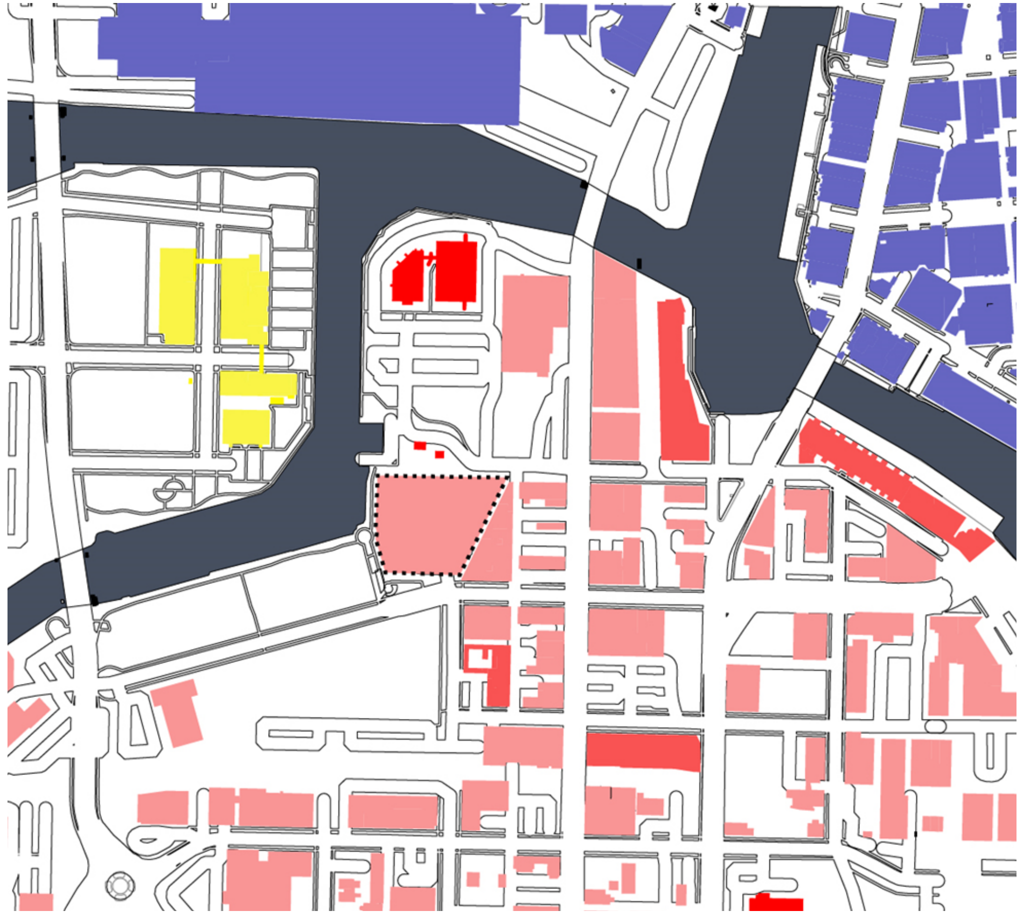
310 W. Freshwater Way
Milwaukee, Wisconsin

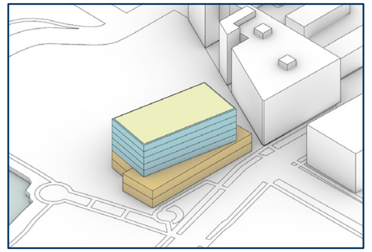
Key

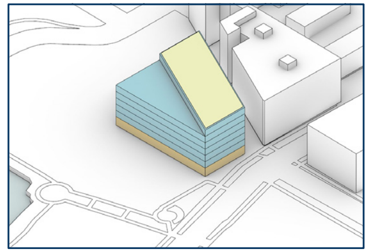
Industrial
- Heavy (IH)
- Commercial (IC)
- Mixed (IM)
- Light (IL2)

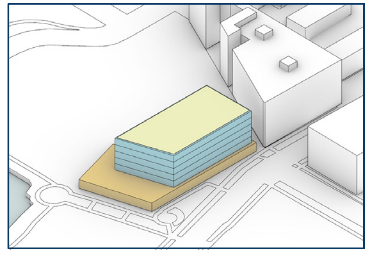
Commercial
- Central Buisness (C9G)

Special
- Redevelopment (RED)

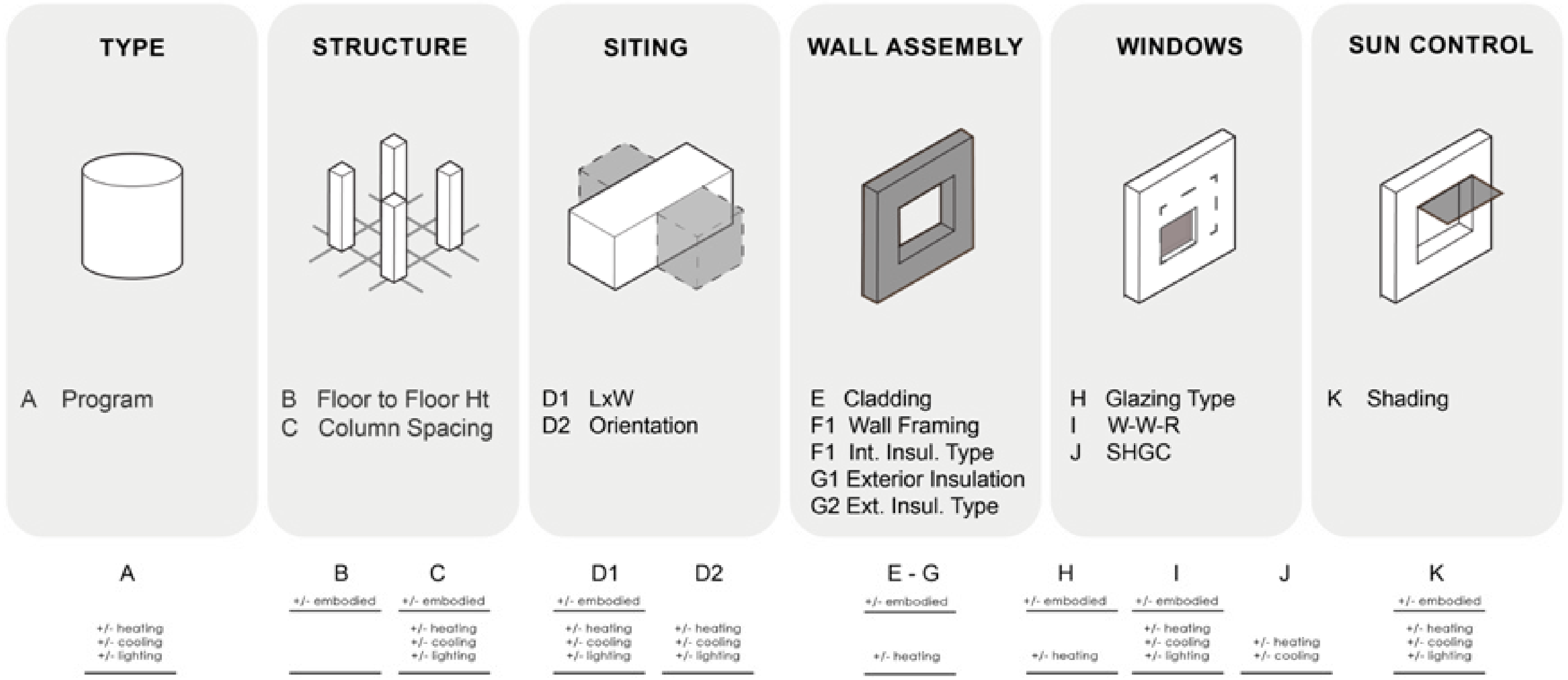


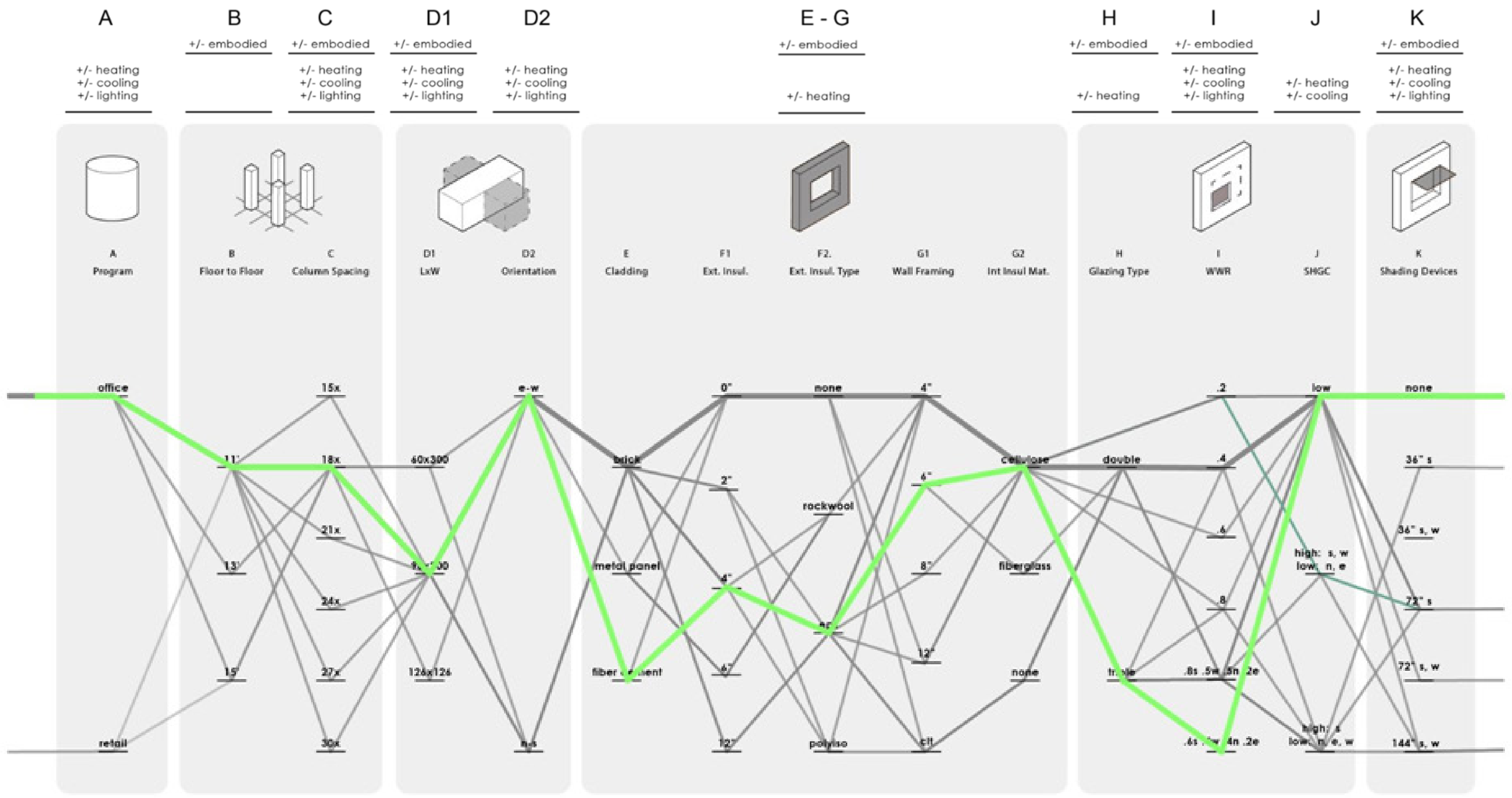


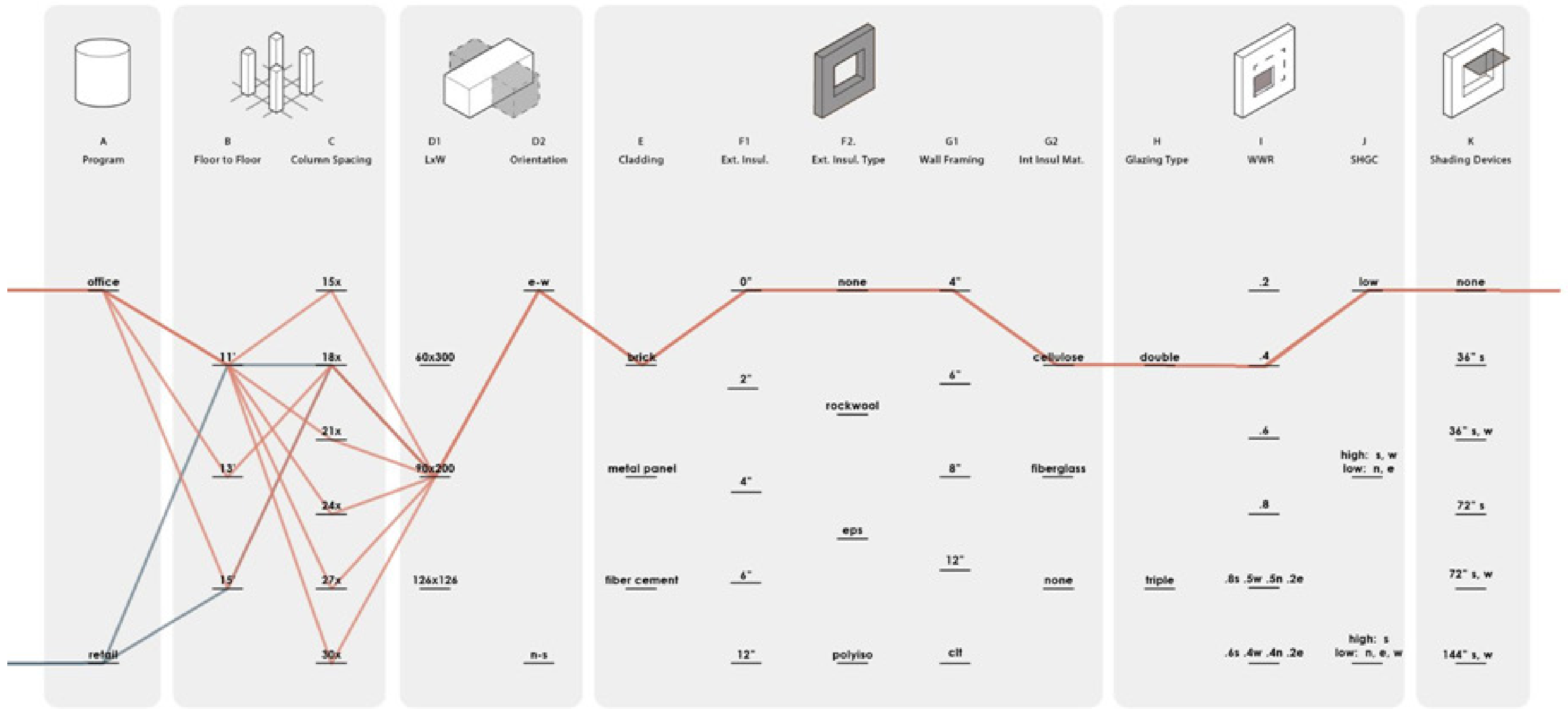




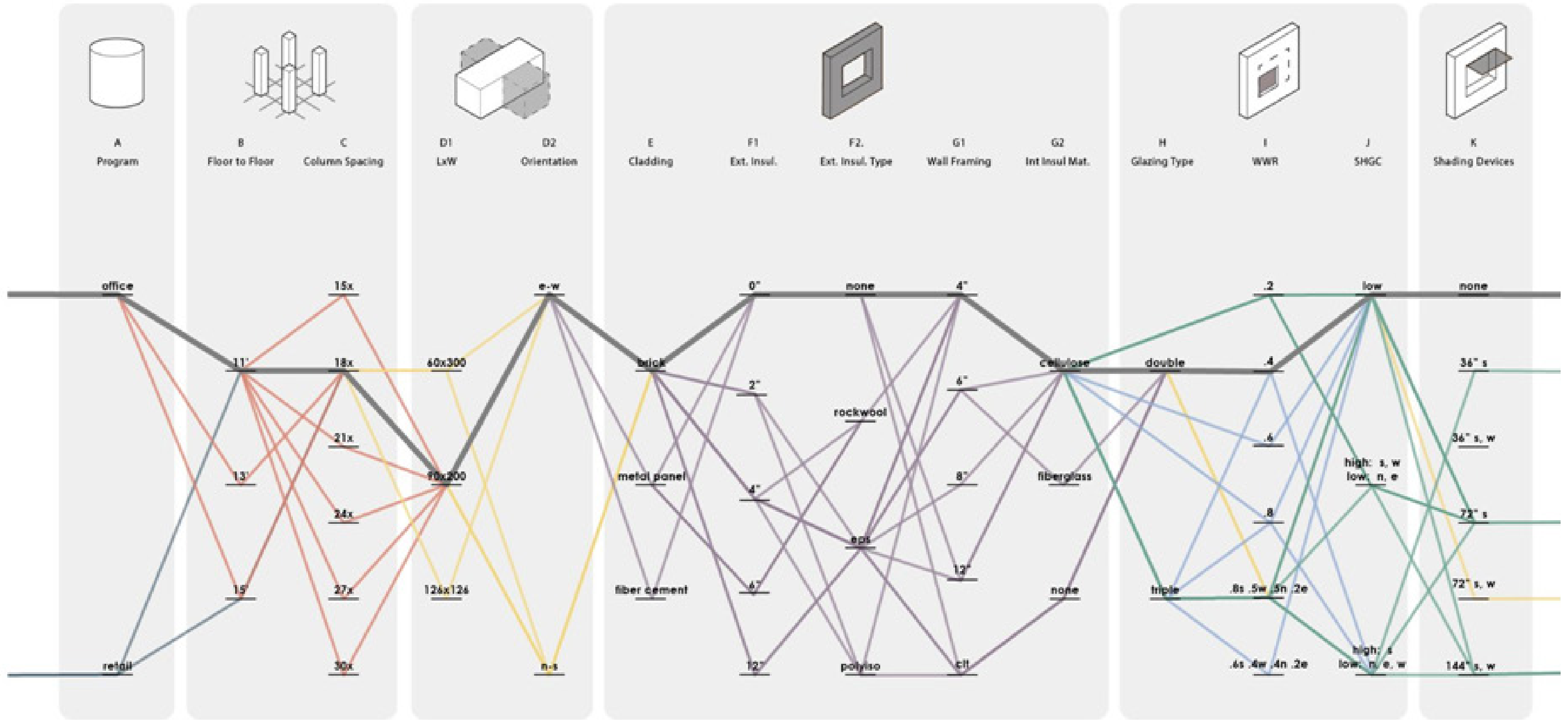
	Option 1 Operational	Option 2 Embodied	Option 3 Experience
Gross Square Footage (gsf)	86,746	148,326	102,091
Calculated EUI (kBtu/ft²-yr)	**31**	**34**	**31**
Annual Operational Carbon Output (kg CO2e/yr)	436,147	817,934	562,974
Embodied Carbon per sf (kgCO2e/ft²)	**14**	**13.09**	**13.28**
Total Embodied Carbon Output (kgCO2e)	1,214,484	1,941,077	1,355,629
PV Capture Rate (kBtu/ft²-yr)	**10.99**	**7.22**	**11.29**
PV Capture Total (kWh/yr)	3,287,918	3,698,908	3,940,905


TYPE
A Program
STRUCTURE
B Floor to Floor Ht
C Column Spacing
SITING
D1 LxW
D2 Orientation
WALL ASSEMBLY
E Cladding
F1 Wall Framing
F1 Int. Insul. Type
G1 Exterior Insulation
G2 Ext. Insul. Type
WINDOWS
H Glazing Type
I W-W-R
J SHGC
SUN CONTROL
K Shading
A
+/- heating
+/- cooling
+/- lighting
B
+/- embodied
C
+/- embodied
+/- heating
+/- cooling
+/- lighting
D1
+/- embodied
+/- heating
+/- cooling
+/- lighting
D2
+/- heating
+/- cooling
+/- lighting
E - G
+/- embodied
+/- heating
H
+/- embodied
+/- heating
I
+/- embodied
+/- heating
+/- cooling
+/- lighting
J
+/- heating
+/- cooling
K
+/- embodied
+/- heating
+/- cooling
+/- lighting


A
+/- heating
+/- cooling
+/- lighting
B
+/- embodied
C
+/- embodied
+/- heating
+/- cooling
+/- lighting
D1
+/- embodied
+/- heating
+/- cooling
+/- lighting
D2
+/- heating
+/- cooling
+/- lighting
E - G
+/- embodied
+/- heating
H
+/- embodied
+/- heating
I
+/- embodied
+/- heating
+/- cooling
+/- lighting
J
+/- heating
+/- cooling
K
+/- embodied
+/- heating
+/- cooling
+/- lighting
Program
Floor to Floor
Column Spacing
LxW
Orientation
Cladding
Ext. Insul.
Ext. Insul. Type
Wall Framing
Int Insul Mat.
Glazing Type
WWR
SHGC
Shading Devices
office
retail
15x
18x
21x
24x
27x
30x
60x300
126x126
e-w
n-s
brick
metal panel
0"
2"
4"
6"
12"
none
rockwool
polyiso
4"
6"
8"
12"
cellulose
fiberglass
none
double
triple
.2
.4
.6
.8
low
none
36" s
36" s, w
72" s
72" s, w
144" s, w

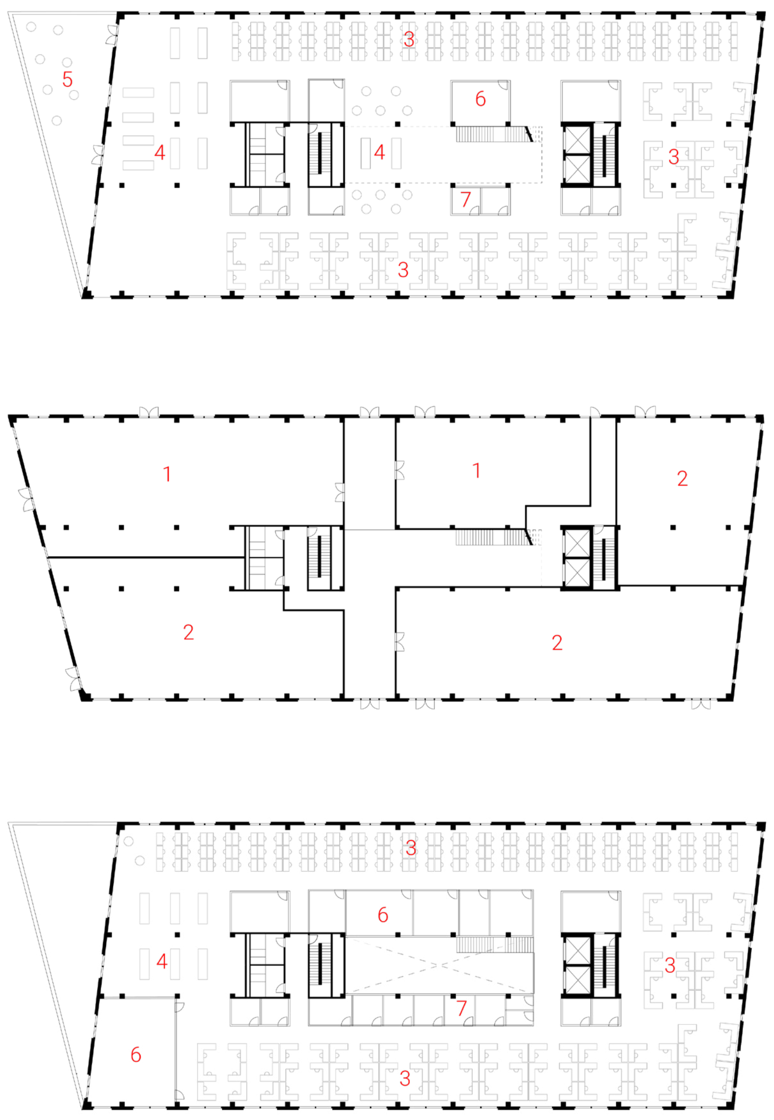


single variable tests

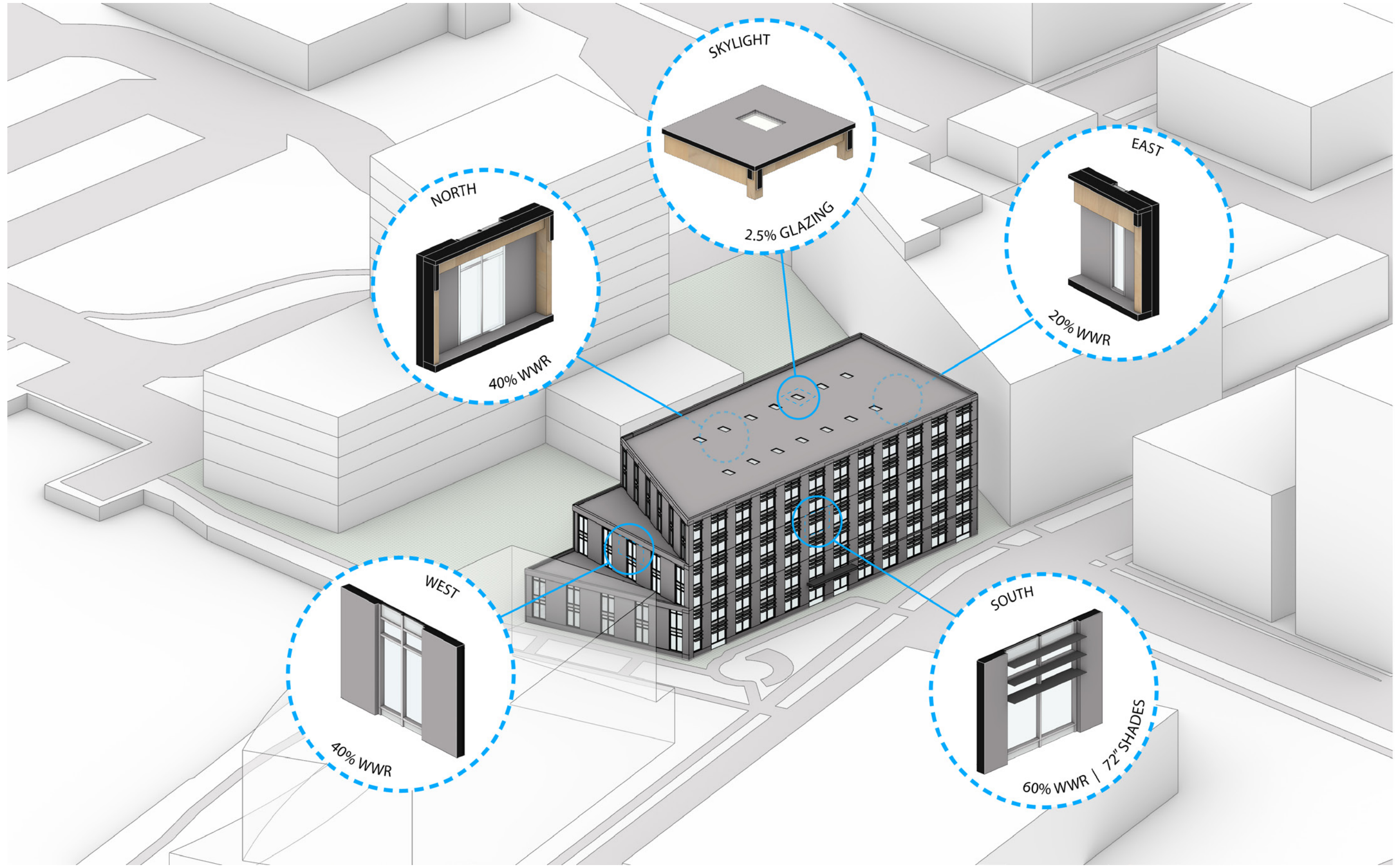


multi variable

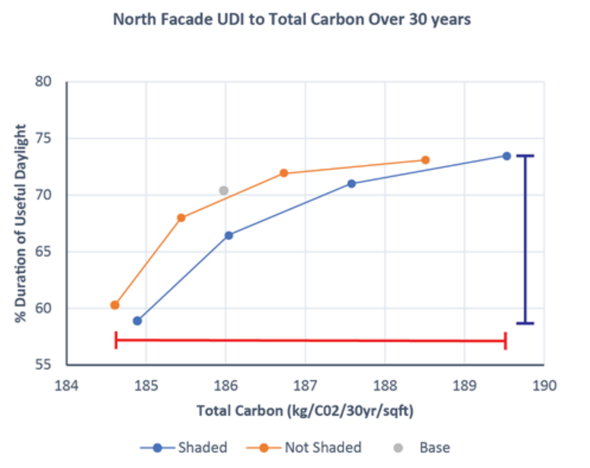
Plans / Sections / Axonometrics

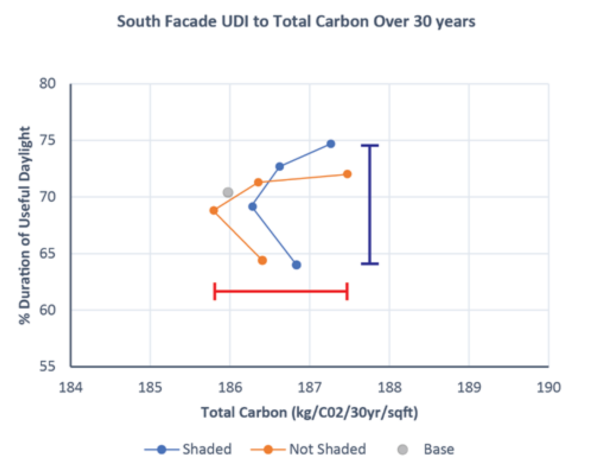


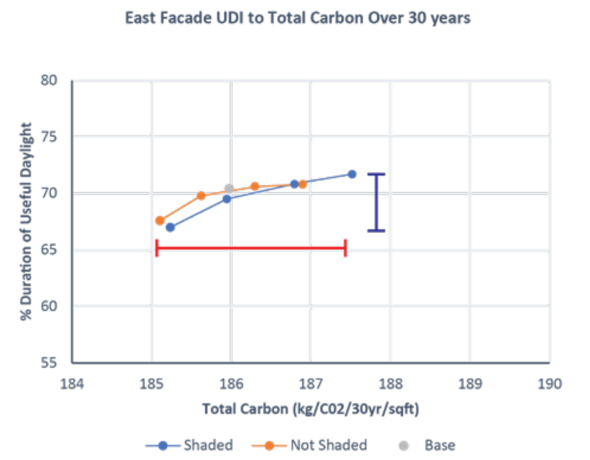
1. Food and beverage
2. Retail
3. Open office
4. Breakout space
5. Terrace
6. Meeting room, typ.
7. Private office, typ.

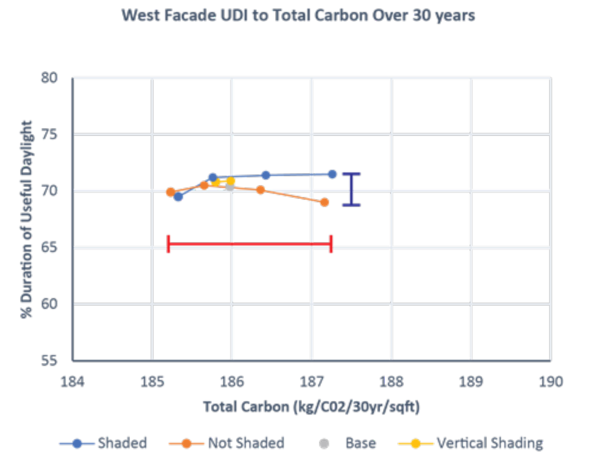


Simulation Data

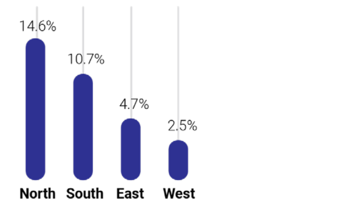




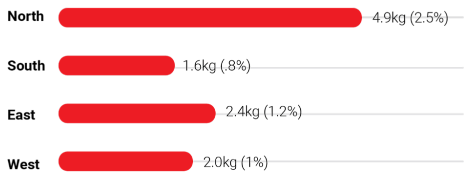


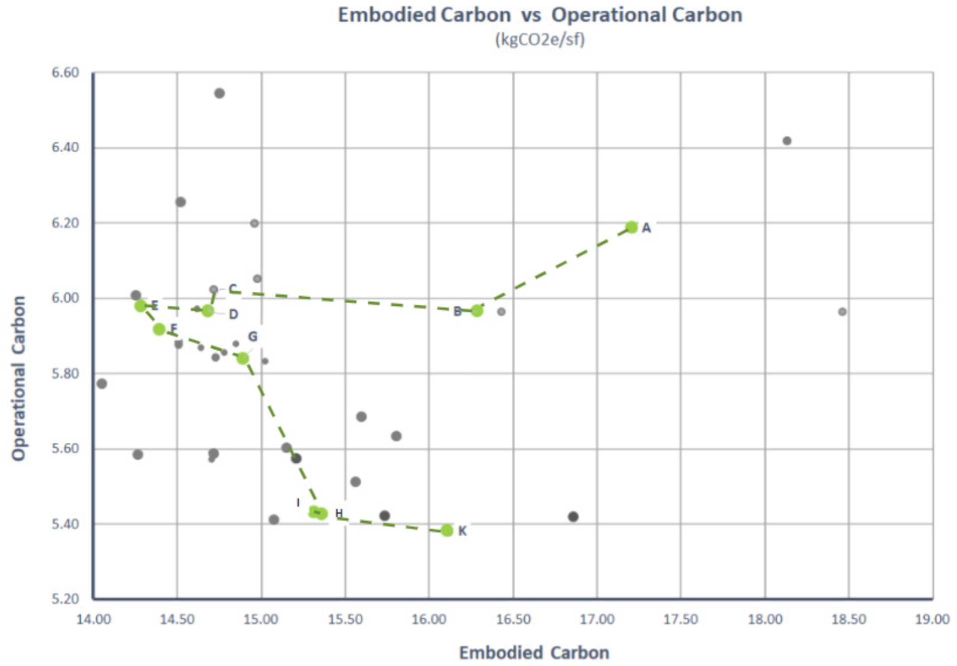


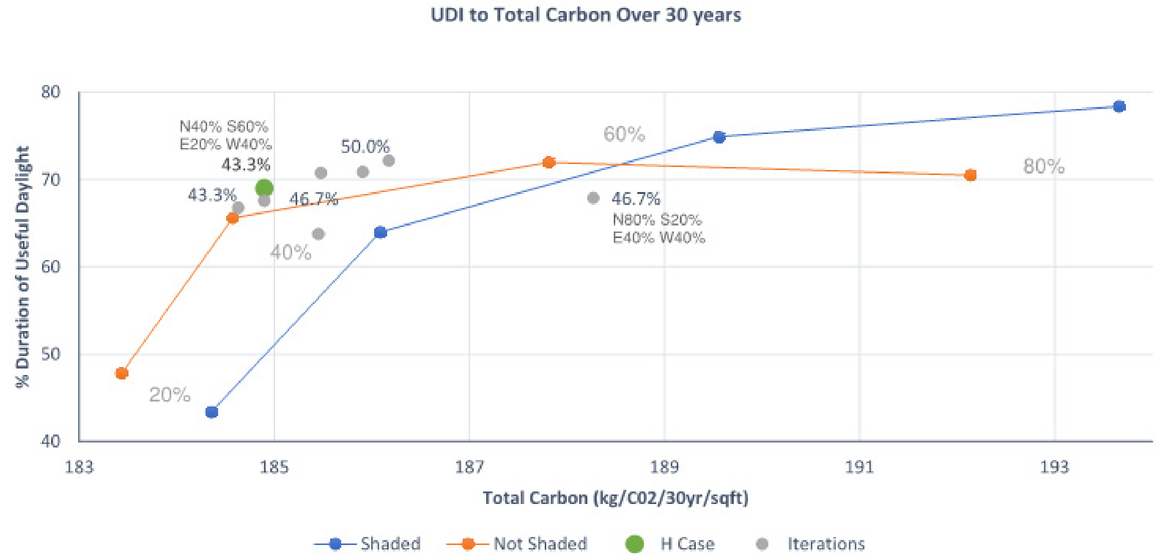
Opportunity in Useful Daylight Illuminance

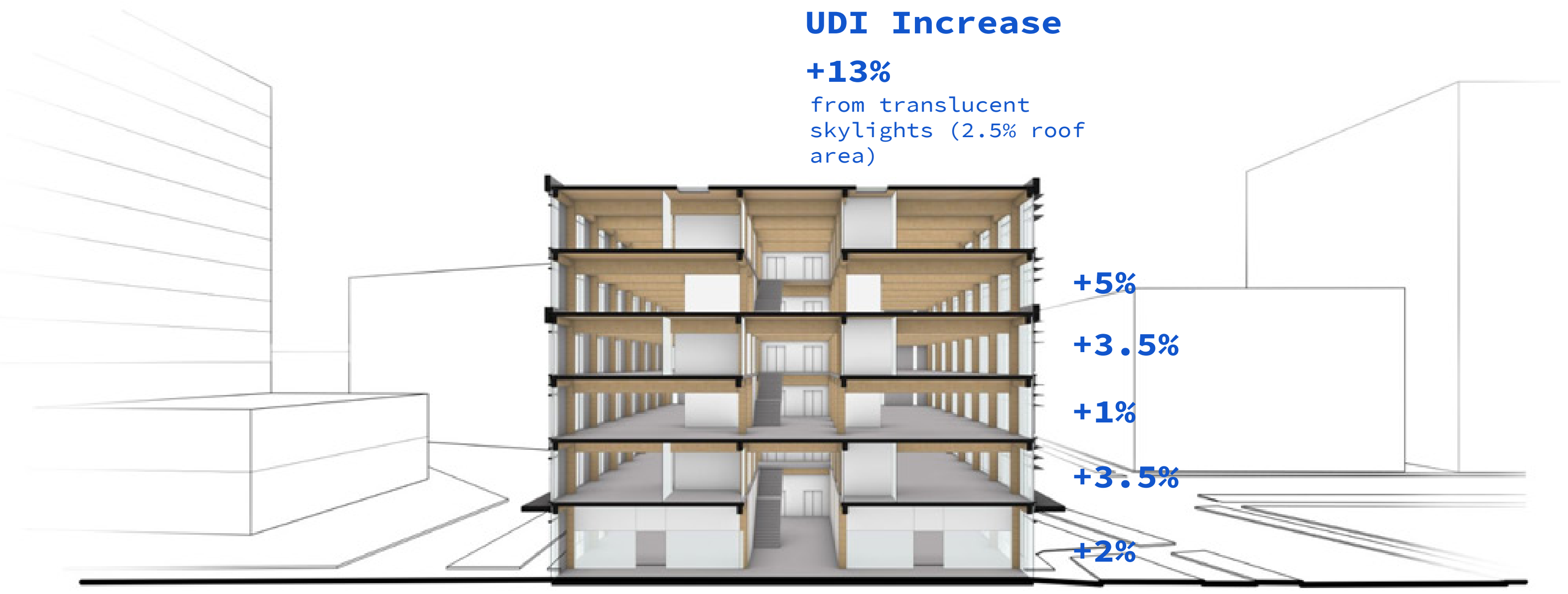


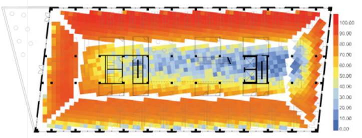
Opportunity in Carbon Emissions

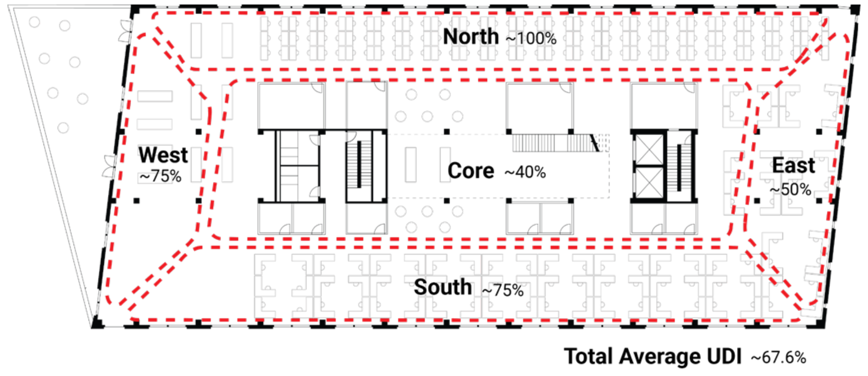


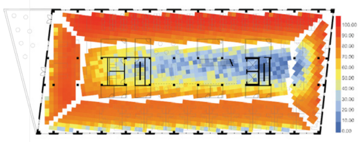


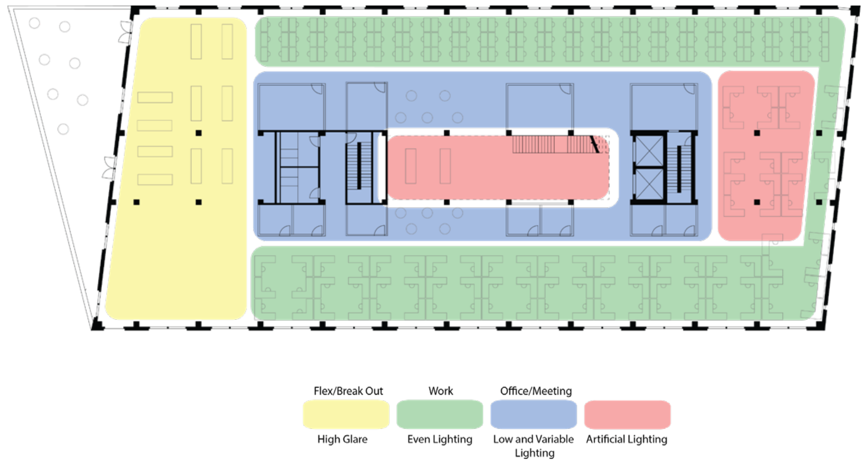



UDI Increase
+13%
from translucent skylights (2.5% roof area)
+5%
+3.5%
+1%
+3.5%
+2%

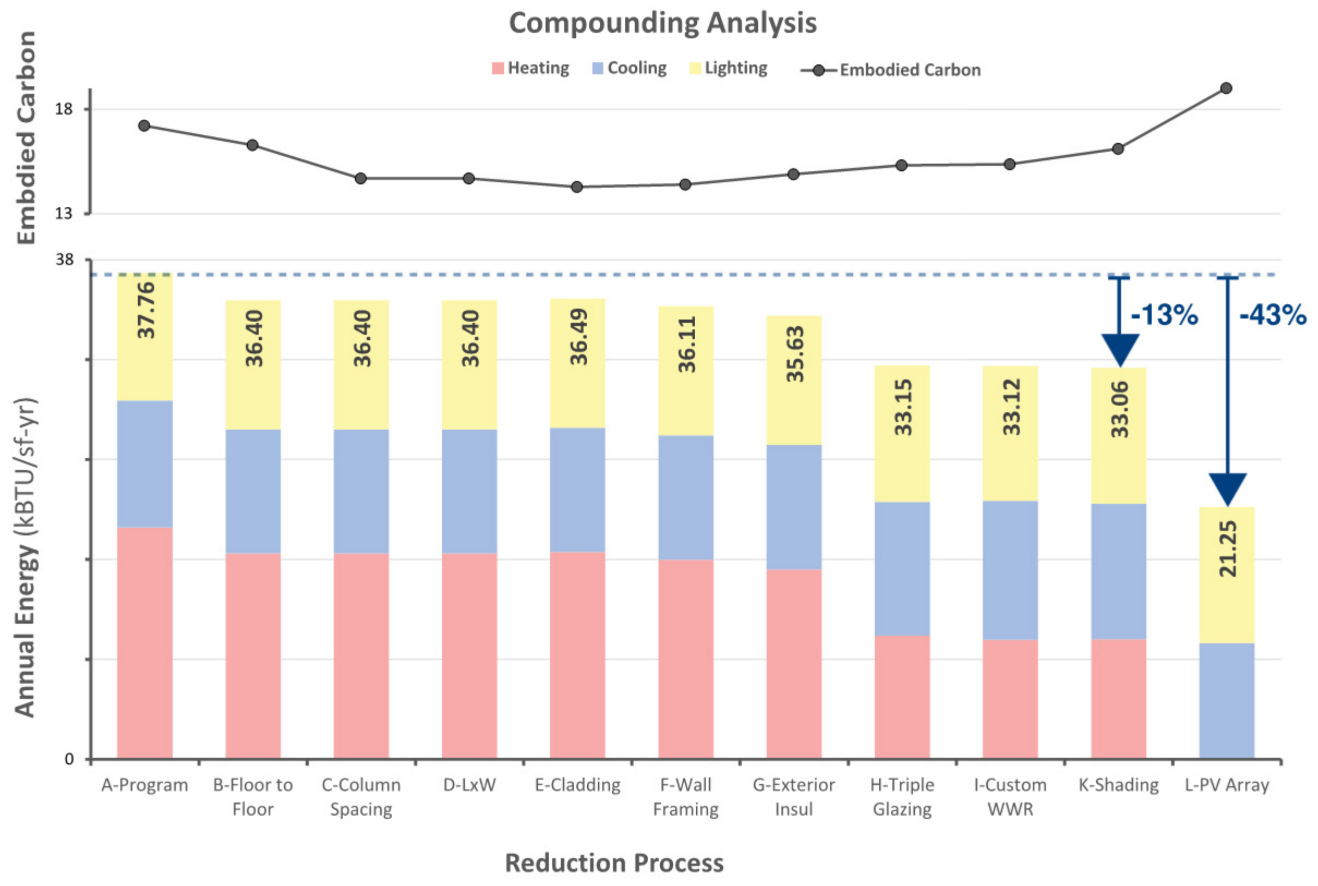


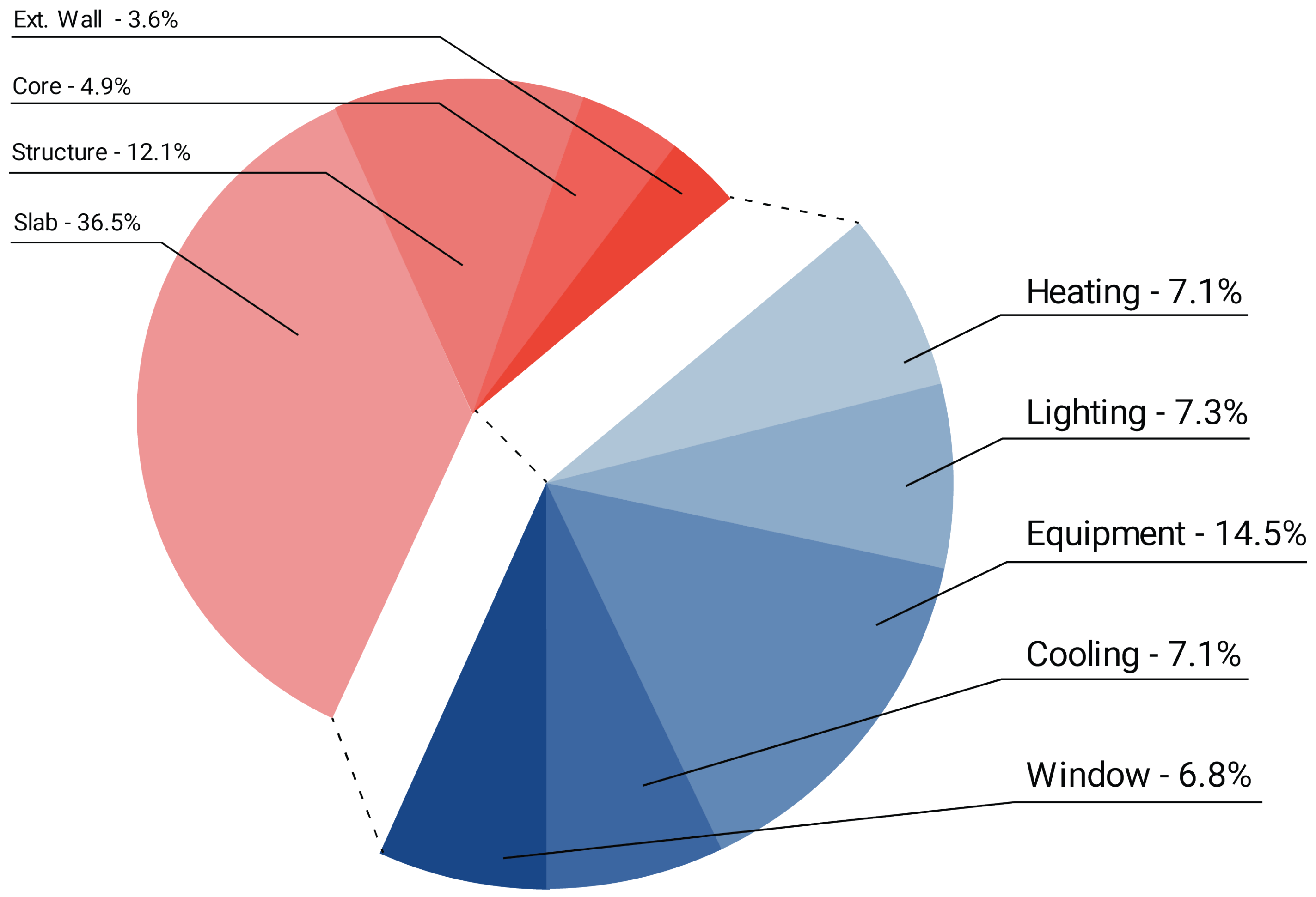

North ~100%
West ~75%
Core ~40%
East ~50%
South ~75%
Total Average UDI ~67.6%



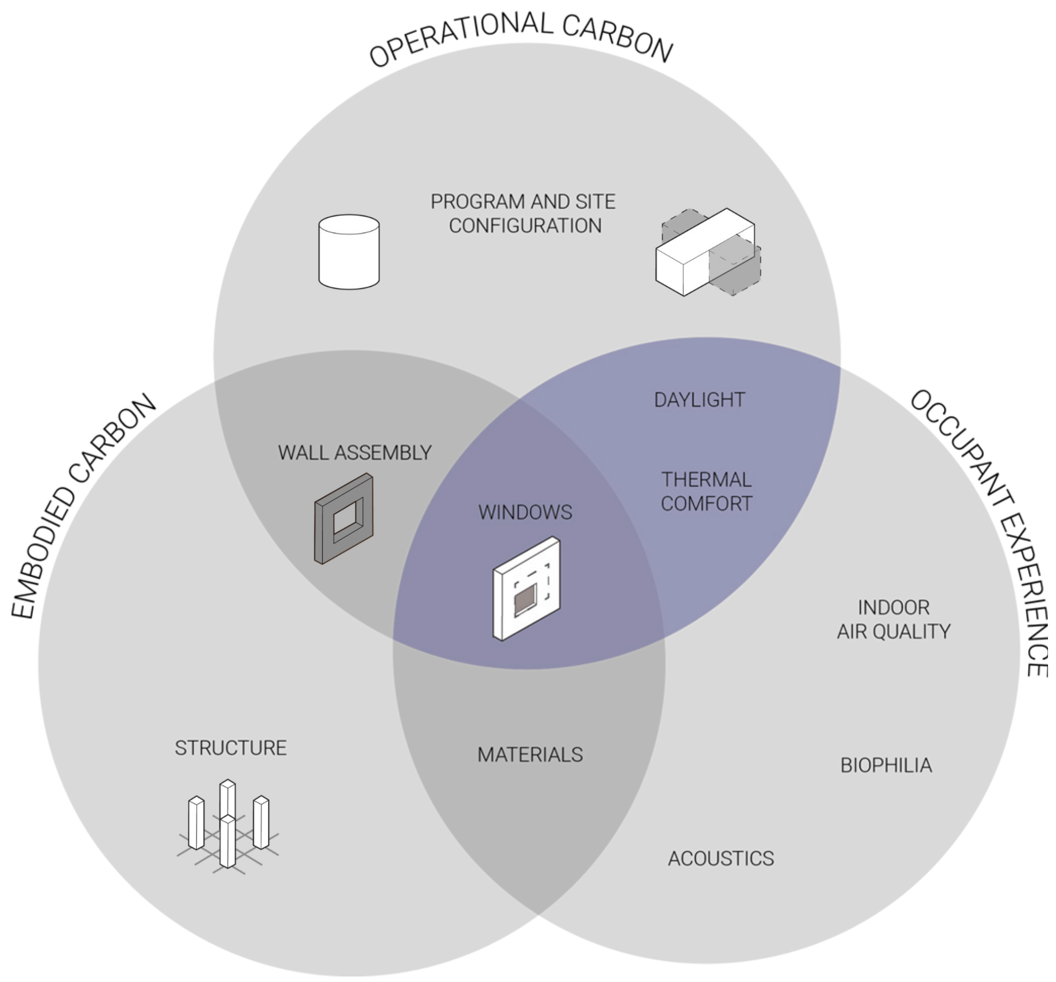

Flex/Break Out
Work
Office/Meeting
High Glare
Even Lighting
Low and Variable Lighting
Artificial Lighting

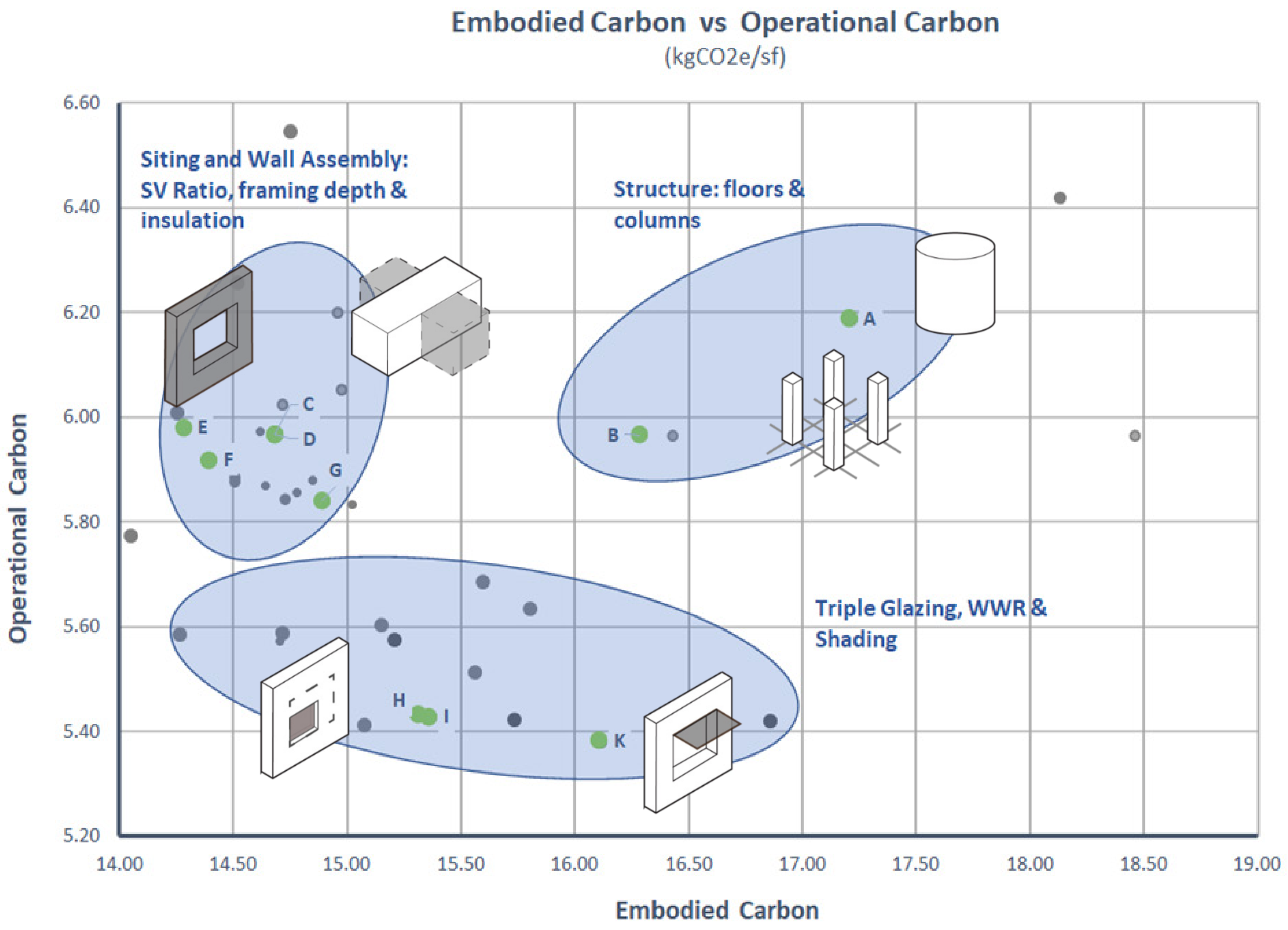
Results





total carbon distro


OPERATIONAL CARBON
EMBODIED CARBON
OCCUPANT EXPERIENCE
PROGRAM AND SITE CONFIGURATION
WALL ASSEMBLY
DAYLIGHT
THERMAL COMFORT
WINDOWS
INDOOR AIR QUALITY
STRUCTURE
MATERIALS
BIOPHILIA
ACOUSTICS


Embodied Carbon vs Operational Carbon
(kgCO2e/sf)
Operational Carbon
Embodied Carbon
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
14.00
14.50
15.00
15.50
16.00
16.50
17.00
17.50
18.00
18.50
19.00
Siting and Wall Assembly: SV Ratio, framing depth & insulation
Structure: floors & columns
Triple Glazing, WWR & Shading
A
B
C
D
E
F
G
H
I
K

CONCLUDING REMARKS: Tomás Méndez Echenagucia

Assistant Professor, University of Washington

Building geometry has implications in many aspects of its performance. Designers are challenged with exploring geometrical options early in their design process while considering a wide range of criteria, such as structural, environmental, acoustical or spatial performance. Computational tools represent a great opportunity to conduct such explorations in a methodical and timely fashion. I was very excited to get the opportunity to teach a research studio where students and faculty would work on reducing carbon emissions and explore the mass timber components using computational methods. Most of the research being done on carbon emissions considers operational or embodied carbon independently, very few articles look into the relationship between these two, and most importantly when they represent contrasting objectives. This research studio gave us a chance to look into this gap in knowledge and develop methods to design for low emissions. I consider myself lucky for such an opportunity and hope to have conveyed my enthusiasm for computational design to our students.

This studio would not have been possible without the participation of Prof. Chris Meek who was fundamental in the creation of the research concept, the definition of the operational carbon objectives and boundary conditions as well as in the organization of the studio. Equal recognition goes to Teresa Moroseos who worked tirelessly in the creation of the studio tool and made it as usable as possible for our students by accommodating a very broad range of geometries. Teresa also dedicated a great amount of time in teaching the ins and outs of the tool to our students. Preston Pape was also fundamental in the tool creation. I would like to extend my gratitude to all three for making the studio run so smoothly.

We enjoyed the presence of a multitude of reviewers and lecturers that brought a wealth of knowledge to our studio and made the experience much more enjoyable for our students. A big thanks goes to Kate Sector, Jonathan Smith, Susan Jones, Jacob Dunn, Tate Walker, Heather Burpee, Rob Peña, Arathi Gowda, Eric Long, Ursula Frick, Indroneil Ganguly, Emily Doe and Brad Liljequist.

Lastly, I would like to express my deepest gratitude to our 16 students. The courage and enthusiasm with which they took on a broad set of new and challenging subjects made teaching this studio a very rewarding experience. We constantly asked our students to “break the tool” and to tell stories with their designs and data. I am very thankful to them for accomplishing both.

CONCLUDING REMARKS: Christopher Meek, AIA, IES

Associate Professor, University of Washington // Director, Integrated Design Lab

This graduate Research Studio is the culmination of a year-long embodied and operational carbon analysis tool development process that I am grateful to have had the opportunity to be part of. Co-teaching with Tomás Mendez Echenagucia was a genuine pleasure and I can confidently say I received much more than I gave in this experience. I would like to extend special thanks and appreciation to the students who participated. It has been gratifying to work with each of you, especially in a context where there is uncertainty in the methods and a challenge to incorporate new tools and methods in the design process. Blending empirically-driven computationally-based decision making tools with the overarching goal reducing net lifecycle carbon emissions messy, inspiring, frustrating, and fun. Thanks for bringing your creativity, hard work, and positive attitude to this exploration – it was a genuine pleasure to be part of your journey in architecture school.

I enjoyed seeing the development and communication of performance-based spatial, material, and formal solutions; and storytelling through performance data communication diagrams. It allowed me to reflect on the process, and to expand my vision of improving the environmental and social impacts of the built environment – and to inform future research directions.

In particular I was pleasantly surprised by the virtual studio teaching environment that was forced by the Covid-19 pandemic. Over the past decade, working mostly in the digital realm had diminished some of the visible dynamism of the physical studio environment. Working and sketching on Zoom and in particular using shared Miro boards made visible the broad and diverse production of the studio as a whole. I am looking forward to a return to in-person teaching, but there were aspects to the experiment of remote studio teaching that I think helped improve my teaching and that I will want to continue in the future.

I would like to thank Teresa Moroseos with UW Integrated Design Lab (UW IDL) who provided invaluable technical and teaching assistance in delivering the studio experience; and Preston Pape (M.S. Design Technology Candidate) who helped Tomás, Teresa, and me develop the analysis tools.

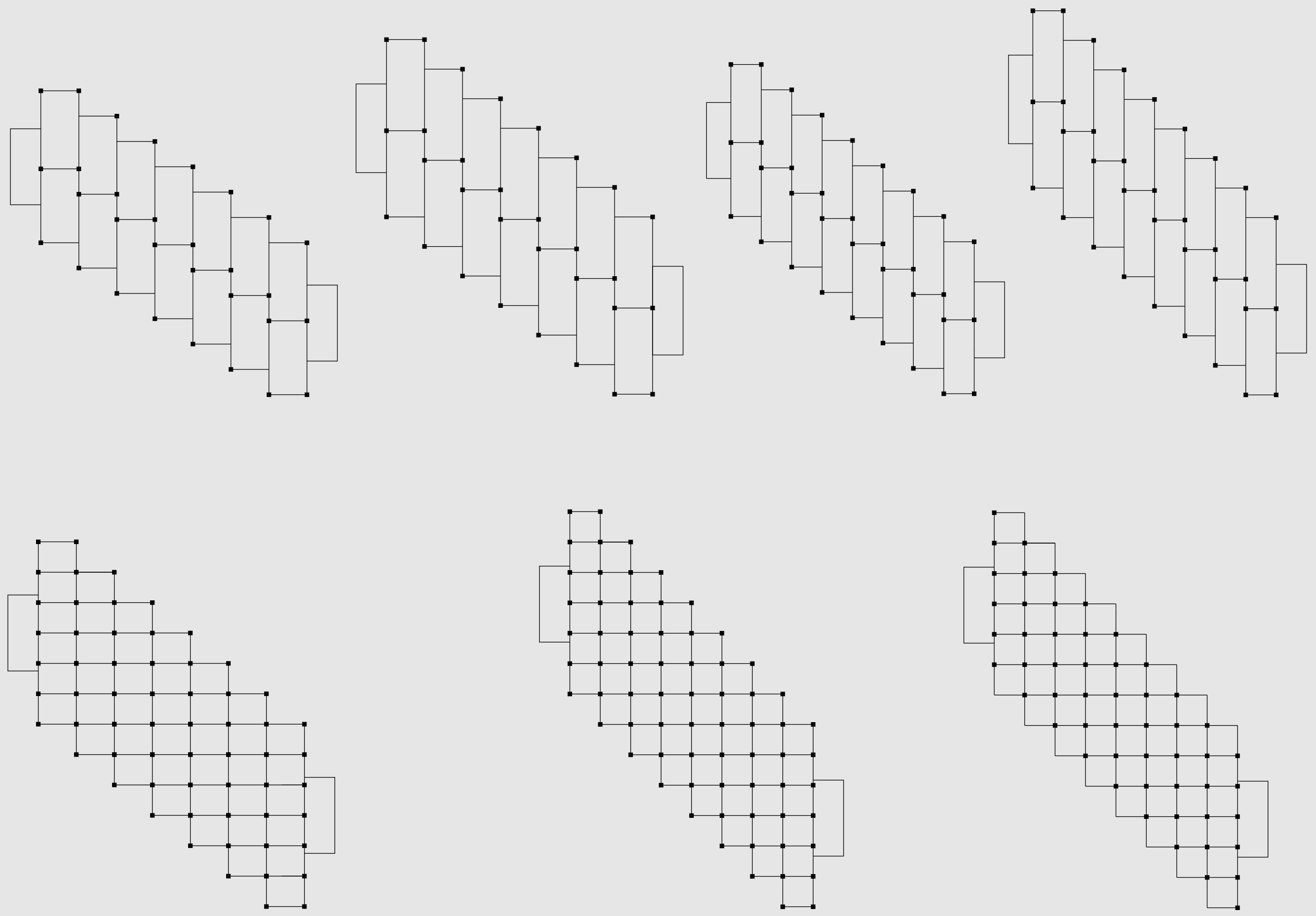
Lastly, I would also like to thank the professionals that contributed their time and wisdom to the studio: Arathi Gowda and Eric Long at SOM, Kate Sector and Jonathan Smith at Lake Flato Architects, Emily Doe at Weber+Thompson, Tate Walker at OPN Architects, and our other reviewers, Jacob Dunn with ZGF, Susan Jones with Atelier Jones, and Heather Burpee with UW Integrated Design Lab and without whom the studio would not be possible. I would also like to thank Kate Simonen, Chair of the Department of Architecture, and Rob Pena, Graduate Program Coordinator for their participation, expertise and support of this work.

FORTHCOMING RESEARCH

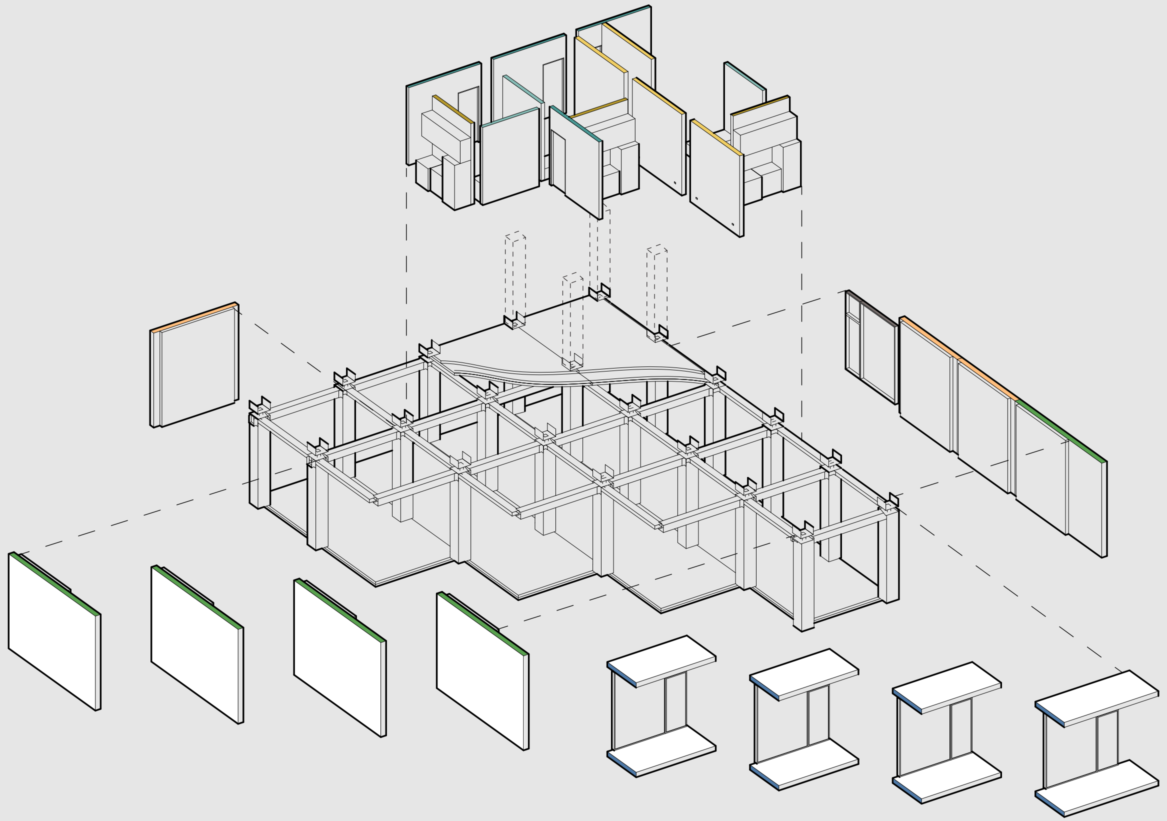
Research on the relationship between embodied and operational carbon is still very young. There is much to be understood about how local climates, material supply chains and architectural systems will play a role in determining carbon emissions. The studio marked the start of a series of studies based in the US climates and markers, where possible areas of focus include a deeper understanding of the building envelope and a study of mass timber geometries, spans and bracing systems, as well as window-to-wall ratios (WWRs) and their determination of daylighting quality and carbon emissions.

The building envelope has been shown to contain a good percentage of the embodied carbon in most modern buildings. Glazing systems, thermal insulation and cladding panels are all typical culprits of significant emissions. The envelope also has a very large role in determining the operational emissions, and more importantly, embodied and operational concerns are often in contrast. The study of this tradeoff design process for the envelope is of considerable importance. Daylighting performance has also been shown to have an important connection to embodied emissions in the envelope, especially in assemblies where walls have a significantly lower embodied carbon compared to windows.

Equally important is the study of the role that mass timber structural systems can play in the reduction of embodied emissions, and how their geometrical, fabrication and spatial constraints might affect operational carbon as well. An example is the use of load bearing CLT panels in the building envelope, and its relationship to WWRs and their structural and thermal performance.



CARBON RESEARCH STUDIO 2021 **DESIGNING FOR LOW EMISSIONS** TOMÁS MÉNDEZ ECHENAGUCIA AND CHRIS MEEK



CARBON RESEARCH STUDIO 2021
DESIGNING FOR LOW EMISSIONS
A COMPUTATIONAL APPROACH TO MASS TIMBER BUILDINGS

TOMÁS MÉNDEZ ECHENAGUCIA AND CHRISTOPHER MEEK

UNIVERSITY of WASHINGTON