Advancing Passive House at an Institutional Scale

Bush School, Seattle WA

MITHŪN PAE

D

4

DESIGN FOR POSI+IVE CHANGE

+

△

Buildings that Teach

Processes that Teach

R+D

Resilience

thrive in the face of climate change

Health & Wellbeing

enhance the human condition

Carbon

achieve carbon positivity

Artificial Intelligence

empower designers & enable superior decision-making

Construction Technology

transform building delivery for positive change

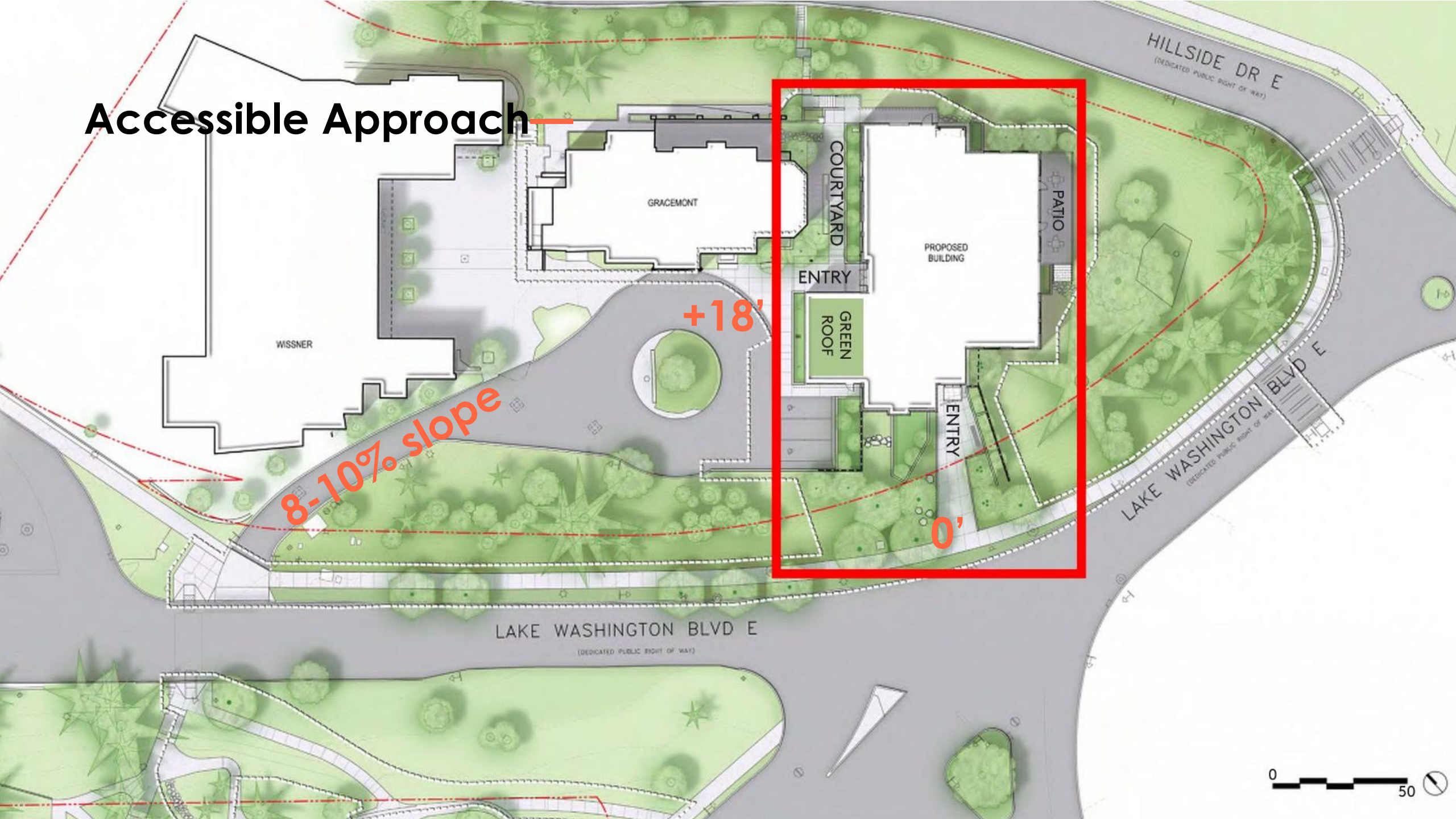
Design + Planning


Project Context
THE BUSH SCHOOL

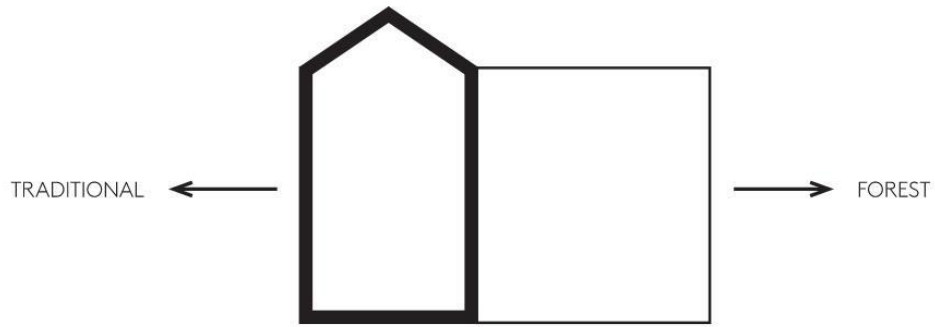
Connecting Campus Halves

Connecting Campus Halves

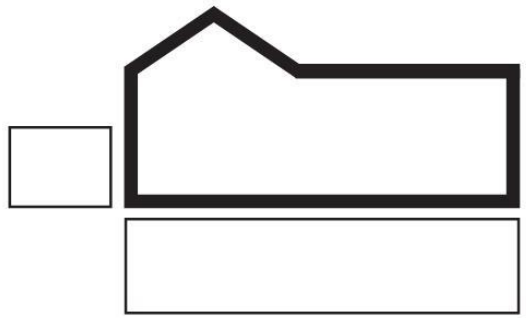
Accessible Approach



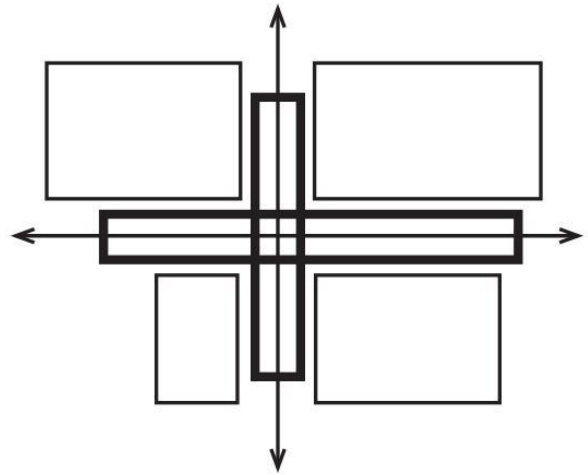
DESIGN DIAGRAMS *INTERIOR ARCHITECTURE*



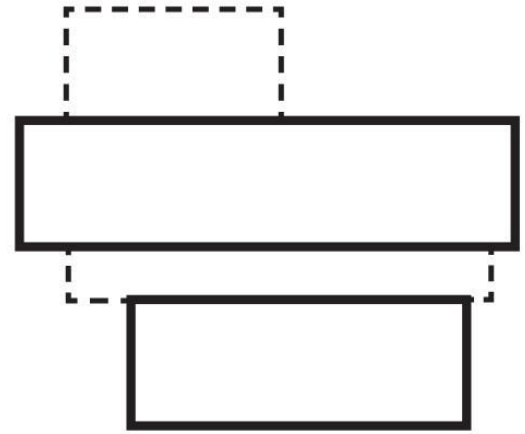
EMBRACE OF SITE CONTEXT
TRADITIONAL TO FOREST



LEARNING ENVIRONMENTS
FORMAL TO INFORMAL



PLAN PARTI
PROSPECT TO REFUGE



PLAN CONTRAST
SOLID TO PERMEABLE

The Bush School
EXPERIENCE EDUCATION

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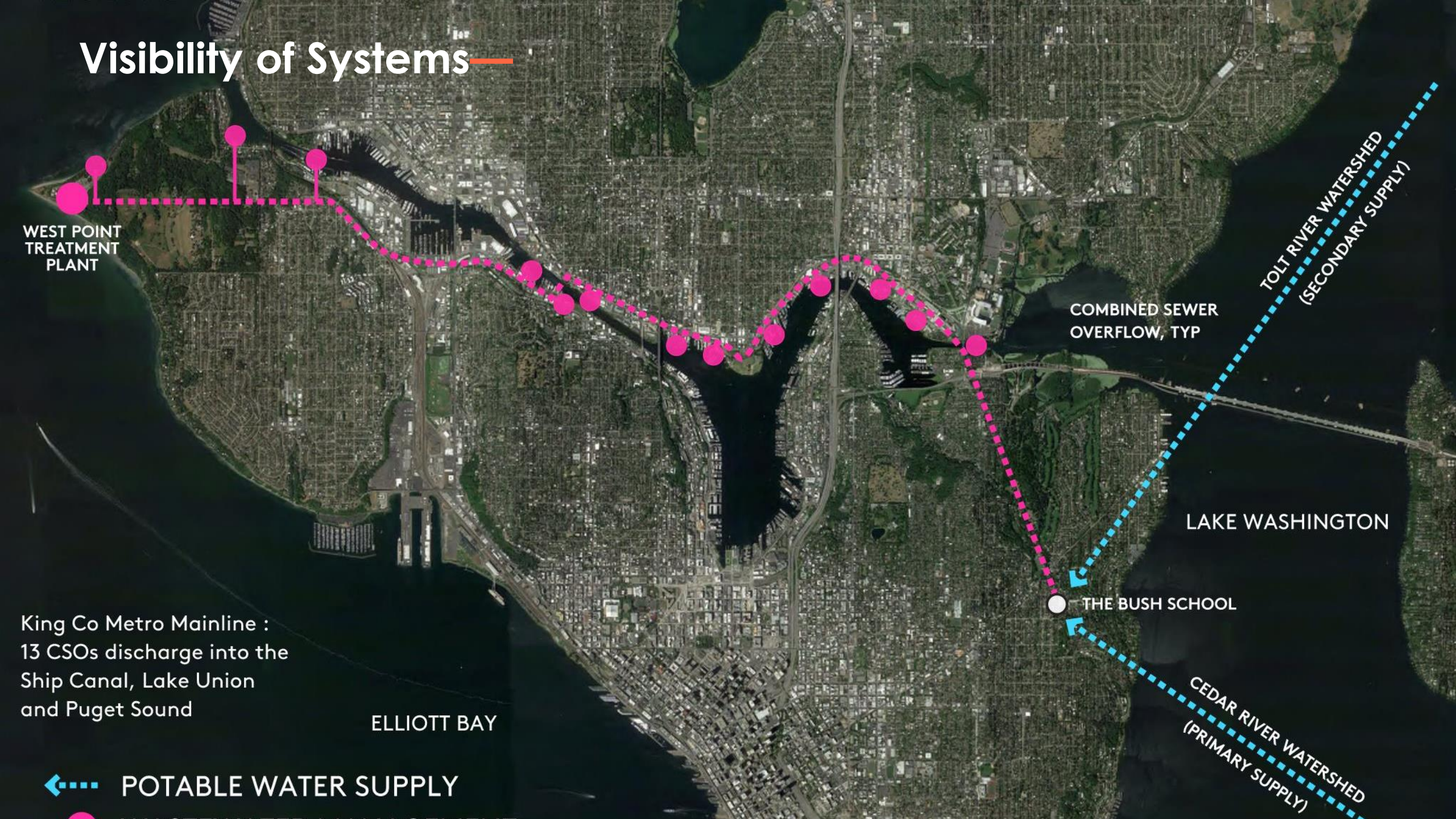
Visible Front Door + Portal

Visible Front Door + Portal

Lowered Embodied Carbon/Mass Plywood Integration

Visibility of Systems

Visibility of Systems



Salmon Safe

KEY POINTS

- Focused on reducing downstream impacts and protection of urban watersheds
- Regionally Based Program

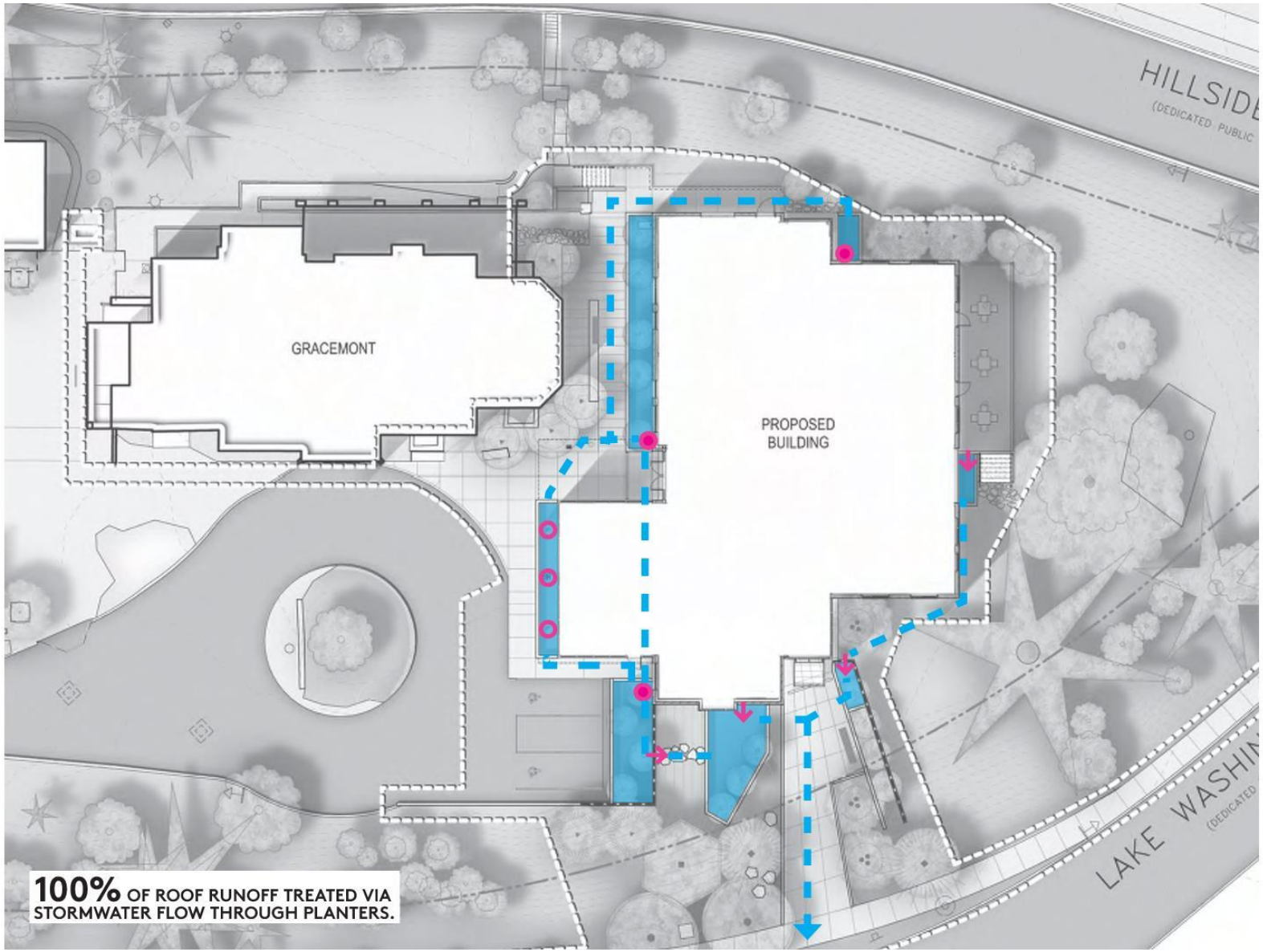
RATING SYSTEM

- Focused on Campus Wide practices

WATER	Stormwater Management
WATER	Water Use Management
WATER	Erosion Prevention and Sediment Control
ECOSYSTEM	Pesticide Reduction and Water Quality Protection
ECOSYSTEM	Enhancement of Urban Ecological Function

Visibility of Systems

STORMWATER DESIGN



100% OF ROOF RUNOFF TREATED VIA STORMWATER FLOW THROUGH PLANTERS.

SCUPPER

RAINCHAIN

DOWNSPOUT

STORMWATER OVERFLOW ROUTE

STORMWATER PLANTER

+ STORMWATER PLANTER SECTION

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LANDSCAPE DESIGN

COURTYARD

LOWER ENTRY

STORMWATER

GREEN ROOF

N= PNW NATIVE

Passive House

MAIN DIFFERENCES FROM LEED

- Based on U.S. DOE-funded research conducted in partnership with Building Science Corporation
- Peer-reviewed by U.S. DOE and vetted through public comment

RATING SYSTEM

- Criteria Specific to Local Climate

SCORING

- Certification is based on actual, rather than modeled or anticipated performance.

ENERGY AND ATMOSPHERE	Employs continuous insulation throughout its entire envelope without any thermal bridging.
ENERGY AND ATMOSPHERE	The building envelope is extremely airtight, preventing infiltration of outside air and loss of conditioned air.
ENERGY AND ATMOSPHERE	Employs high-performance windows (typically triple-paned) and doors.
ENERGY AND ATMOSPHERE	Solar gain is managed to exploit the sun's energy for heating purposes in the heating season and to minimize overheating during the cooling season.
INDOOR ENVIRONMENTAL QUALITY	Uses some form of balanced heat- and moisture-recovery ventilation and a minimal space conditioning system.

ZERO ENERGY CERTIFICATION

Net Zero Energy

KEY POINTS

- Focus on reduction of overall carbon footprint

RATING SYSTEM

- Requires 12 consecutive months of operating data to demonstrate actual performance

ENERGY & ATMOSPHERE	One hundred percent of the operational energy use associated with the project must be offset by new on-site renewable energy.
ENERGY & ATMOSPHERE	No combustion allowed.

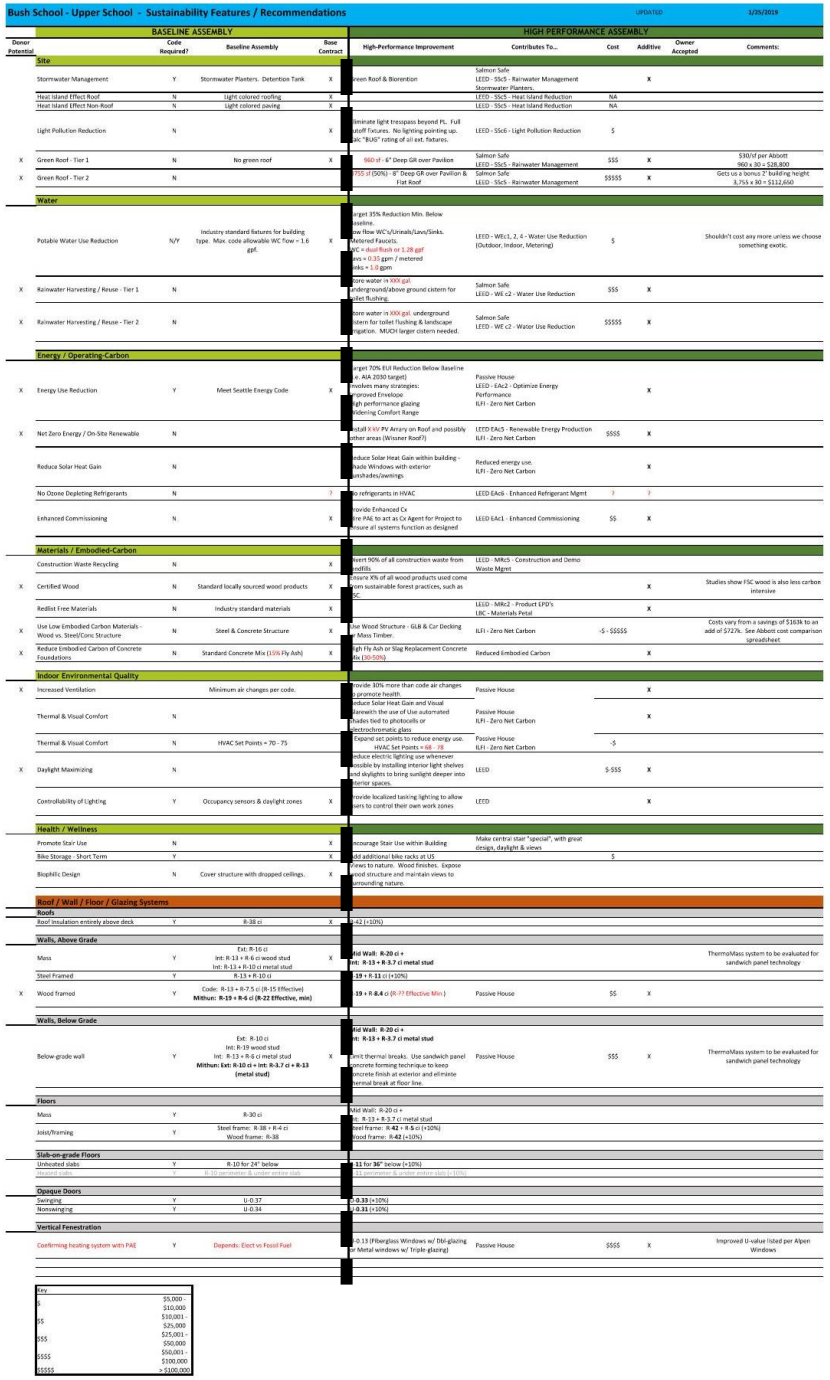
Implementation

Collaboration…early & often

Decision Making Process

Baseline vs. High Performance

- Align w/ Goals?
- Design Consequence
- Construction Consequence
- Cost Comparison $ vs. $$$



Bush School - Upper School - Sustainability Features / Recommendations — UPDATED: 1/25/2019

Donor Potential	BASELINE ASSEMBLY: Code Required?	Baseline Assembly	Base Contract	HIGH PERFORMANCE ASSEMBLY: High-Performance Improvement	Contributes To...	Cost	Additive	Owner Accepted	Comments:
Site									
	Stormwater Management — Y	Stormwater Planters. Detention Tank	X	reen Roof & Bioretention	Salmon Safe LEED - SSc5 - Rainwater Management Stormwater Planters		X		
	Heat Island Effect Roof — N	Light colored roofing	X		LEED - SSc5 - Heat Island Reduction	NA			
	Heat Island Effect Non-Roof — N	Light colored paving	X		LEED - SSc5 - Heat Island Reduction	NA			
	Light Pollution Reduction — N		X	liminate light trespass beyond PL. Full utoff fixtures. No lighting pointing up. BC "BUG" rating of all ext. fixtures.	LEED - SSc6 - Light Pollution Reduction	$			
X	Green Roof - Tier 1 — N	No green roof	X	980 sf - 6" Deep GR over Pavilion	Salmon Safe LEED - SSc5 - Rainwater Management	$$$	X		$30/sf per Abbott 960 x 30 = $28,800
X	Green Roof - Tier 2 — N			755 sf (50%) - 6" Deep GR over Pavilion & Flat Roof	Salmon Safe LEED - SSc5 - Rainwater Management	$$$$$	X		Gets us a bonus 2' building height 3,755 x 30 = $112,650
Water									
	Potable Water Use Reduction — N/Y	Industry standard fixtures for building type. Max. code allowable WC flow = 1.6 gpf.	X	rget 35% Reduction Min. Below seline. ow flow WC's/Urinals/Lave/Sinks. etered Faucets. C = dual flush or 1.28 gpf ws = 0.35 gpm / metered aks = 1.0 gpm	LEED - WEc1, 2, 4 - Water Use Reduction (Outdoor, Indoor, Metering)	$			Shouldn't cost any more unless we choose something exotic.
X	Rainwater Harvesting / Reuse - Tier 1 — N			ore water in XXX gal. nderground/above ground cistern for ilet flushing.	Salmon Safe LEED - WE c2 - Water Use Reduction	$$$	X		
X	Rainwater Harvesting / Reuse - Tier 2 — N			ore water in XXX gal. underground stern for toilet flushing & landscape rigation. MUCH larger cistern needed.	Salmon Safe LEED - WE c2 - Water Use Reduction	$$$$$	X		
Energy / Operating Carbon									
X	Energy Use Reduction — Y	Meet Seattle Energy Code	X	rget 70% EUI Reduction Below Baseline e. AIA 2030 target) volves many strategies: gnproved Envelope gh performance glazing dening Comfort Range	Passive House LEED - EAc2 - Optimize Energy Performance ILFI - Zero Net Carbon		X		
X	Net Zero Energy / On-Site Renewable — N			stall X kW PV Array on Roof and possibly her areas (Wissner Roof?)	LEED EAc5 - Renewable Energy Production ILFI - Zero Net Carbon	$$$$	X		
	Reduce Solar Heat Gain — N			educe Solar Heat Gain within building - ilable Windows with exterior ns/shades/awnings	Reduced energy use. ILFI - Zero Net Carbon		X		
	No Ozone Depleting Refrigerants — N		?	o refrigerants in HVAC	LEED EAc6 - Enhanced Refrigerant Mgmt	?	?		
	Enhanced Commissioning — N		X	rovide Enhanced Cx re PAE to act as Cx Agent for Project to sure all systems function as designed	LEED EAc1 - Enhanced Commissioning	$$	X		
Materials / Embodied Carbon									
	Construction Waste Recycling — N		X	vert 90% of all construction waste from ndfills	LEED - MRc5 - Construction and Demo Waste Mgmt				
X	Certified Wood — N	Standard locally sourced wood products	X	sure X% of all wood products used come om sustainable forest practices, such as SC			X		Studies show FSC wood is also less carbon intensive
	Redlist Free Materials — N	Industry standard materials	X		LEED - MRc2 - Product EPD's LBC - Materials Petal		X		
X	Use Low Embodied Carbon Materials - Wood vs. Steel/Conc Structure — N	Steel & Concrete Structure	X	se Wood Structure - GLB & Csr Decking r Mass Timber	ILFI - Zero Net Carbon	-$ - $$$$$			Costs vary from a savings of $163k to an add of $727k. See Abbott cost comparison spreadsheet
X	Reduce Embodied Carbon of Concrete Foundations — N	Standard Concrete Mix (15% Fly Ash)	X	gh Fly Ash or Slag Replacement Concrete ix (30-55%)	Reduced Embodied Carbon		X		
Indoor Environmental Quality									
X	Increased Ventilation —	Minimum air changes per code.		rovide 30% more than code air changes promote health.	Passive House		X		
	Thermal & Visual Comfort — N			educe Solar Heat Gain and Visual fort with the use of Use automated hades tied to photocells or lectrochromatic glass	Passive House ILFI - Zero Net Carbon		X		
	Thermal & Visual Comfort — N	HVAC Set Points = 70 - 75		Expand set points to reduce energy use. HVAC Set Points = 68 - 78	Passive House ILFI - Zero Net Carbon	-$			
X	Daylight Maximizing — N			educe electric lighting use wherever ossible by installing interior light shelves nd daylights to bring sunlight deeper into terior spaces.	LEED	$-$$$	X		
	Controllability of Lighting — Y	Occupancy sensors & daylight zones	X	rovide localized tasking lighting to allow sers to control their own work zones	LEED		X		
Health / Wellness									
	Promote Stair Use — N		X	courage Stair Use within Building	Make central stair "special", with great design, daylight & views				
	Bike Storage - Short Term — Y		X	dd additional bike racks at US		$			
	Biophilic Design — N	Cover structure with dropped ceilings.	X	iews to nature. Wood finishes. Expose ood structure and maintain views to rrounding nature.					
Roof / Wall / Floor / Glazing Systems									
Roofs									
	Roof Insulation entirely above deck — Y	R-38 ci	X	-42 (+10%)					
Walls, Above Grade									
	Mass — Y	Ext: R-16 ci Int: R-13 + R-6 ci wood stud Int: R-13 + R-10 ci metal stud	X	**id Wall: R-20 ci + nt: R-13 + R-3.7 ci metal stud**					ThermoMass system to be evaluated for sandwich panel technology
	Steel Framed — Y	R-13 + R-10 ci		**-19 + R-11** ci (+10%)					
X	Wood framed — Y	Code: R-13 + R-7.5 ci (R-15 Effective) **Mithun: R-19 + R-6 ci (R-22 Effective, min)**		**-19 + R-8.4** ci (R-?? Effective Min.)	Passive House	$$	X		
Walls, Below Grade									
	Below grade wall — Y	Ext: R-10 ci Int: R-19 wood stud Int: R-13 + R-6 ci metal stud **Mithun: Ext: R-10 ci + Int: R-3.7 ci + R-13 (metal stud)**	X	id Wall: R-20 ci + **nt: R-13 + R-3.7 ci metal stud** mit thermal breaks. Use sandwich panel concrete forming technique to keep concrete finish at exterior and eliminate thermal break at floor line.	Passive House	$$$	X		ThermoMass system to be evaluated for sandwich panel technology
Floors									
	Mass — Y	R-30 ci		Mid Wall: R-20 ci + R-13 + R-3.7 ci metal stud					
	Joist/Framing — Y	Steel frame: R-38 + R-4 ci Wood frame: R-38		teel frame: **R-42 + R-5** ci (+10%) Wood frame: **R-42** (+10%)					
Slab-on-grade Floors									
	Unheated slabs — Y	R-10 for 24" below		**11 for 36"** below (+10%)					
	Heated slabs — Y	R-10 perimeter & under entire slab		11 perimeter & under entire slab (+10%)					
Opaque Doors									
	Swinging — Y	U-0.37		**-0.33** (+10%)					
	Nonswinging — Y	U-0.34		**-0.31** (+10%)					
Vertical Fenestration									
	Confirming heating system with PAE — Y	Depends: Elect vs Fossil Fuel		-0.19 (Fiberglass Windows w/ Dbl-glazing or Metal windows w/ Triple-glazing)	Passive House	$$$$	X		Improved U-value listed per Alpen Windows

Key	
$	$5,000 - $10,000
$$	$10,001 - $25,000
$$$	$25,001 - $50,000
$$$$	$50,001 - $100,000
$$$$$	> $100,000

Decision Making Process

Donor

Baseline | High Performance

Bush School - Upper School - Sustainability Features / Recommendations — UPDATED 1/25/2019

	BASELINE ASSEMBLY				HIGH PERFORMANCE ASSEMBLY					
Donor Potential		Code Required?	Baseline Assembly	Base Contract	High-Performance Improvement	Contributes To...	Cost	Additive	Owner Accepted	Comments:
	Roof / Wall / Floor / Glazing Systems									
	Roofs									
	Roof Insulation entirely above deck	Y	R-38 ci	X	R-42 (+10%)					
	Walls, Above Grade									
	Mass	Y	Ext: R-16 ci Int: R-13 + R-6 ci wood stud Int: R-13 + R-10 ci metal stud	X	**Mid Wall: R-20 ci + Int: R-13 + R-3.7 ci metal stud**					ThermoMass system to be evaluated for sandwich panel technology
	Steel Framed	Y	R-13 + R-10 ci		**R-19** + R-**11** ci (+10%)					
X	Wood framed	Y	Code: R-13 + R-7.5 ci (R-15 Effective) **Mithun: R-19 + R-6 ci (R-22 Effective, min)**		**R-19** + R-**8.4** ci (R-?? Effective Min.)	Passive House	$$	X		
	Walls, Below Grade									
	Below-grade wall	Y	Ext: R-10 ci Int: R-19 wood stud Int: R-13 + R-6 ci metal stud **Mithun: Ext: R-10 ci + Int: R-3.7 ci + R-13 (metal stud)**	X	**Mid Wall: R-20 ci + Int: R-13 + R-3.7 ci metal stud** Limit thermal breaks. Use sandwich panel concrete forming technique to keep concrete finish at exterior and eliminte thermal break at floor line.	Passive House	$$$	X		ThermoMass system to be evaluated for sandwich panel technology
	Floors									
	Mass	Y	R-30 ci		Mid Wall: R-20 ci + Int: R-13 + R-3.7 ci metal stud					
	Joist/framing	Y	Steel frame: R-38 + R-4 ci Wood frame: R-38		Steel frame: R-**42** + R-**5** ci (+10%) Wood frame: R-**42** (+10%)					

PHIUS

Cost Tracking Process

Baseline | Our Project
- PHIUS
- Net Zero Energy
- SalmonSafe

Bush School - Upper School

Sustainability Features List

11/1/2019

Component	Code Compliant Base	Sustainability/Passive House Alternative
Building Superstructure	Steel structure (columns & beams) with corrugated metal deck & concrete fill. Ceiling finishes to cover structure.	Wood structure (glulam columns & beams) and mass plywood floor decking, for carbon sequestration.
Wall Insulation	R-13 between studs + R-7.5 ci exterior insulation	2" exterior mineral wool insulation (R-8.4)outboard R-19 batt insulation between wood studs Fiberglass clips for cladding (Cascadia clips)
Roof Insulation	R-38 continuous insulation	R-50 insulation (9" polyiso)
Below Grade Wall Insulation	Exterior: R-10 continuous insulation	Exterior: R-11 insulation (3" EPS) Interior: R-11.2 continuous (2" polyiso) and R-13 batt insulation between metal studs
Below Grade Floor Insulation	Exterior: R-10 continuous insulation	Exterior: R-11 insulation (3" EPS)
Fenestration	Metal windows: U-0.38, SHGC 0.35	Triple pane windows (Cascadia-Fiberglass): U-0.15, SHGC 0.24
Fenestration	Standard manually operable windows	Electrically operated windows (tied to BDS)
Air Sealing	0.25 CFM/ft^2	0.06 CFM/ft^2
Air Sealing	PVA paint only for vapor retarder.	Added interior air - vapor barrier, per 072721 - Interior Air Barriers at inside face or all exterior walls (selective walls at basement).
Thermal Bridging	Standard construction with typical thermal bridging of materials	Specialized details to eliminate most thermal bridges. See 1,2,4,5/A5.11 for example.
Air Handling Unit AHU-R01	Code compliant DOAS with 50% effective heat recovery	DOAS with 80% effective heat recovery
Lighting Systems	Code compliant lighting power density levels	Lighting power density 15% below code values
Mechanical Heating/Cooling	Air-cooled VRF system - 45 tons total Indoor wall mounted cassettes Outdoor condensing units with electric resistance backup	Air-cooled heat pump - 400 MBH Two pipe loop with changeover Primary/secondary pumps Electric boiler backup Fin tube radiators Ceiling fans in all classrooms
DHW Heating	Electric water heater	Heat pump water heater
PV Generation	1.5 kW rooftop system	20 kW rooftop system (minimum for PHIUS certification) 180 kW rooftop system (Alternate for total for Net Zero Energy)
Vegetated Roof	No green roof	Addition of 870 sf Green Roof, 8" deep, over Study Lounge

Cost Verification Process —

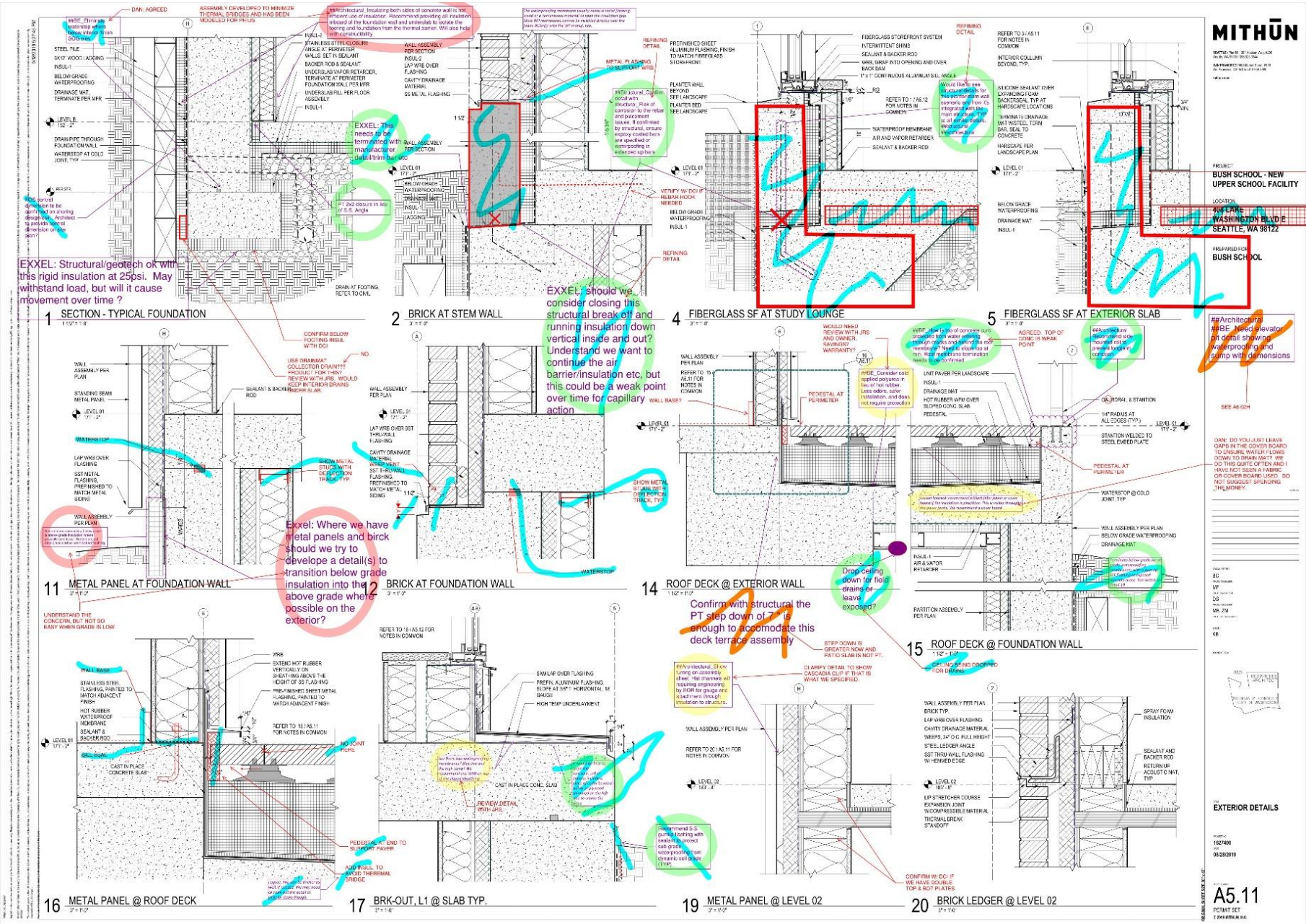
Baseline |

Our Project
- PHIUS
- Net Zero Energy
- SalmonSafe

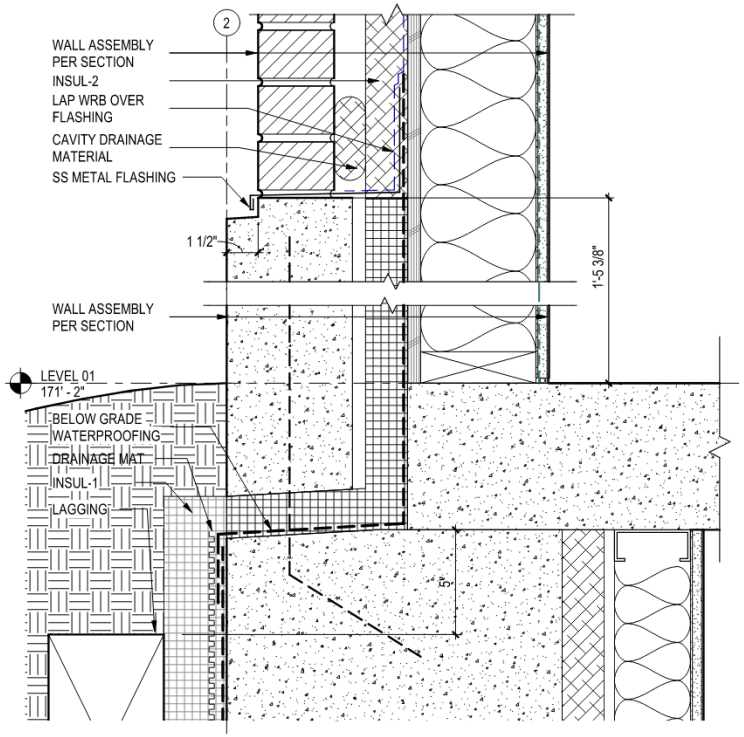
Bush School - Upper School - Sustainability Matrix
Updated: 3/31/2020

Component	Code Compliant Base	Assumptions	Code Compliant Cost	Sustainability/Passive House Alternative	Assumptions	Sustainability/ Passive House Alternative Cost	Sustainability Upgrade Cost in GMP	Comments
Building Superstructure	Steel structure (columns & beams)	SF Cost of structural steel building with SOMD and concrete/steel shear walls	$ 2,317,94	Wood structure (glulam columns & glulam beams)	GMP Scope	$ 2,644,632	$ 326,684	
	3" corrugated metal deck w/ 2 1/2" concrete	See above	In item #	Mass plywood floor decking w/ 3" concrete topping	GMP Scope	In item #1	In item #1	
	Ceiling finishes to cover structure	20,637 SF	$ 247,64	Open structure w/ ceiling clouds	GMP Scope	$ 307,820	$ 60,176	
	Concrete shear walls	7,560 SF	In item #	Wood shear walls	GMP Scope	In item #1	In item #1	
Wall Insulation	R-13 between studs w/ R-7.5 exterior continuous extruded polystyrene	9,828 SF	$ 32,16	R-19 batt insulation between studs w/ R-8.4 exterior mineral wool insulation	GMP Scope	$ 42,703	$ 10,541	
Wall Insulation	R-19 fiberglass batt insulation	GMP Scope	Base Scop	R-19 wool batt insulation	Add Alternate	Add $18,865	Not in GMP	
	Non-thermally broken z-girts	GMP Scope	Base Scop	Fiberglass clips for cladding (Cascadia clips)	Add Alternate	Add $5,940	Not in GMP	
Roof Insulation	R-38 continuous insulation (polyiso)		$ 108,92	R-50 continuous insulation (polyiso)	GMP Scope	$ 137,920	$ 28,995	
Below Grade Wall Insulation	Exterior face of wall: R-10 XPS continuous insulation		$ 14,80	Exterior face of wall: R-11 (3") EPS insulation Interior face of wall: R-11.2 continuous (2" polyiso) and R-13 batt insulation	GMP Scope	$ 30,400	$ 15,600	
Below Grade Floor Insulation	R-10 XPS at perimeter only (2" insulation at 2' perimeter)	900 SF	$ 4,95	R-11 EPS insulation (3" continuous)	GMP Scope	$ 25,625	$ 20,675	
Fenestration	Aluminum frame storefront windows: U-0.38, SHGC 0.35	Assumes code compliant fiberglass windows in lieu of Cascadia	$ 206,14	Triple pane windows (Cascadia-Fiberglass): U-0.15, SHGC 0.24	GMP Scope	$ 391,200	$ 185,056	
Air Sealing	0.25 CFM/ft^2	Industry Standard	$ -	0.06 CFM/ft^2	Additional Detailing and caulking	$ 12,500	$ 12,500	
Air Sealing	PVA paint only for vapor retarder		$ 12,28	Added interior air - vapor barrier, per 072721 - Interior Air Barriers at inside face or all exterior walls (selective walls at basement)	GMP Scope	$ 21,690	$ 9,405	
Thermal Bridging	Standard construction with typical thermal bridging of materials	General Scope	$ -	Specialized details to eliminate most thermal bridges.	Added insulation under footings - additional insulation details	$ 14,400	$ 14,400	
Lighting Systems	Code compliant lighting power density levels	Assumes Permit Set Scope	$ 659,180	Lighting power density 15% below code values	GMP Scope	$ 801,480	$ 142,300	PAE/Stantec to verify that this is still relavant (PAE: Stantec to confirm if this is achievable with the current design)
Air Handling Unit AHU-R01	Code compliant DOAS with 50% effective heat recovery		See mechanic heating/coolin	DOAS with 90% effective heat recovery		See mechanical heating/cooling	See mechanical heating/cooling	
Air Handling Unit AHU-R02	Code compliant DOAS with 50% effective heat recovery		See mechanic heating/coolin	VAV with 56% effective heat recovery, chilled and hot water coils		See mechanical heating/cooling	See mechanical heating/cooling	
Mechanical Heating/Cooling	Air-cooled VRF system - 50 tons total Ceiling-mounted cassettes in T-grid ceiling Outdoor condensing units with electric resistance backup		$ 474,06	Air-cooled heat pump - 430 MBH Two pipe loop with changeover Primary/secondary pumps Electric boiler backup (154 MBH) Fin tube radiators Ceiling fans in all classrooms	Total current HVAC design	$ 1,371,596	$ 897,528	Proposed mechanical system has a smaller capacity due to high building envelope performance and reduced loads.
Kitchen Equipment	Standard refrigeration for kitchen equipment		$ 143,08	Remote refrigeration (outdoor condensing units) for kitchen equipment	GMP Scope	$ 170,347	$ 27,259	
DHW Heating	Electric water heater			Electric heat pump water heater - 82 gallon storage capacity Recovery @ 90F Rise (84 Gal/hr)			$ -	Code compliant based electric heater would have similar capacity to the heat pump
PV Generation	1.5 kW rooftop system		$ 16,63	30 kW rooftop system on Upper School.	GMP Scope	$ 106,743	$ 90,111	GMP Scope - May not fit on new building.
PV Generation	1.5 kW rooftop system		Worth $16,632	22 kW rooftop system - located on Upper School 178 kW rooftop system - located on Lower Campus	Solar - $499,459.85 Roofing - $115,000	Add $614,460 from Code Minimum System	Not in GMP	Refer to design by Artisan Electric for specifics on PV panels and changes to existing lower school infrastucture. Include re-roofing.
Exterior Metal Panel finish	Flouropolymer coating	GMP Scope		Floropon Pure coating	Add Alternate		Not in GMP	Refer to spec and alternates list
Tackable/Acoustic Surface	Fabric wrapped panel with PVC frame		$ 26,450	Filz Felt - wool tackable and acoustic panel product	GMP Scope	$ 61,688	$ 35,239	Refer to spec
Carpet	Carpet - standard		$ 35,04	Carpet w/ Declare Label & Cradle to Cradle ceritification	Assumes carpet on A10.05 is sustainability upgrade	$ 51,756	$ 16,715	Mithun to provide standard carpet example
Marker boards	Enamel			Glass (greater longevity, less waste due to replacement)	Assumes GMP Scope - Only Glass Markerboard shown is in Seminar Room 207		$ -	
Bioretention	11,000 gallon detention tank		$ 42,000	100% of detention to bioretention planters and associated infrastructure	GMP Scope	$ 145,600	$ 103,600	KPFF to verify and provide more definition
		Total Code Compliant Cost	**$ 4,353,11**		Total Sustainability Cost in GMP	**$ 6,355,073**		
					Total Sustainability Upgrades Included in GMP		**$ 2,001,956**	

Constructability

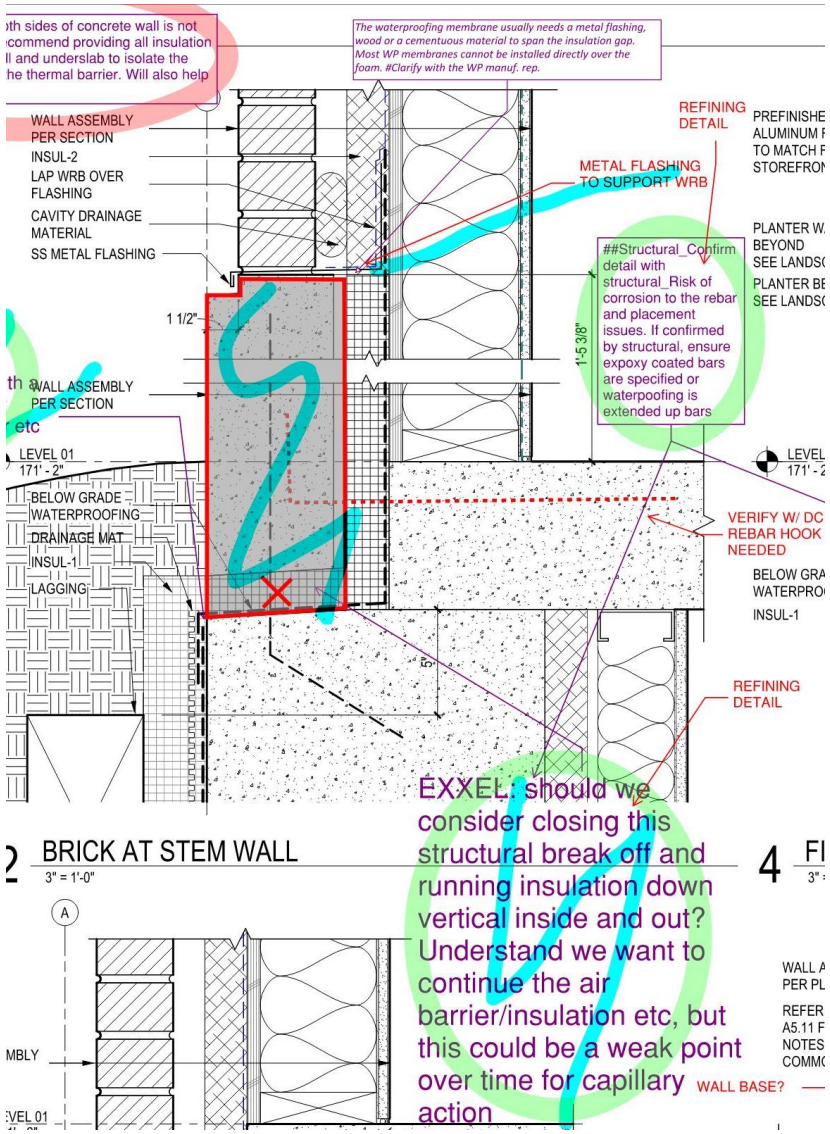


Design



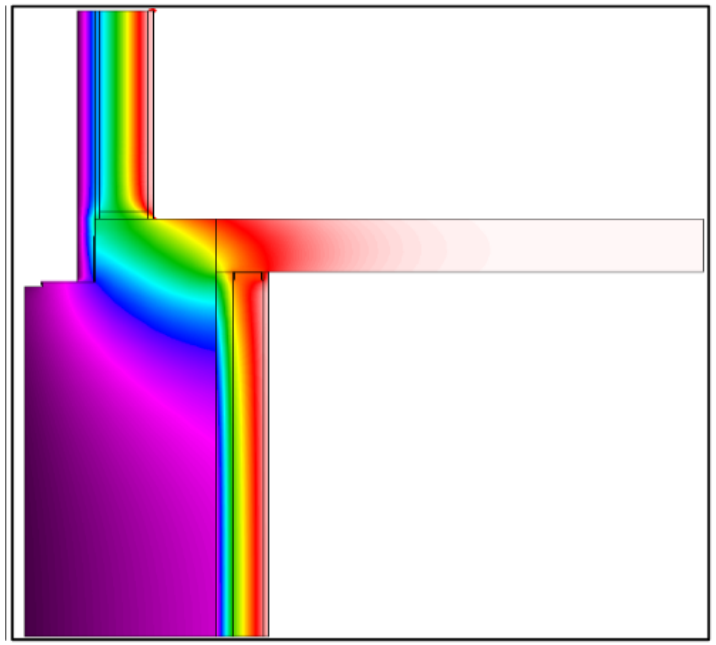
2 BRICK AT STEM WALL
3" = 1'-0"

Constructability



2 BRICK AT STEM WALL
3" = 1'-0"

Modeling



Construction

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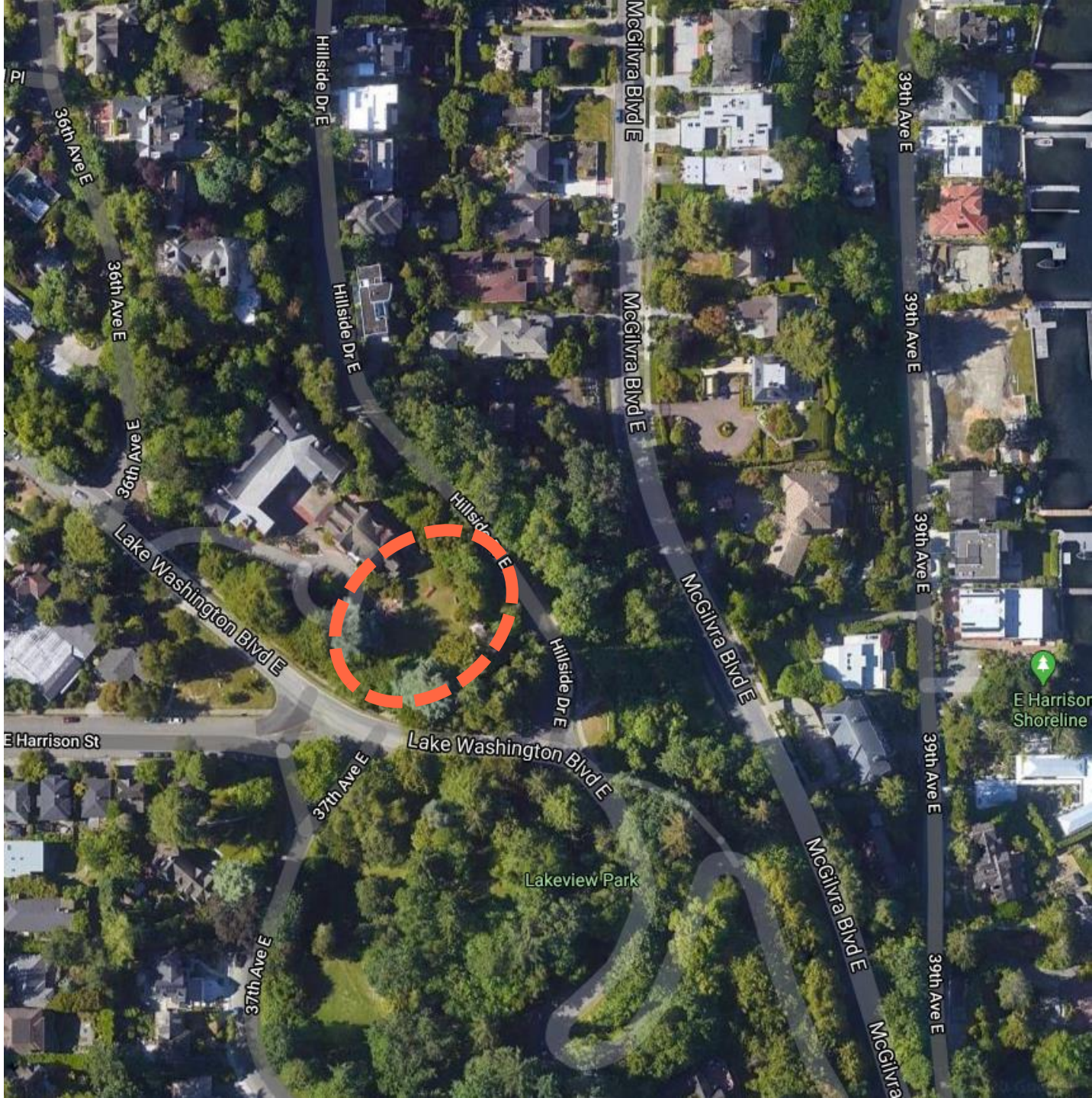
Lessons Learned

Site Advantages

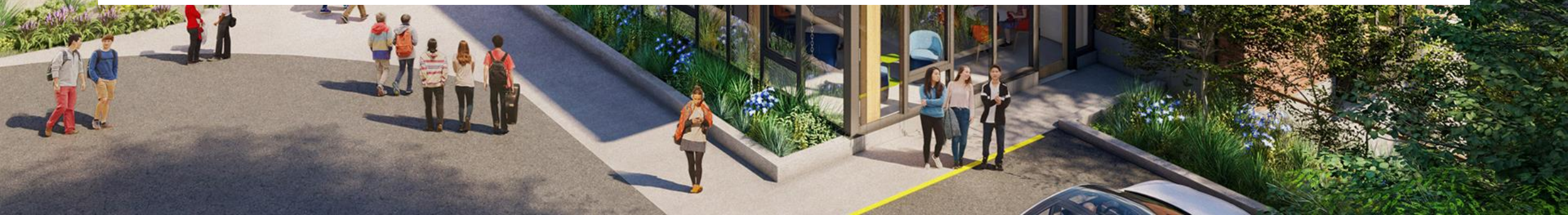
- Mild climate
- Hillside location
- Shading from surrounding buildings and trees
- Clean energy grid (Seattle City Light)
- 2015 Seattle Energy Code
  - High R-values
  - Dedicated outdoor air systems with heat recovery (DOAS)
  - Air leakage testing



Passive House Lessons Learned

- Densely occupied buildings = cooling load dominant
- Envelope requirements informed by internal loading
- Heating and cooling loads shrink – ventilation stays the same
- Simplify for cost and complexity

Assembly	Code Insulation	Bush School Design Insulation
Walls	R-13 + R-7.5ci	R-19 + R-8.4ci
Roof	R-38	R-50
Underground Wall	R-10 ci (exterior)	R-6.4ci (exterior) R-8.4ci + R-13 (interior)
Windows	U-0.30 SHGC 0.35	U-0.15 SHGC 0.24



Passive House Design Approach

1. Incremental envelope improvements over energy code
2. Address plug loads
3. High performance energy recovery
4. Hydronic heating and cooling w/ AWHP

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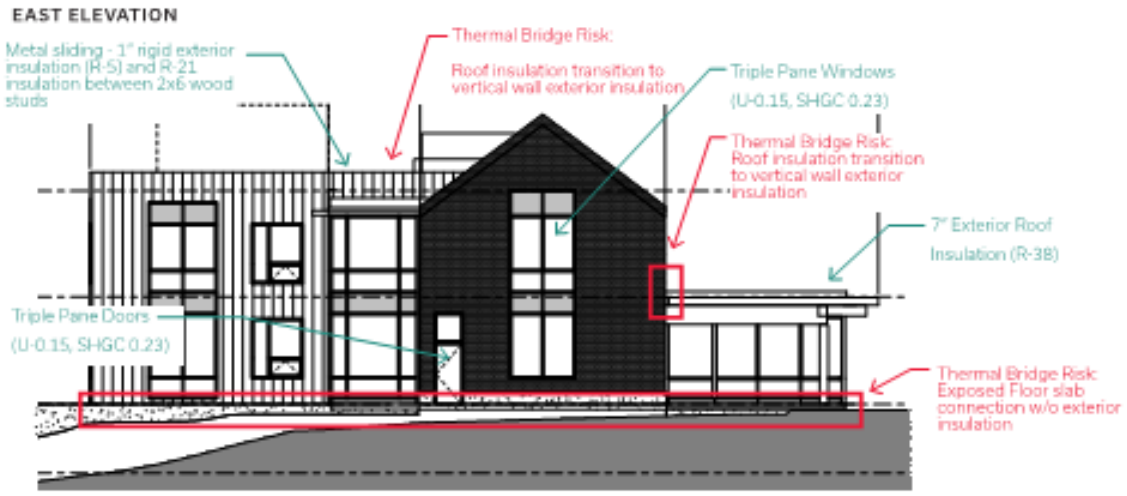
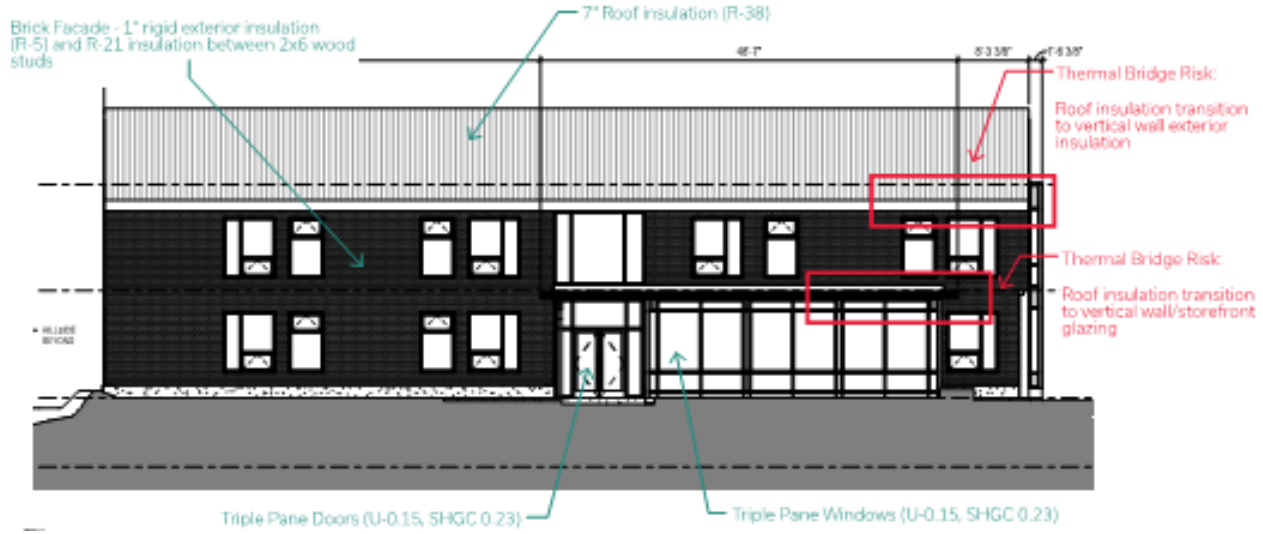
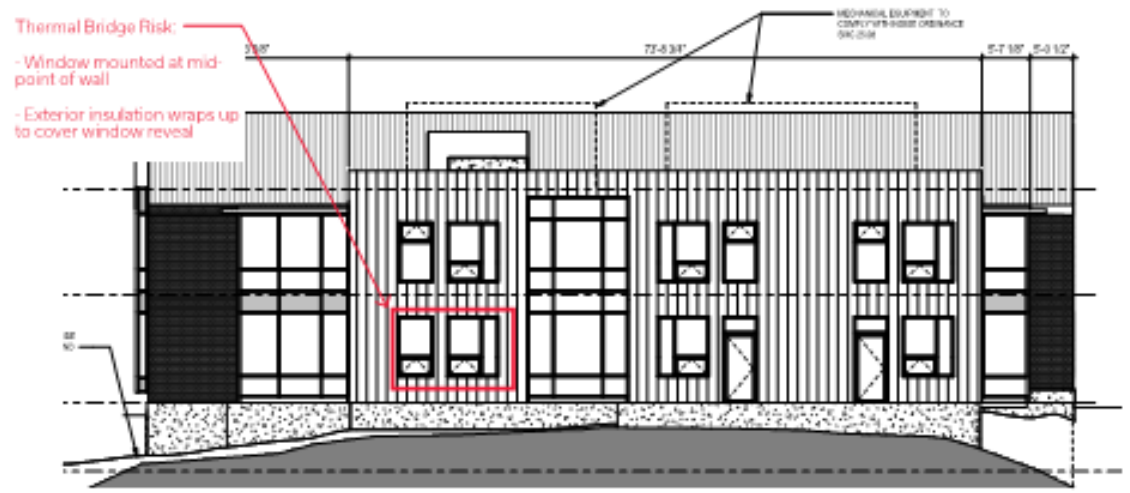
Envelope | Iterative Design Process







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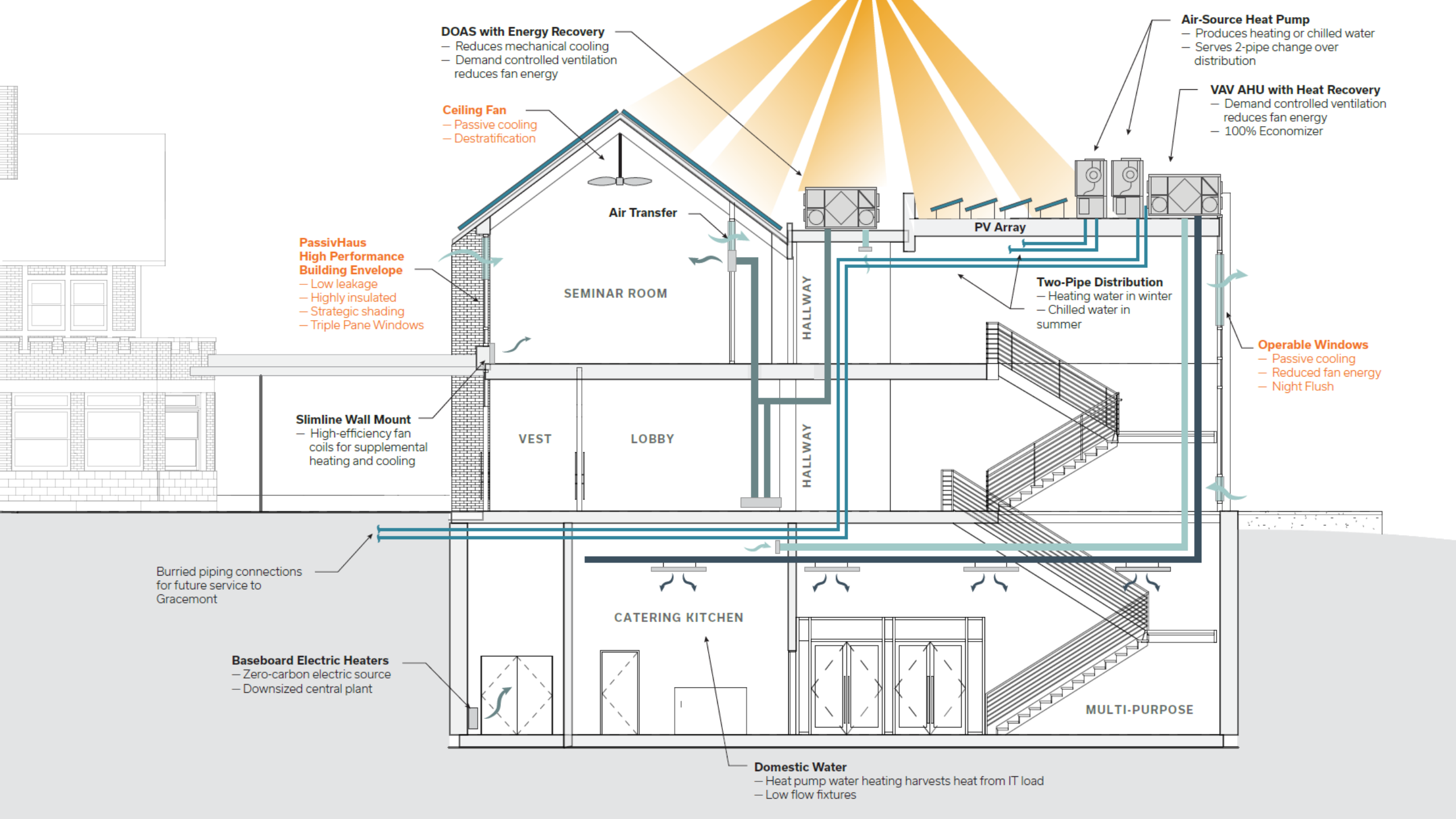
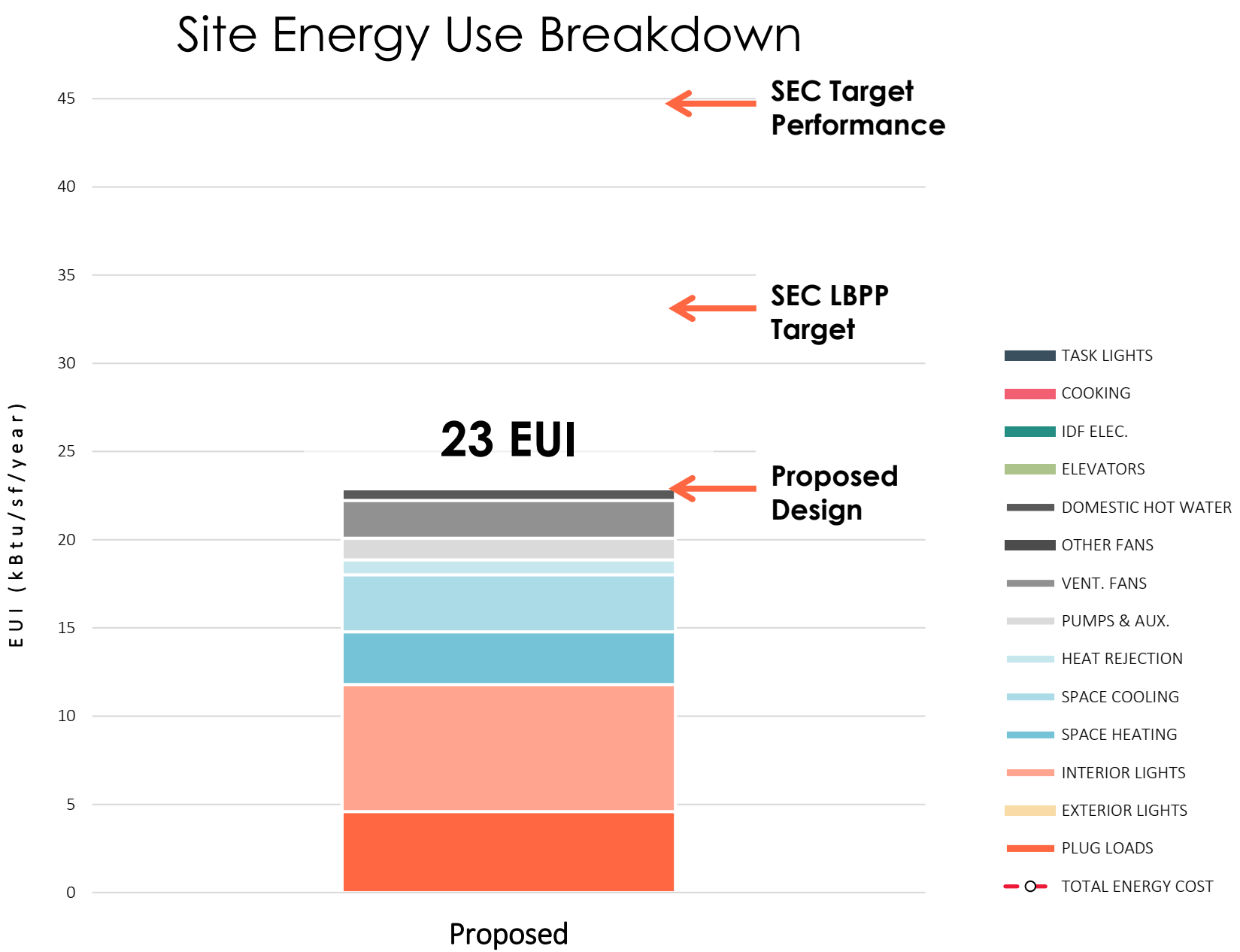
Mechanical Solutions

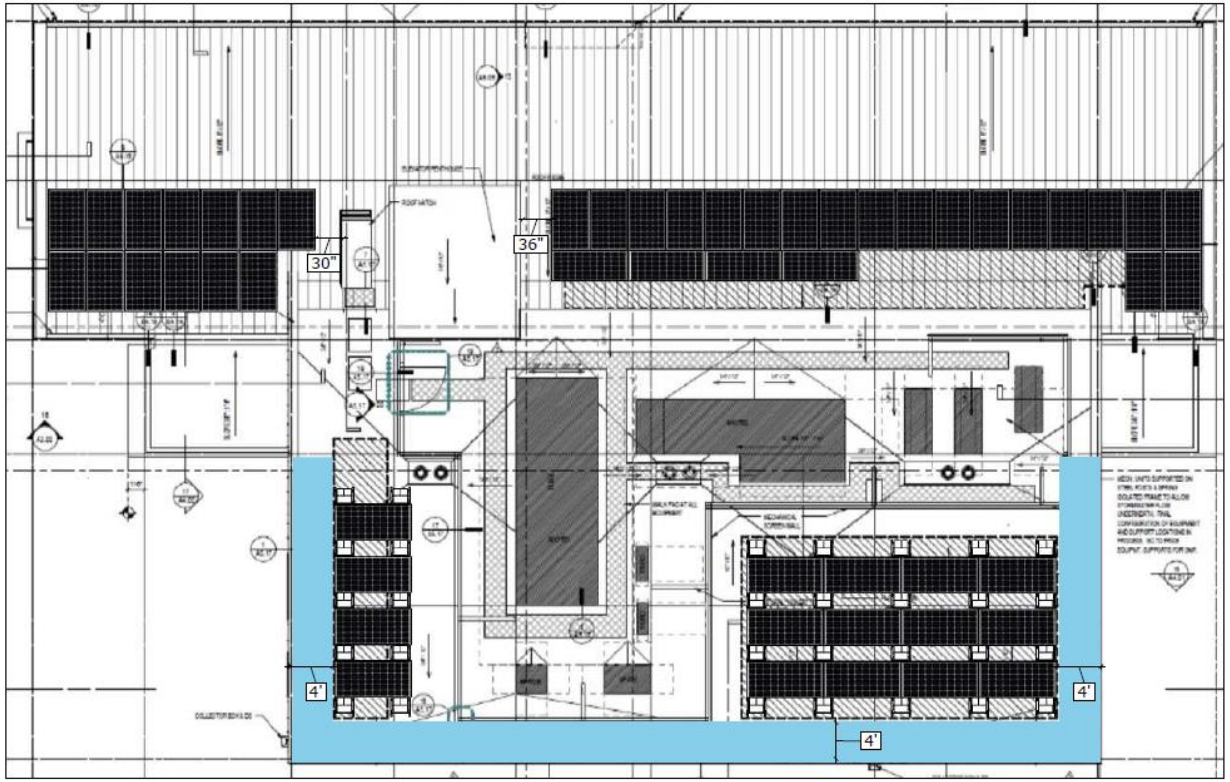
	WEIGHTING FACTOR	OPTION 1: PACKAGED ROOFTOP W/ VAV	OPTION 2: DOAS W/ HW BOILER	OPTION 3: DOAS W/ AIR COOLED VRF	OPTION 4: DOAS W/ AIR COOLED HP
FIRST COST	4	BEST	BETTER	BETTER	BETTER
GHG IMPACT	3	GOOD	GOOD	GOOD	BEST
FLEXIBILITY	1	BETTER	BETTER	BETTER	BETTER
AESTHETICS	2	GOOD	BETTER	BETTER	BETTER
ROOF IMPACT	2	GOOD	BEST	BETTER	BETTER
CEILING HEIGHT	1	GOOD	BEST	BEST	BEST
USEABLE AREA	1	GOOD	BETTER	BETTER	BETTER
THERMAL COMFORT	3	BEST	BETTER	BEST	BEST
MAINTENANCE	2	BETTER	BETTER	BETTER	BETTER
ENERGY COST	4	GOOD	BETTER	BEST	BEST
IEQ	4	BETTER	BEST	GOOD	BEST
ACOUSTICS	3	GOOD	BEST	BETTER	BEST
RAW SCORE		20	30	28	32
WEIGHTED SCORE		51	67	61	78


DOAS with Energy Recovery
— Reduces mechanical cooling
— Demand controlled ventilation reduces fan energy
Ceiling Fan
— Passive cooling
— Destratification
Air-Source Heat Pump
— Produces heating or chilled water
— Serves 2-pipe change over distribution
VAV AHU with Heat Recovery
— Demand controlled ventilation reduces fan energy
— 100% Economizer
Air Transfer
PV Array
PassivHaus High Performance Building Envelope
— Low leakage
— Highly insulated
— Strategic shading
— Triple Pane Windows
SEMINAR ROOM
HALLWAY
Two-Pipe Distribution
— Heating water in winter
— Chilled water in summer
Operable Windows
— Passive cooling
— Reduced fan energy
— Night Flush
Slimline Wall Mount
— High-efficiency fan coils for supplemental heating and cooling
VEST
LOBBY
HALLWAY
Burried piping connections for future service to Gracemont
CATERING KITCHEN
Baseboard Electric Heaters
— Zero-carbon electric source
— Downsized central plant
MULTI-PURPOSE
Domestic Water
— Heat pump water heating harvests heat from IT load
— Low flow fixtures

Zero Energy Certification



LOWER CAMPUS – 142 KW



UPPER SCHOOL – 23 KW

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Advancing Passive House at an Institutional Scale

Bush School, Seattle WA

MITHŪN PAE