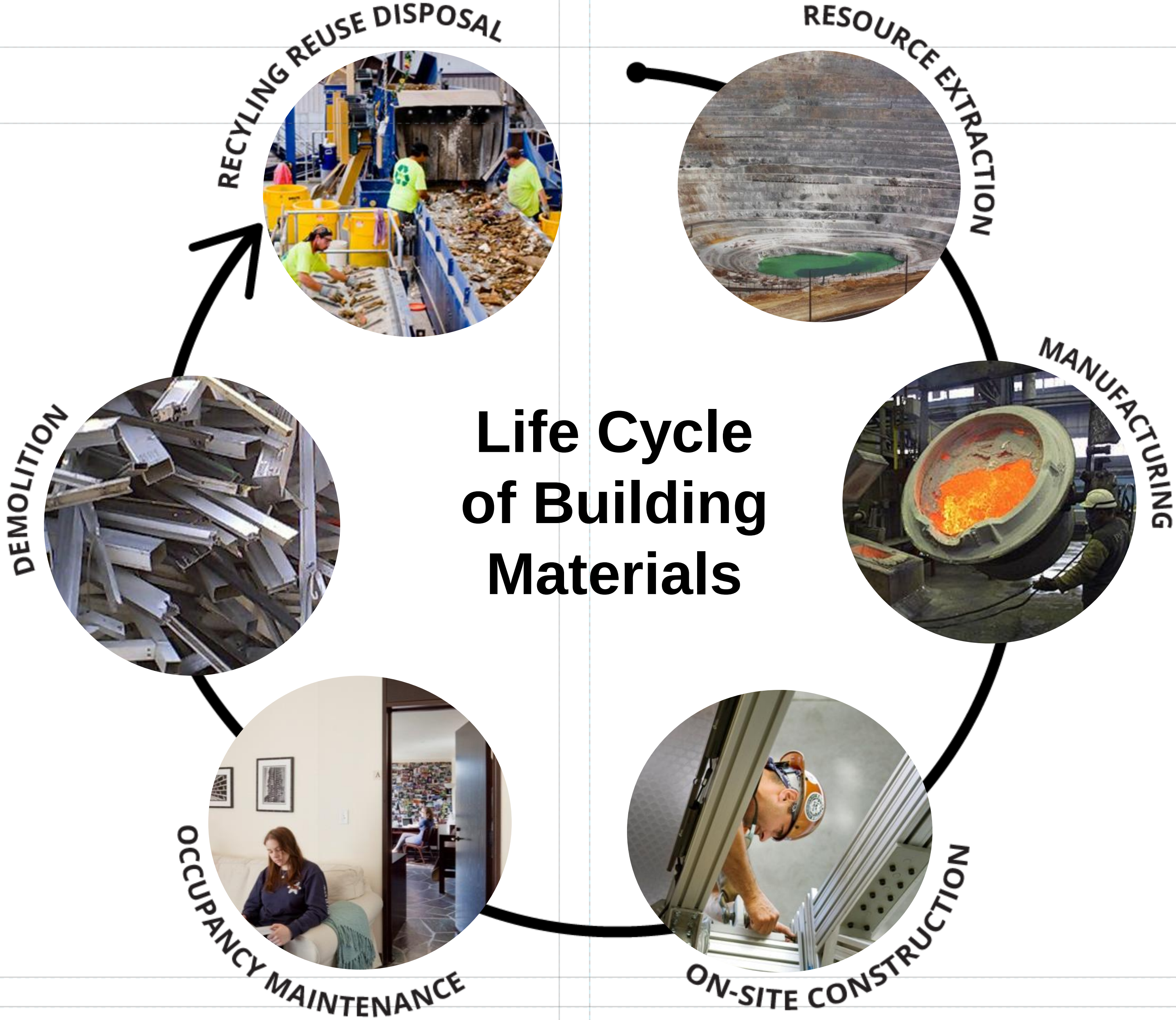

RECYLING REUSE DISPOSAL
RESOURCE EXTRACTION
MANUFACTURING
ON-SITE CONSTRUCTION
OCCUPANCY MAINTENANCE
DEMOLITION
Life Cycle of Building Materials

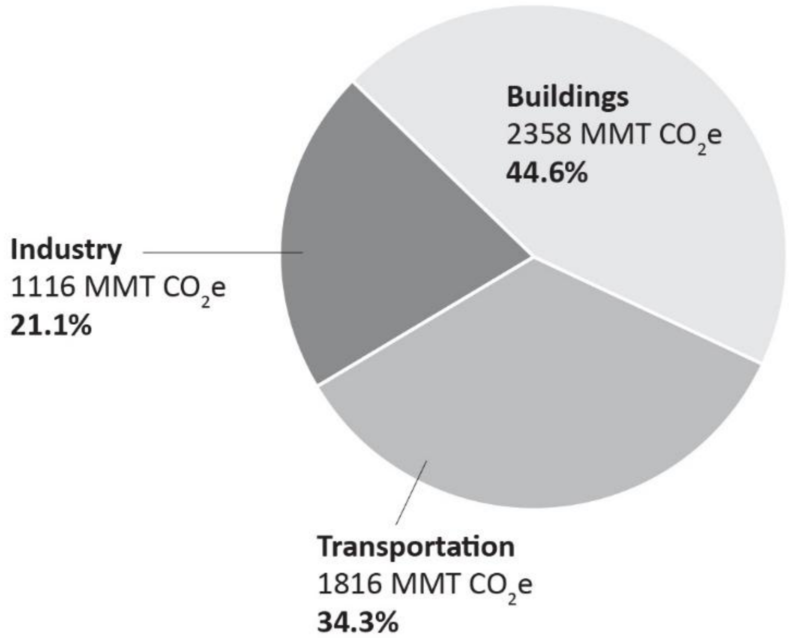
What is the relationship btwn energy efficiency measures and total carbon footprint?

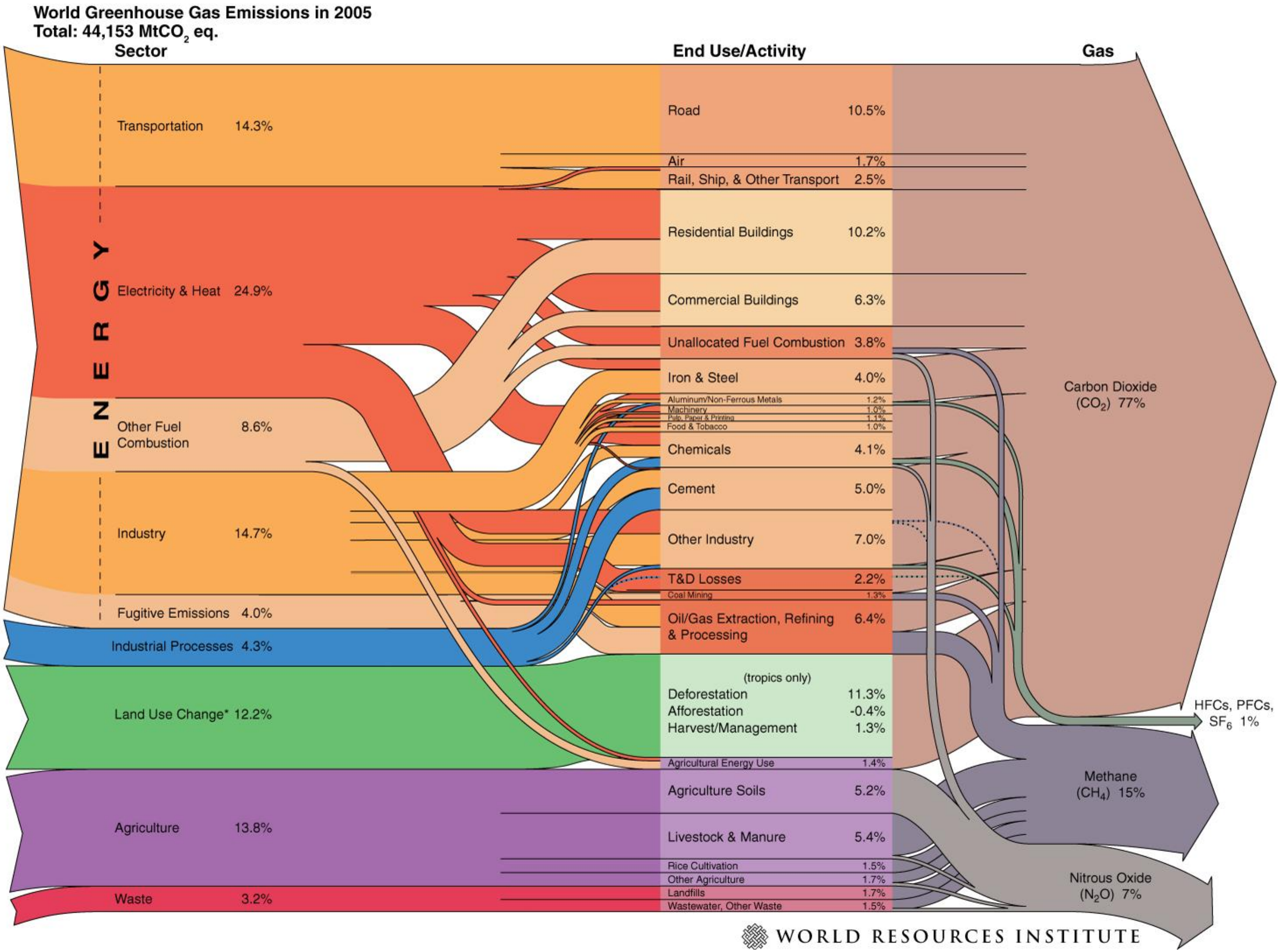
How much does insulation type contribute to environmental impact?

What environmental impacts will my building cause after its useable life?

Can we better articulate (and quantify) the value of building reuse?

US CO_2 EMISSIONS




World Greenhouse Gas Emissions in 2005
Total: 44,153 $MtCO_2$ eq.
Sector
End Use/Activity
Gas
ENERGY
Transportation 14.3%
Electricity & Heat 24.9%
Other Fuel Combustion 8.6%
Industry 14.7%
Fugitive Emissions 4.0%
Industrial Processes 4.3%
Land Use Change* 12.2%
Agriculture 13.8%
Waste 3.2%
Road 10.5%
Air 1.7%
Rail, Ship, & Other Transport 2.5%
Residential Buildings 10.2%
Commercial Buildings 6.3%
Unallocated Fuel Combustion 3.8%
Iron & Steel 4.0%
Aluminum/Non-Ferrous Metals 1.2%
Machinery 1.0%
Pulp, Paper & Printing 1.1%
Food & Tobacco 1.0%
Chemicals 4.1%
Cement 5.0%
Other Industry 7.0%
T&D Losses 2.2%
Coal Mining 1.3%
Oil/Gas Extraction, Refining & Processing 6.4%
(tropics only)
Deforestation 11.3%
Afforestation -0.4%
Harvest/Management 1.3%
Agricultural Energy Use 1.4%
Agriculture Soils 5.2%
Livestock & Manure 5.4%
Rice Cultivation 1.5%
Other Agriculture 1.7%
Landfills 1.7%
Wastewater, Other Waste 1.5%
Carbon Dioxide (CO_2) 77%
HFCs, PFCs, SF_6 1%
Methane (CH_4) 15%
Nitrous Oxide (N_2O) 7%
WORLD RESOURCES INSTITUTE

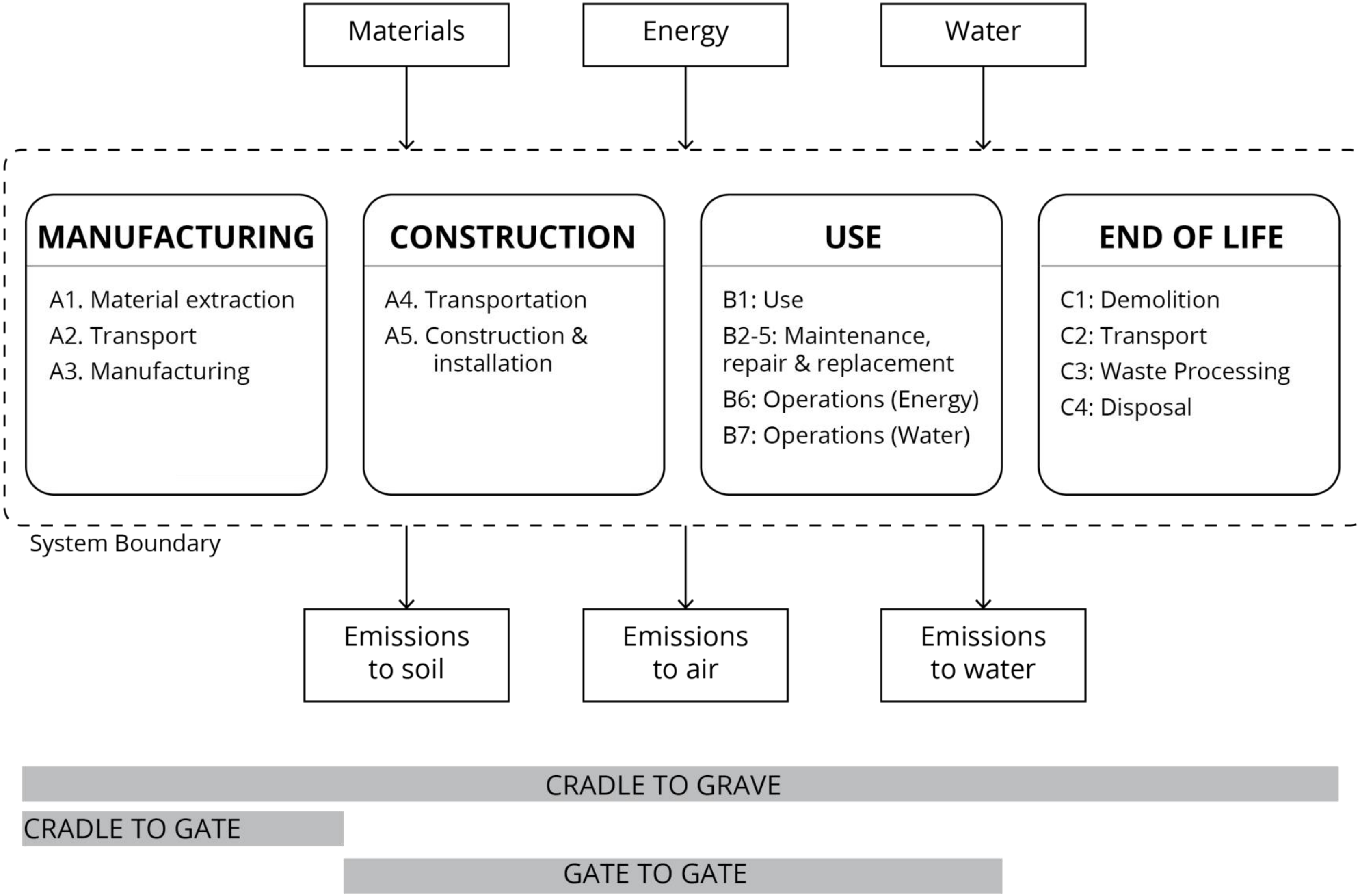
Source: J. Henry Fair

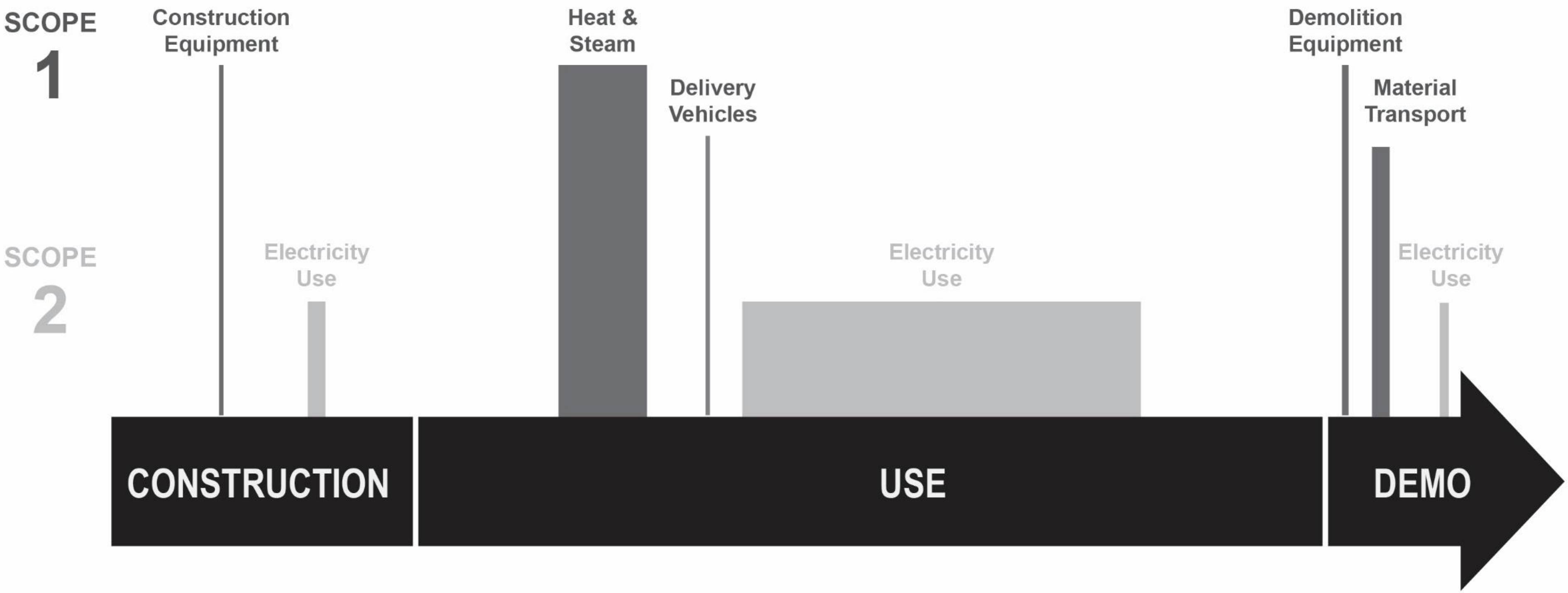
UNCOVERING ENVIRONMENTAL IMPACTS APPALACHIAN COAL MINING

Qian’an steelworks in Tangshan
Source: Xiaolu Chu / Getty Images

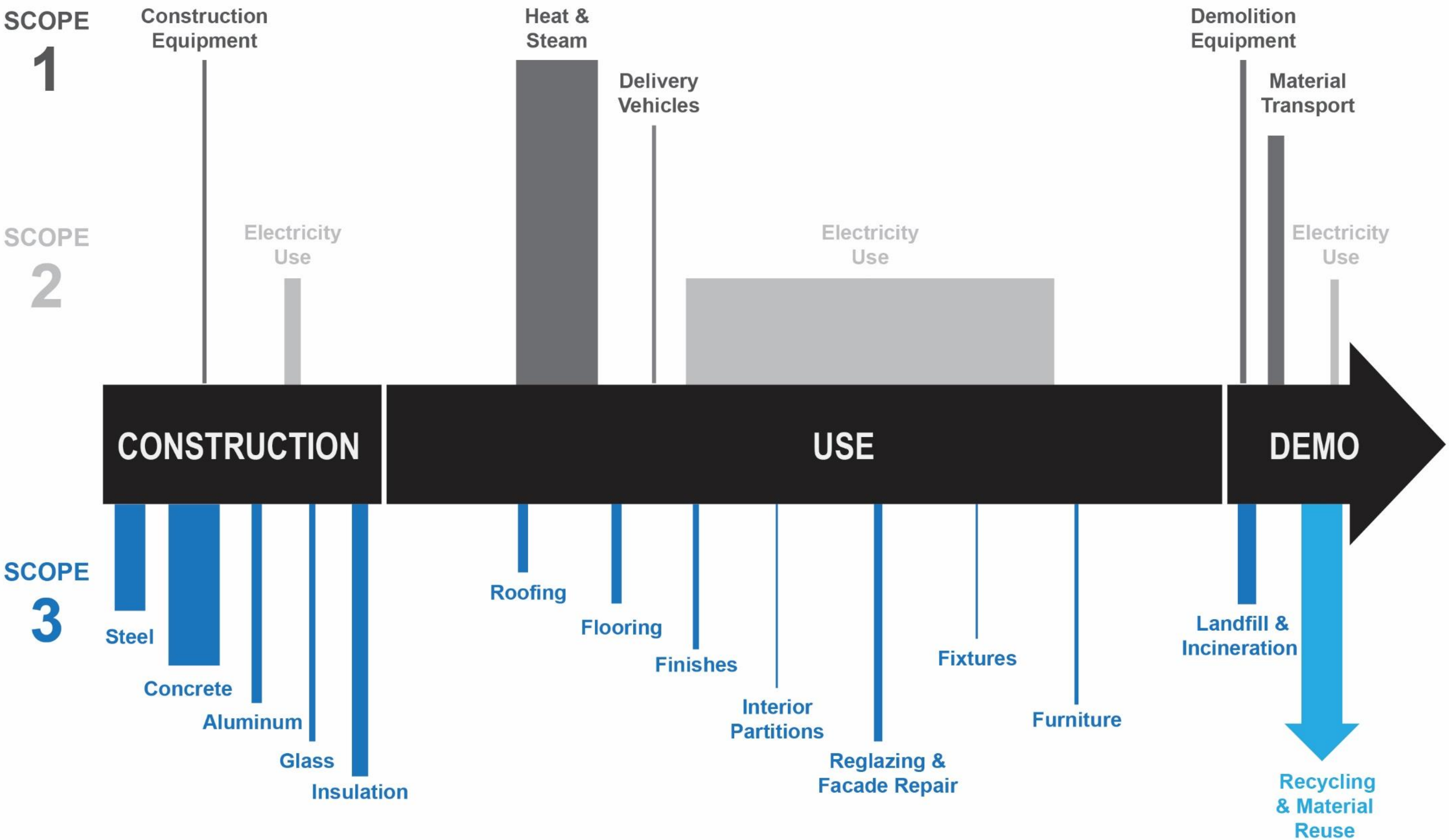
Baotou toxic lake
Source: Liam Young / Unknown Fields

UNCOVERING ENVIRONMENTAL IMPACTS REFINING RARE EARTH MINERALS


Materials
Energy
Water
MANUFACTURING
A1. Material extraction
A2. Transport
A3. Manufacturing
CONSTRUCTION
A4. Transportation
A5. Construction & installation
USE
B1: Use
B2-5: Maintenance, repair & replacement
B6: Operations (Energy)
B7: Operations (Water)
END OF LIFE
C1: Demolition
C2: Transport
C3: Waste Processing
C4: Disposal
System Boundary
Emissions to soil
Emissions to air
Emissions to water
CRADLE TO GRAVE
CRADLE TO GATE
GATE TO GATE



SCOPE 1, 2 & 3 FROM A BUILDING PERSPECTIVE



SCOPE 1, 2 & 3 FROM A BUILDING PERSPECTIVE

Global warming potential (GWP)

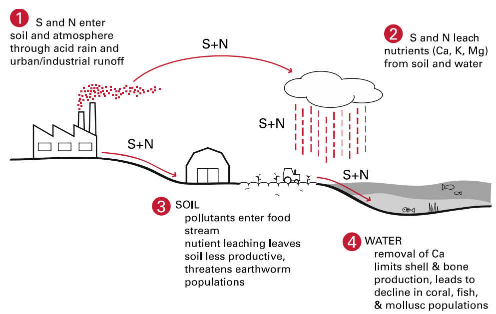
Acidification potential (AP)

Eutrophication potential (EP)

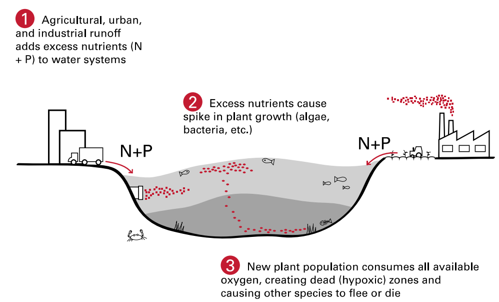
Ozone depletion potential (ODP)

Smog potential (SP)

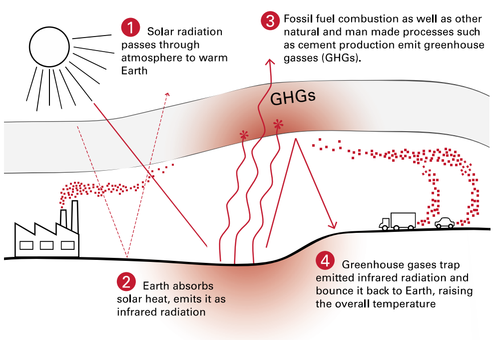
Primary Energy Demand (PED)



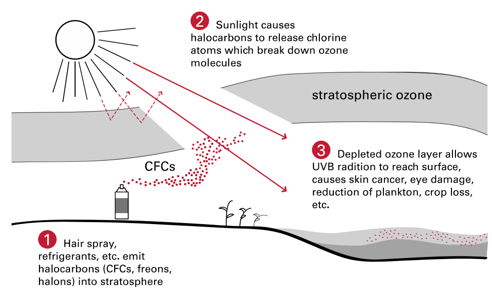
ACIDIFICATION



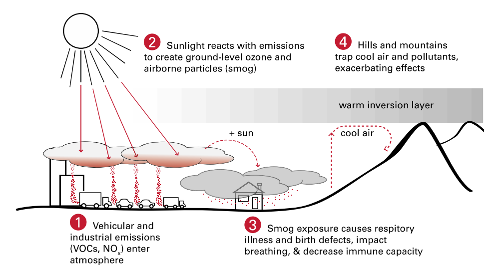
EUTROPHICATION



GLOBAL WARMING

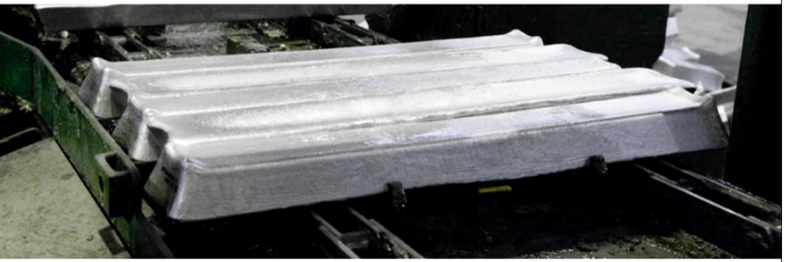


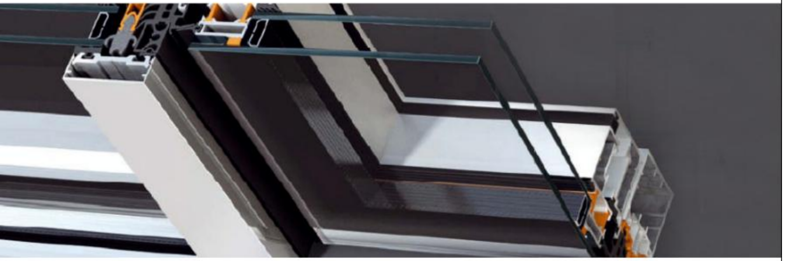
OZONE DEPLETION



SMOG

Source: K. Simonen, *Life Cycle Assessment,* Routledge, 2014





LOBLOLLY HOUSE: UNBOLT, DETACH, REASSEMBLE

KIERANTIMBERLAKE

ELEMENT INTEGRATION
SCAFFOLD TO CARTRIDGE

DETAILED FOR DISASSEMBLY
STRUCTURAL ALUMINUM SCAFFOLD

RAIN SCREEN

WALL CARTRIDGE

FLOOR CARTRIDGE

Loblolly House, located on the shore of the Chesapeake Bay, represents a novel approach to pre-fabricated and modular housing concepts. The house introduces off-site fabricated elements which are detailed for on-site assembly, future disassembly and redeployment.

This entry conducts a virtual house disassembly/reassembly, an embodied energy and carbon footprint analysis and accounts a design-for-reassembly scenario to evidence the potential of a near 100% waste diversion design intent.

Architect	KieranTimberlake
Disassembly Team	Billie Faircloth, AIA, Roderick Bates, Haley Gilbert
Design Team	Stephen Kieran, FAIA, James Timberlake, FAIA, David Riz, AIA, Marilia Rodrigues, Johnathan Ferrari, Alex Gauzza, Jeff Goldstein AIA, Shawn Protz, George Ristow, Mark Rhoads
Fabrication & Assembly	Bensonwood Homes
Construction Manager	Arena Program Management
Structural Engineer	CVM Structural Engineers
MEP Engineer	Bruce Brooks & Associates
Civil Engineer	Lane Engineering
Geotechnical Engineer	John D. Hynes & Associates, Inc.
Interiors	Marguerite Rodgers, Ltd.
Landscape	Barbara Seymour Landscapes
Photographers	Peter Aaron/Esto, Barry Halkin

01 DETACH exterior steel stair.
02 DETACH cedar rain-screen from east, north and south walls: UNCLIP prefabricated screen units from each wall
03 REMOVE all wall cartridges: UNBOLT from structural scaffold (wall cartridges contain no building systems).
04 DISCONNECT building systems: UNPLUG systems from service spine in roof, second floor and first floor.
05 REMOVE roof cartridges: PEEL OFF TPO membrane and XPS insulation, UNBOLT roof cartridges from structural scaffold.
06 REMOVE 2nd floor block (master bathroom: UNBOLT three scaffold members at the northeast corner of the 2nd floor and HOIST bathroom block to truck with crane.
07 REMOVE interior stair: UNBOLT stair and HOIST stair to truck with crane assist.
08 REMOVE 1st floor blocks (guest bath/ mechanical room and kitchen): UNBOLT three scaffold members at southeast corner of 2nd floor and HOIST each block to truck with crane.
09 REMOVE hangar doors: UNBOLT exterior horizontally folding hangar doors from tube steel frame comprising west wall.
10 REMOVE Nanawall™: UNBOLT interior vertically folding hangar doors from tube steel frame comprising west wall.
11 DETACH tube steel frame: UNBOLT u-clips between the west wall's tube steel frame and structural scaffold; HOIST away frame.
12 REMOVE all floor cartridges, and floor service spines on the first and second floor: UNBOLT cartridges and spines.
13 DISASSEMBLE structural scaffold: UNBOLT frame column, beam and cross bracing sections, sort and pile.
14 DISASSEMBLE structural sub-framing: UNBOLT timber beams from the pile foundation system.
15 REMOVE piles: CUT exposed pile sections.
16 PACK parts for REASSEMBLY on two flatbed trucks.

CARBON INVENTORY BY ELEMENT

	STAIRS	RAIN SCREEN	ROOF CARTRIDGES	WEST WALL GLAZING	WALL CARTRIDGES	FLOOR CARTRIDGES	SCAFFOLD	FOUNDATION
MATERIAL	Steel	Cedar	TPO Membrane Rigid Insulation Plywood BATT Insulation Wood Joist	Steel Frame Acrylic Panels Nana Wall™	Glass Veneer Plywood PU Spray Foam Cement Board Wood Studs	BATT Insulation Bamboo Cedar Veneer Plywood Wood Joist	Bosch Aluminum Scaffold Steel Connectors	Wood Piles Engineered Timber frame
WEIGHT (LBS)	2,000 lbs. steel	2,896 lbs. cedar	311 lbs. TPO 255 lbs. rigid 7,776 lbs. plywood 1,568 lbs. BATT 1,425 lbs. joist	2,000 lbs. steel 1,369 lbs. acrylic 22,356 lbs. nana wall™	2,862 lbs. glass 12,359 lbs. birch 2,682 lbs. PU foam 715 lbs. cement board 6,672 lbs. wood studs	2,284 lbs. BATT 2,461 lbs. bamboo 238 lbs. cedar 2,974 lbs. birch 2,850 lbs. joist	8,549 lbs. aluminum 1000 lbs. steel	11,402 lbs. piles 5,100 lbs. timber
EMBODIED ENERGY (Kcal)†	4,854,000 Kcal steel	1,135,988 Kcal cedar	*Kcal TPO 3,304,590 Kcal rigid 10,528,704 Kcal plywood 4,926,028 Kcal BATT 558,944 Kcal joist	4,854,000 Kcal steel 13,588,512 Kcal acrylic 33,914,052 Kcal nana wall™	4,340,999 Kcal glass 16,733,620 Kcal birch 383,520 Kcal PU foam 735,884 Kcal cement board 2,616,683 Kcal wood studs	7,175,580 Kcal BATT 399,859 Kcal bamboo 93,187 Kcal cedar 40,226,176 Kcal birch 1,117,888 Kcal joist	177,000,000 Kcal aluminum 2,427,000 Kcal steel	4,471,743 Kcal piles 2,000,110 Kcal timber
CARBON FOOTPRINT (LBS CO2)†	3,800 lbs. steel	-3,360 lbs. cedar	*lbs. TPO 5,240 lbs. rigid -6,532 lbs. plywood 2,446 lbs. BATT -1,653 lbs. joist	3,800 lbs. steel 4,423 lbs. acrylic 17,885 lbs. nana wall™	2,289 lbs. glass -10,381 lbs. birch 115,357 lbs. PU foam * lbs. cement board -7,739 lbs. wood studs	3,563 lbs. BATT -2,854 lbs. bamboo -276 lbs. cedar -2,498 lbs. birch -3,306 lbs. joist	102,583 lbs. aluminum 1,900 lbs. steel	-13,226 lbs. piles -5,916 lbs. timber

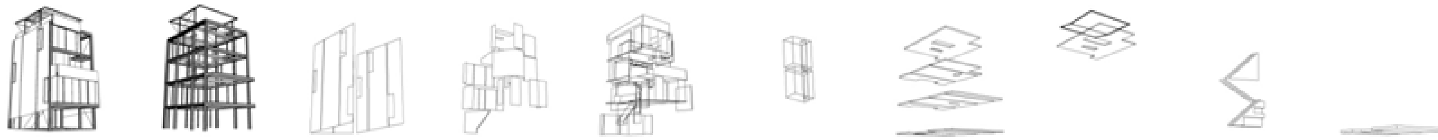
DESIGN FOR

REASSEMBLY								
RECYCLE								

CO2 RECOVERED
= 205,545 LBS

* Information not currently available for material
† All information from Granta CES Material Selector for virgin material extraction
‡ Bathroom, Kitchen, and Mechanical blocks not included in carbon footprint analysis but would be redeployed in reassembly scenario

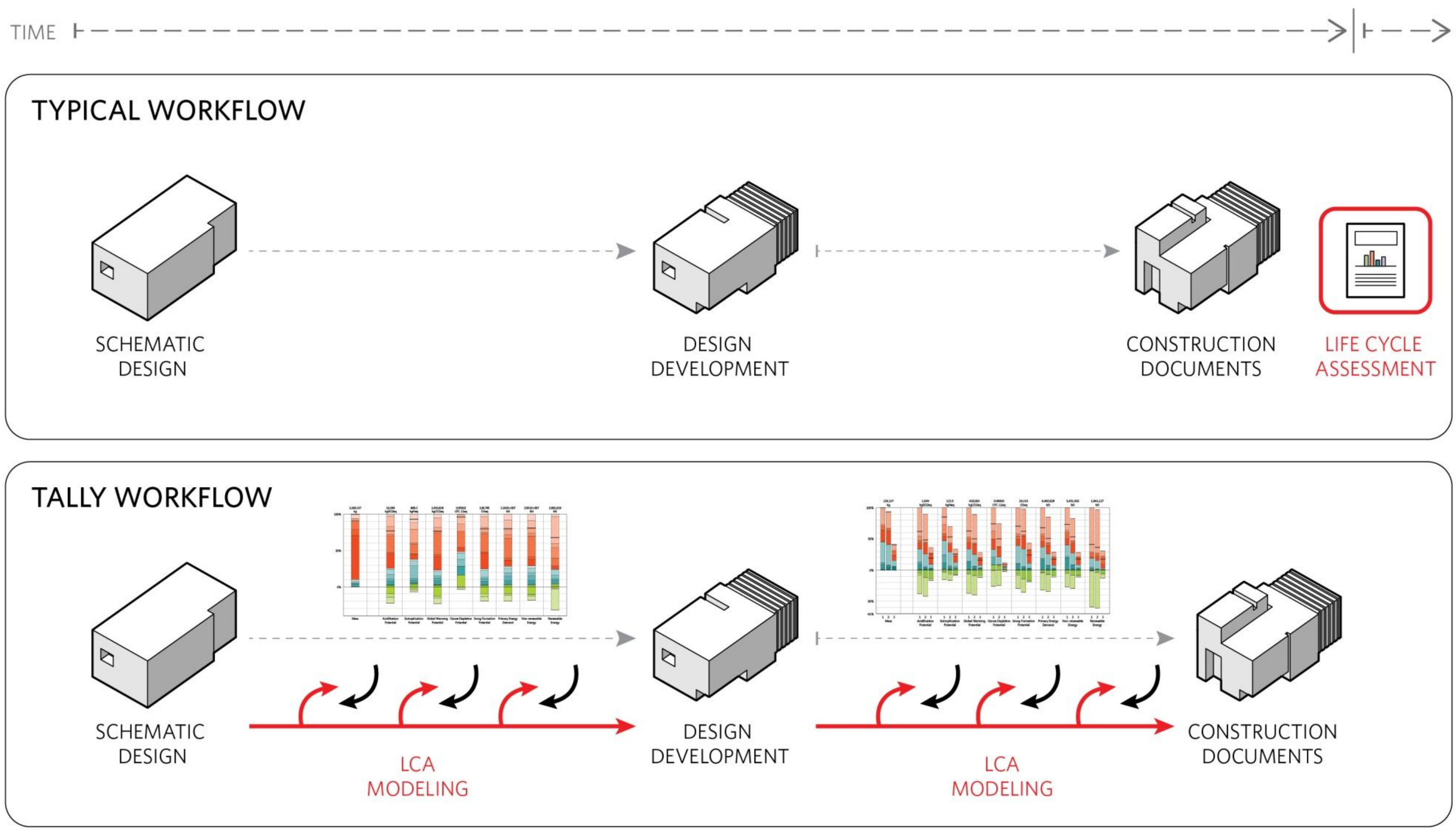
LIFECYCLE BUILDING CHALLENGE 2
designing this building, and the next
KieranTimberlake
Professional Built Building
Winner



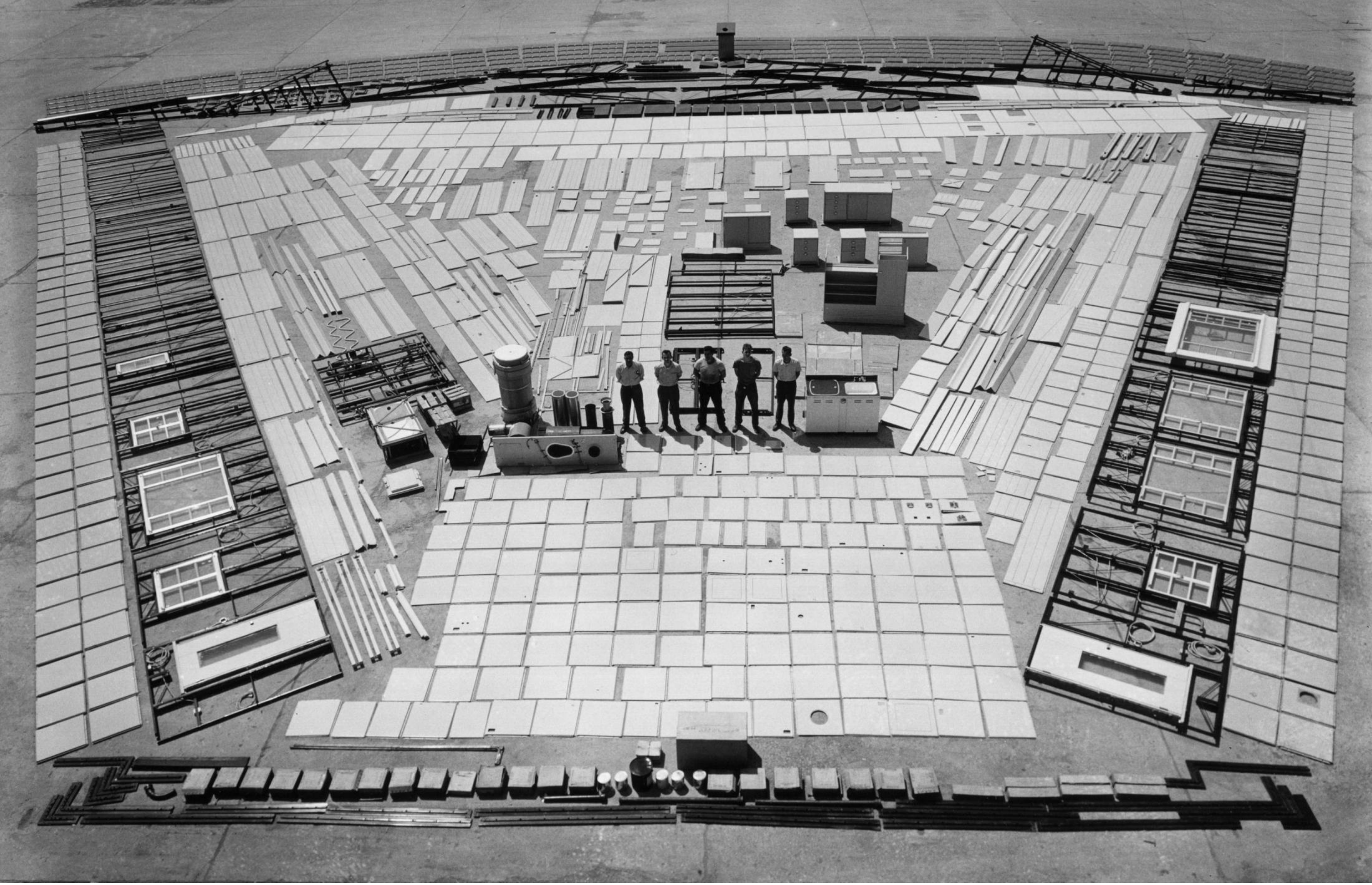
COMPONENT	FRAME	SKIN	GLAZING	WALL PANELS	BATHROOM PODS	FLOORS	ROOF	STAIRS	FOUNDATION	TOTALS 1,800 sf building
MATERIAL	Bosch Aluminum Framing; Steel Connectors; Steel Bolts	NextGen Smart Wrap ™ (PET); Aluminum Louvers	Schüco Glass; Schüco Aluminum Frame	3-Form Varia (PETG)	Fiberglass	Aluminum Grate; 3-Form Stage (PC)	PVC Downspouts; Steel Gutters; Danpalon (PC)	Acrylic	Concrete; Steel Rebar	
TOTAL EMBODIED ENERGY	955,631 kWh	22,224 kWh	71,423 kWh	22,577 kWh	71,448 kWh	146,008 kWh	8,214 kWh	235,001 kWh	15,264 kWh	1,547,790 kWh 860 kWh/sf
PERCENT RECOVERED	99.99%	100%	100%	100%	100%	100%	100%	100%	0%	98.95%
EMBODIED ENERGY RECOVERED	954,675 kWh	22,224 kWh	71,423 kWh	22,577 kWh	71,448 kWh	146,008 kWh	8,214 kWh	235,001 kWh	0 kWh	1,531,570 kWh 851 kWh/sf

MATERIAL	Bosch Aluminum Framing; Steel Connectors; Steel Bolts	NextGen Smart Wrap ™ (PET); Aluminum Louvers	Schüco Glass; Schüco Aluminum Frame
TOTAL EMBODIED ENERGY	955,631 kWh	22,224 kWh	71,423 kWh
PERCENT RECOVERED	99.99%	100%	100%
EMBODIED ENERGY RECOVERED	954,675 kWh	22,224 kWh	71,423 kWh

TOTALS 1,800 sf building
1,547,790 kWh 860 kWh/sf
98.95%
1,531,570 kWh 851 kWh/sf

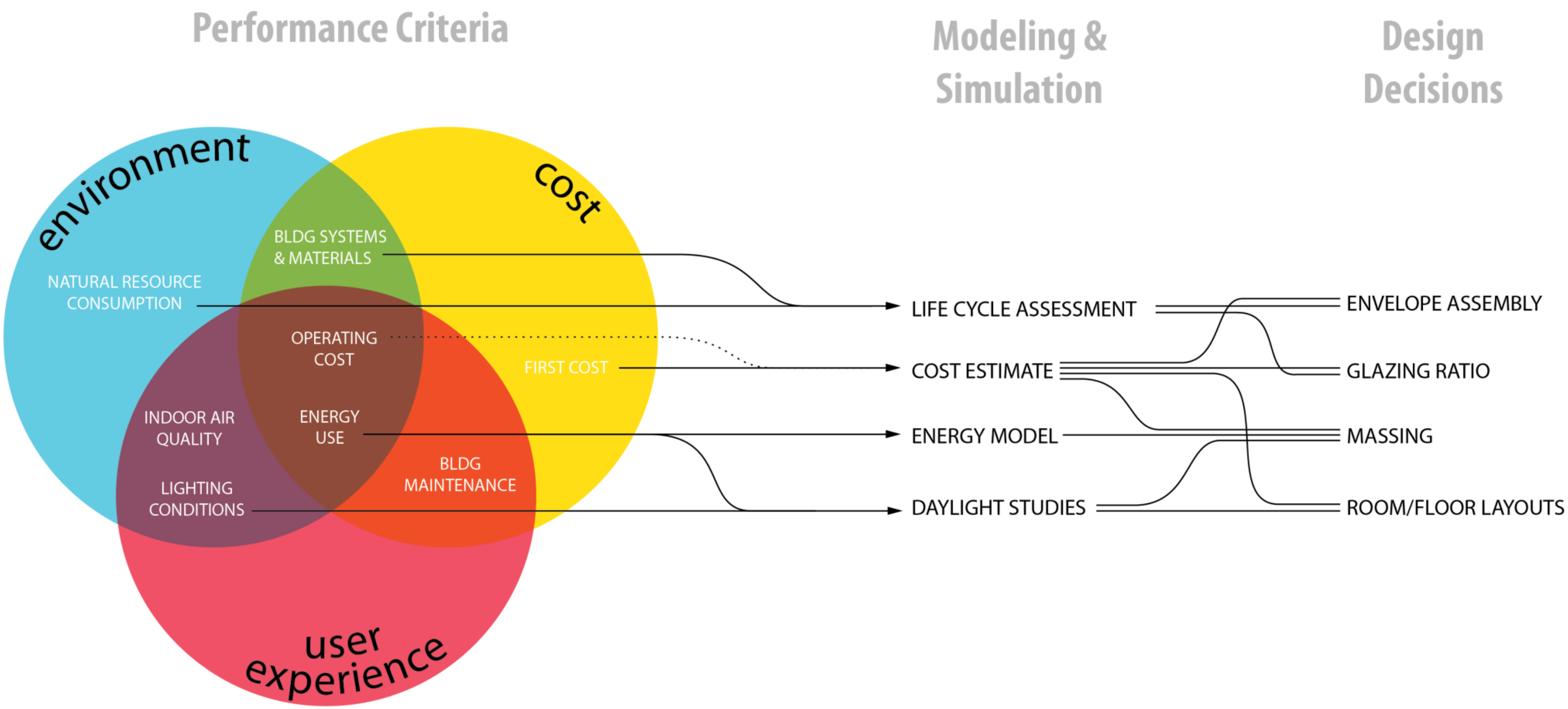


TYPICAL VS. ITERATIVE LCA WORKFLOW



Source: Getty Images

DATA AND COMPLEXITY THE PROBLEM WITH COUNTING


Performance Criteria
Modeling & Simulation
Design Decisions
environment
cost
user experience
BLDG SYSTEMS & MATERIALS
NATURAL RESOURCE CONSUMPTION
OPERATING COST
FIRST COST
INDOOR AIR QUALITY
ENERGY USE
BLDG MAINTENANCE
LIGHTING CONDITIONS
LIFE CYCLE ASSESSMENT
COST ESTIMATE
ENERGY MODEL
DAYLIGHT STUDIES
ENVELOPE ASSEMBLY
GLAZING RATIO
MASSING
ROOM/FLOOR LAYOUTS

tally®

About Support Download News

KNOW YOUR IMPACT

Introducing Tally

The first LCA app that lets you calculate the environmental impacts of your building material selections directly in an Autodesk® Revit® model.

Click to download a free trial

WHOLE BUILDING LCA

Assess the embodied environmental impact of your entire building. Benchmark your impact throughout design.

DESIGN OPTION COMPARISON

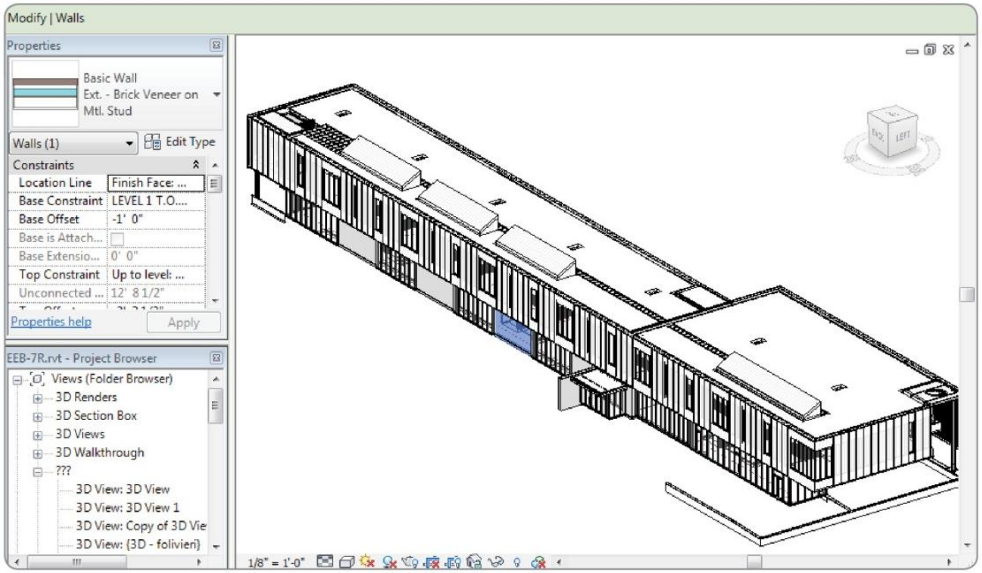
Compare two or more distinct sets of building components side by side.

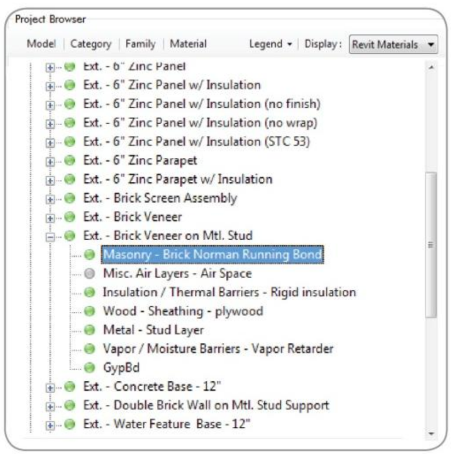
MATERIAL SELECTION

Compare LCA impacts and ingredients of materials and assemblies, including information from manufacturer EPDs.

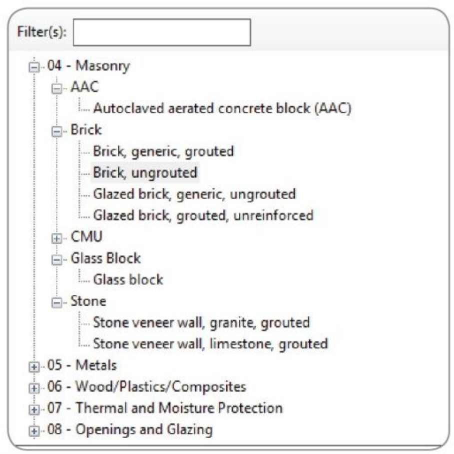
A joint development project from KT Innovations, thinkstep, and Autodesk

REVIT MODEL

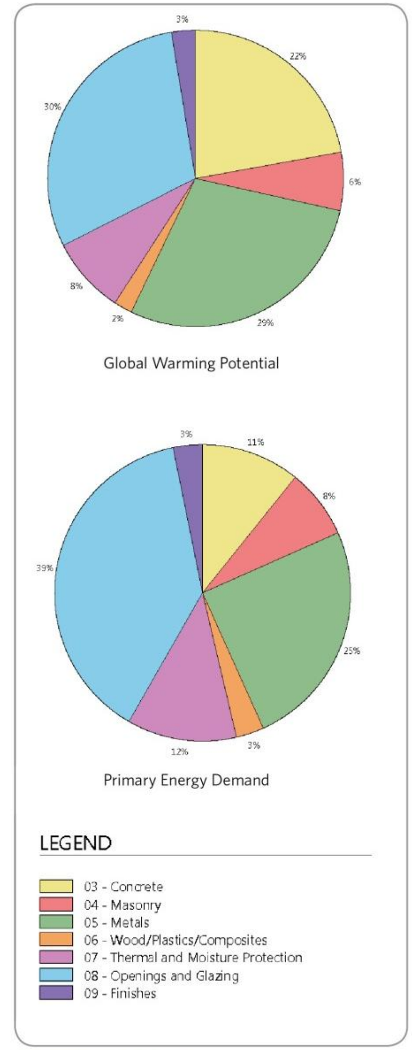




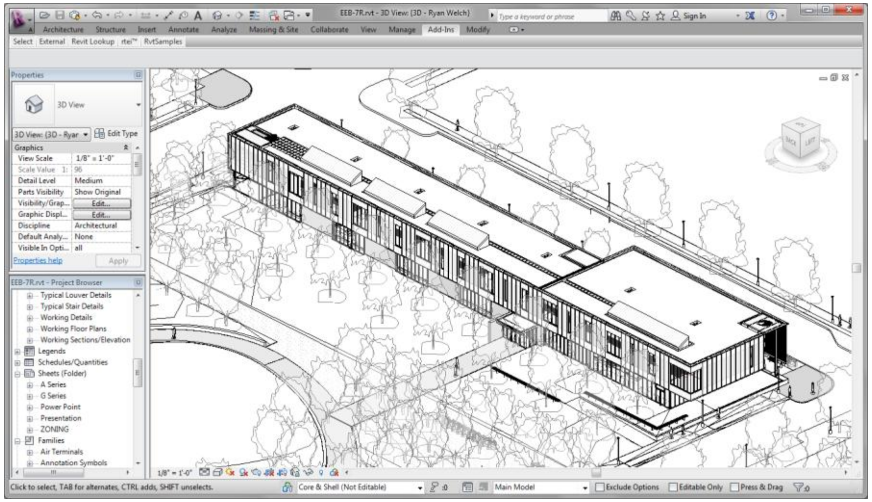
TALLY™ Material quantities are pulled from the Revit model



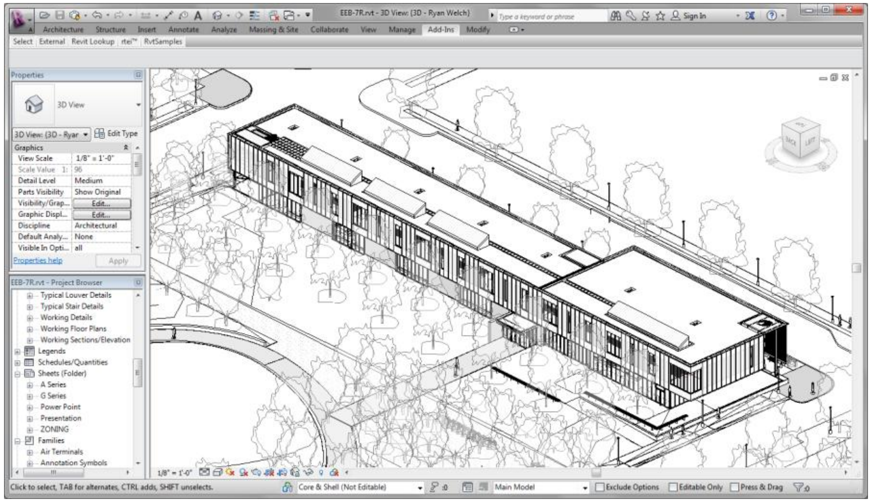
DATABASE Impacts are captured in an LCA database



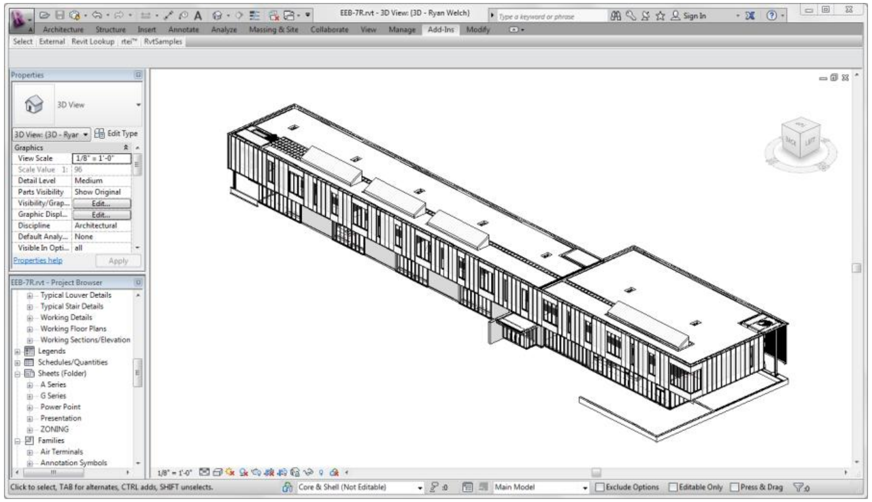
TALLY™ REPORT Design and material selection questions are rapidly answered



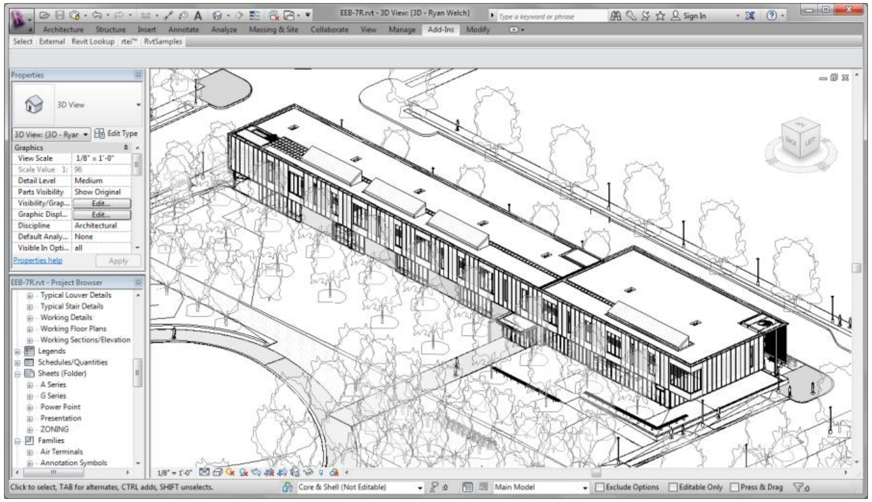
1. Building information model



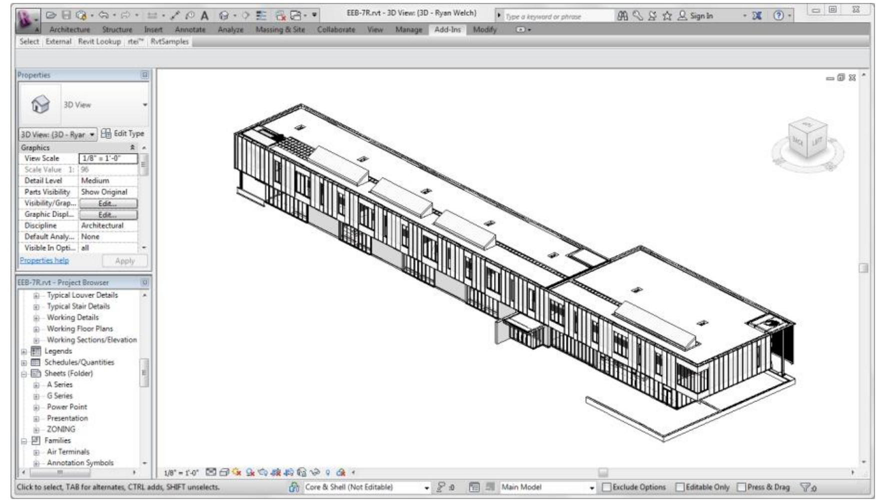
1. Building information model



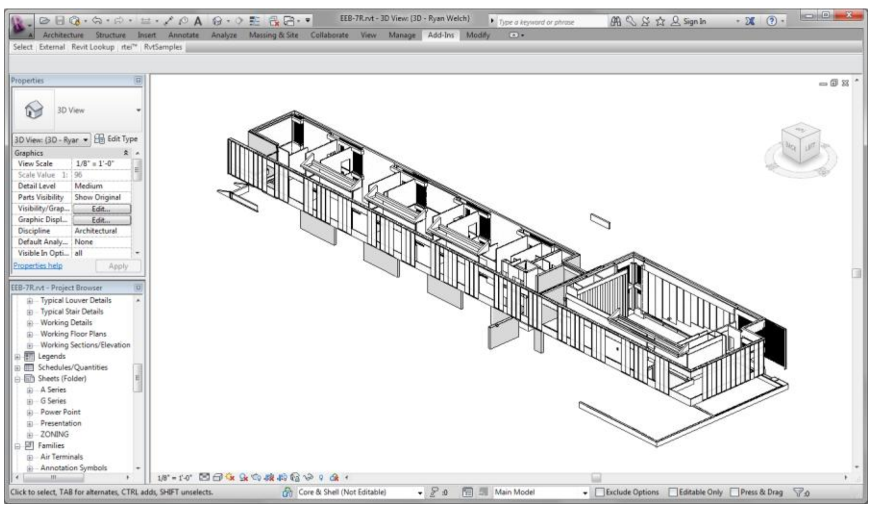
2. Define scope of study



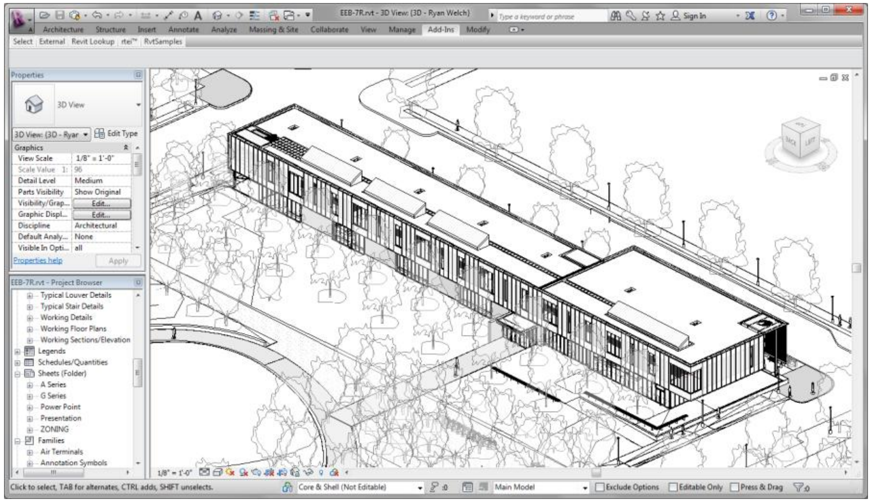
1. Building information model



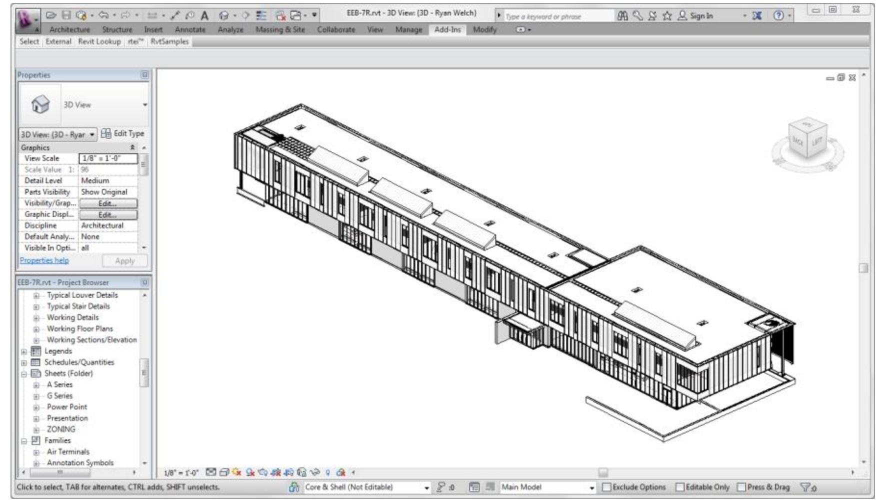
2. Define scope of study



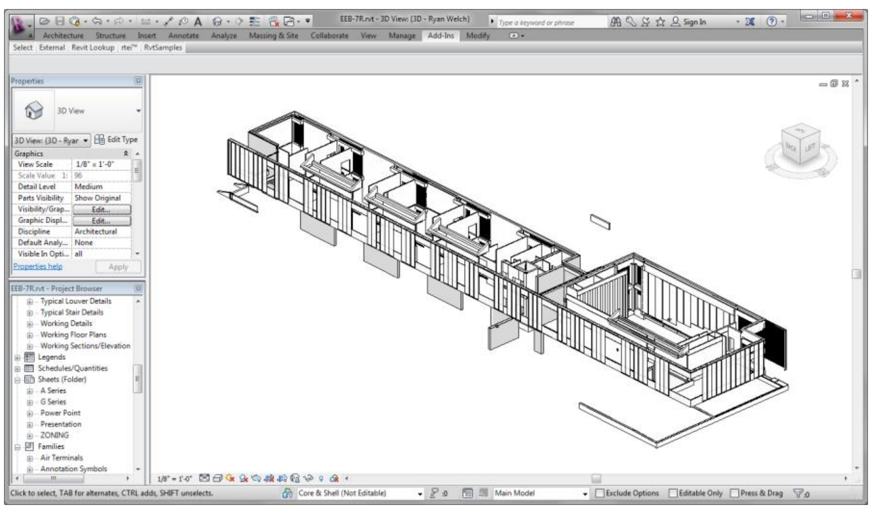
3. Isolate and study



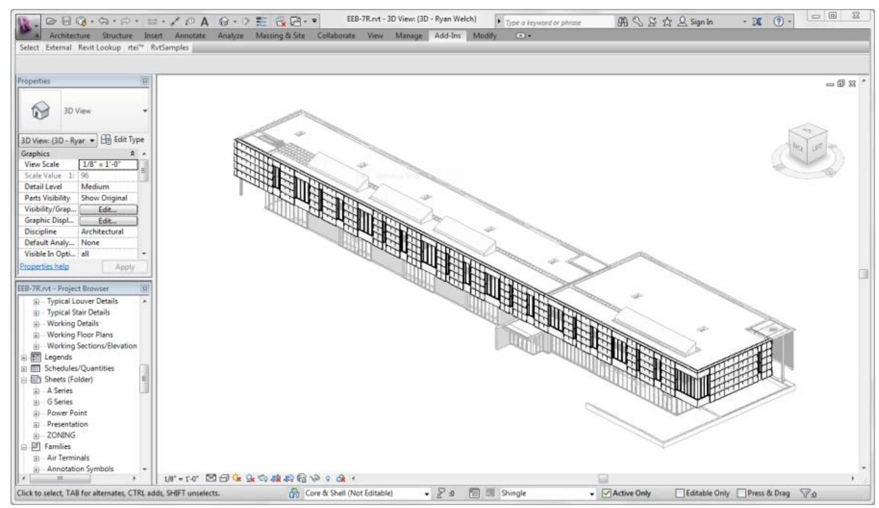
1. Building information model



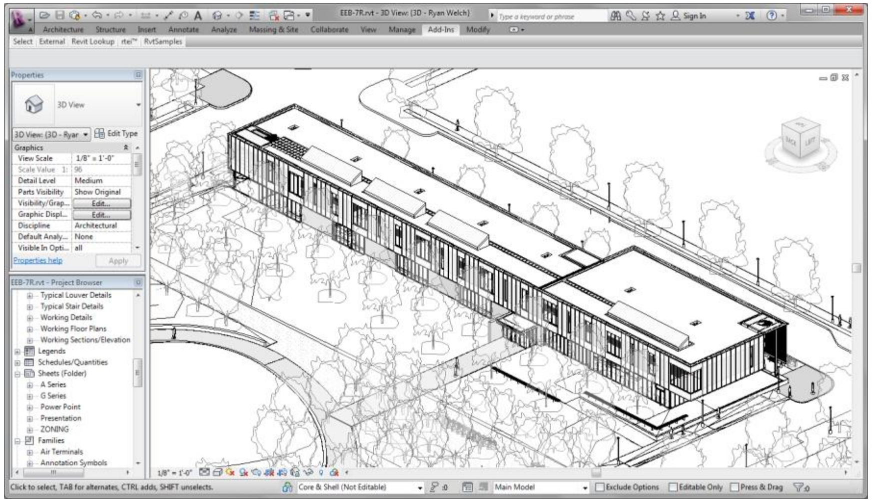
2. Define scope of study



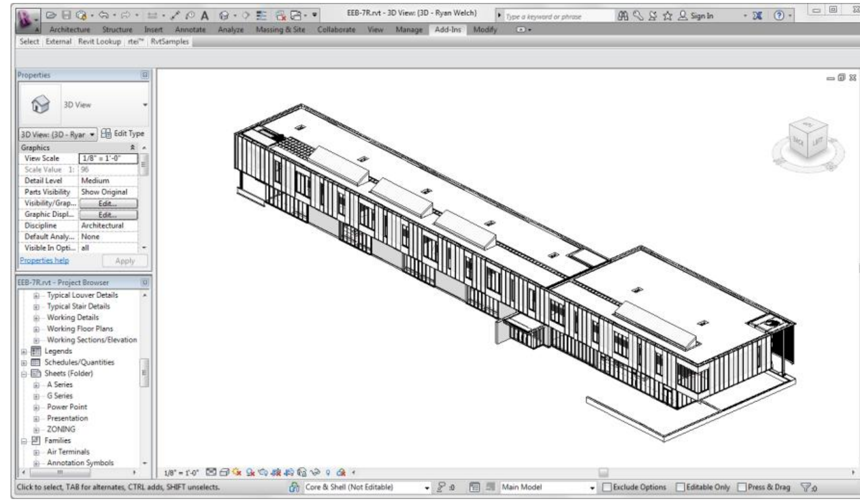
3. Isolate and study



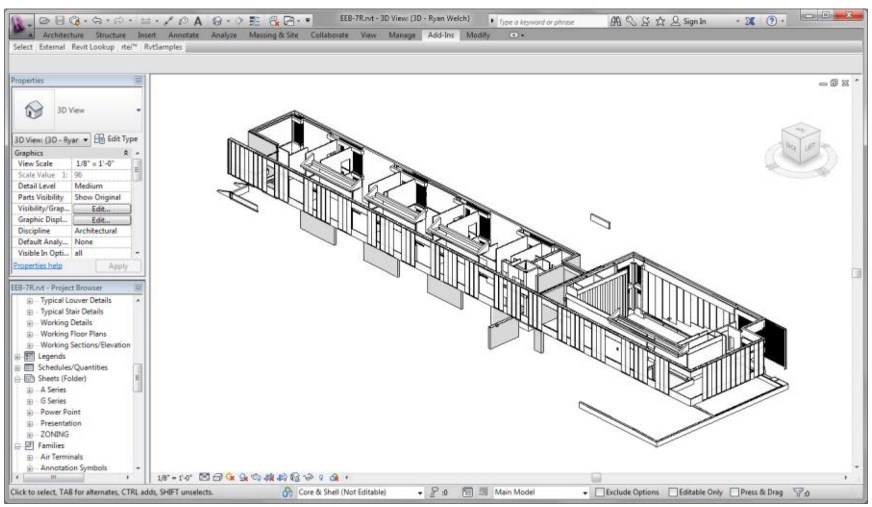
4. Compare options



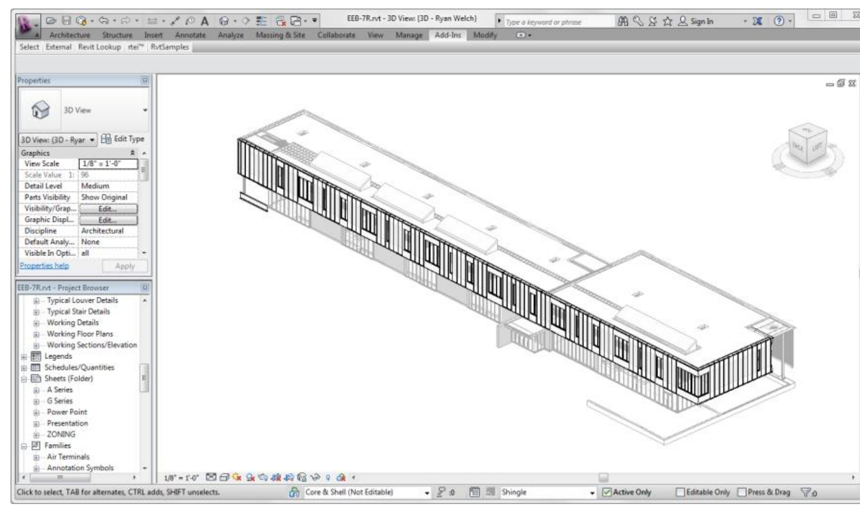
1. Building information model



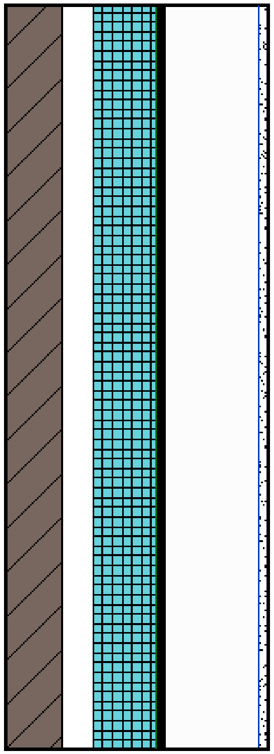
2. Define scope of study



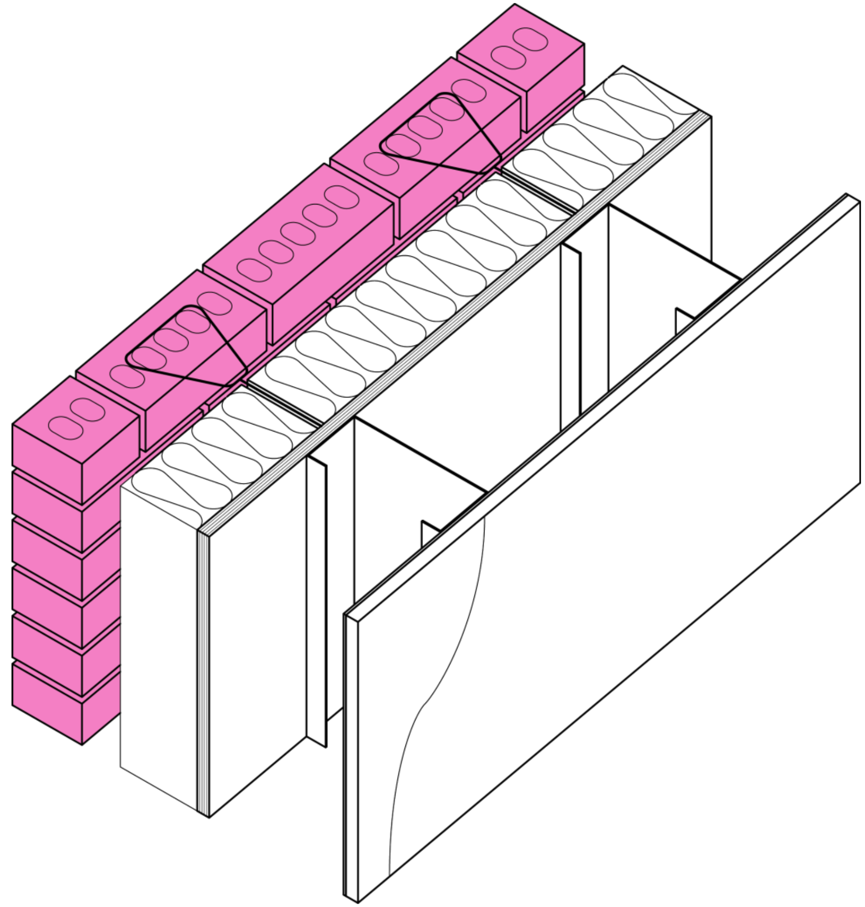
3. Isolate and study

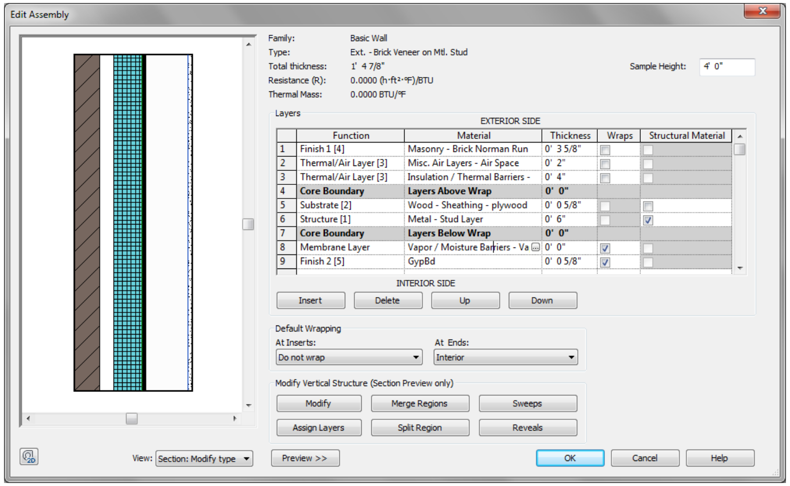


4. Compare options

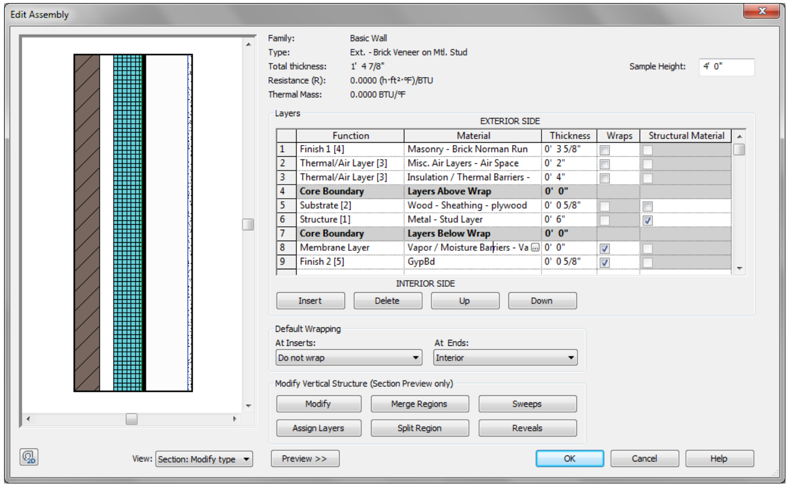


$\neq$

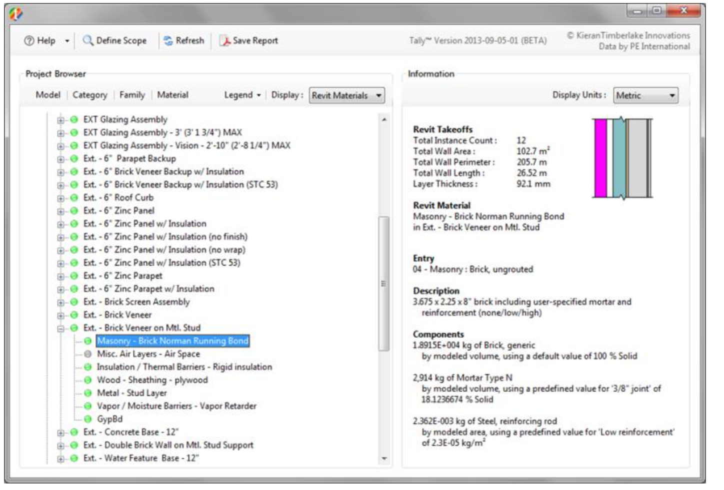




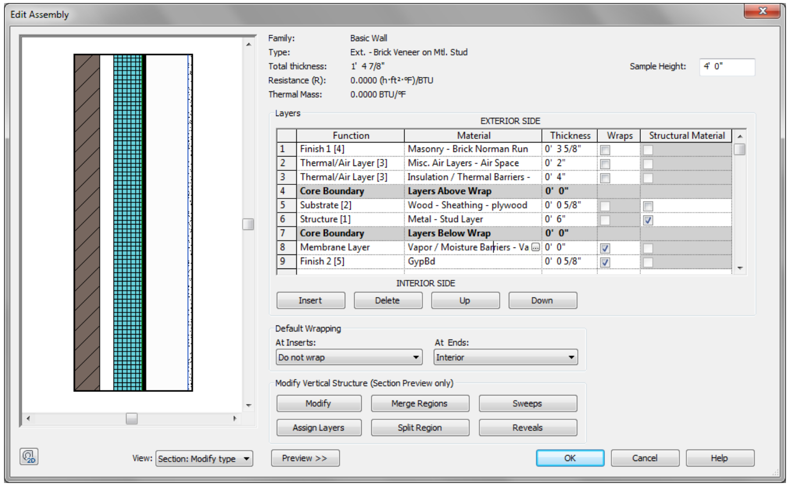
1. Revit materials take-off



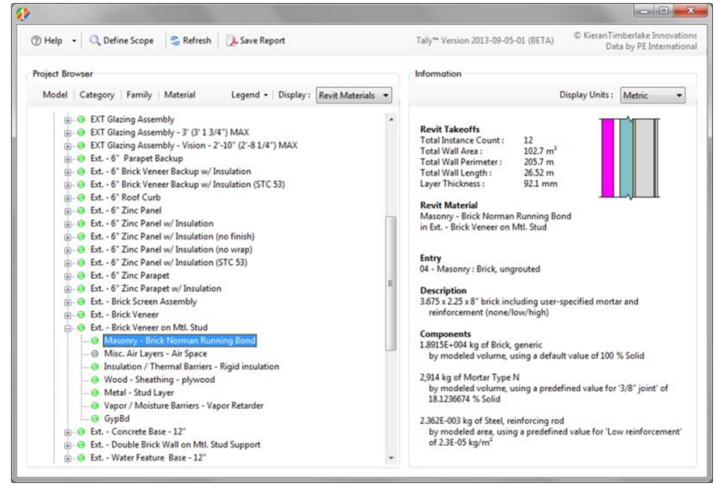
1. Revit materials take-off



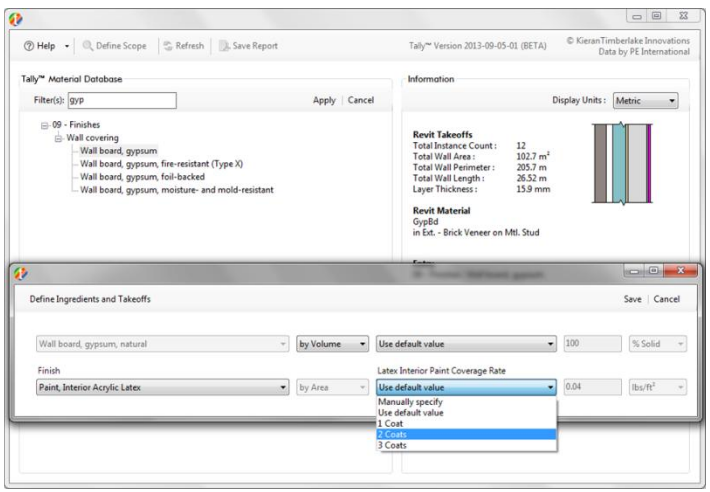
2. Create bill of materials



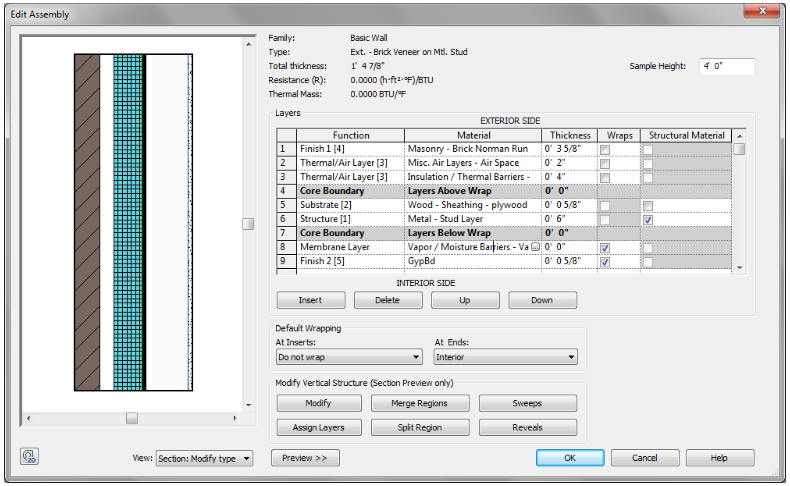
1. Revit materials take-off



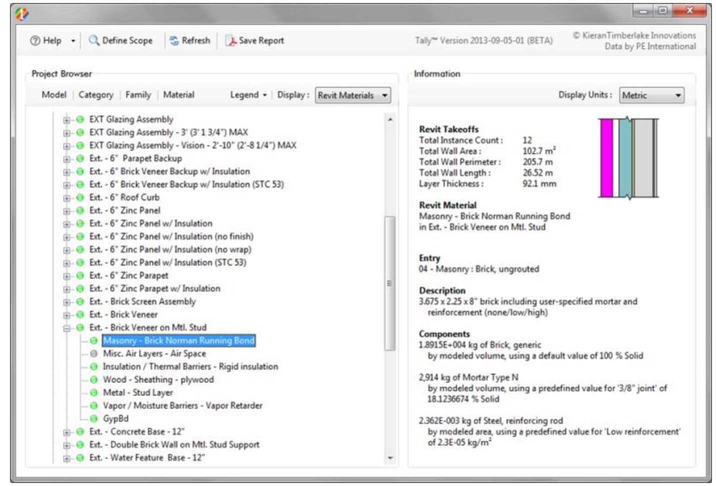
2. Create bill of materials



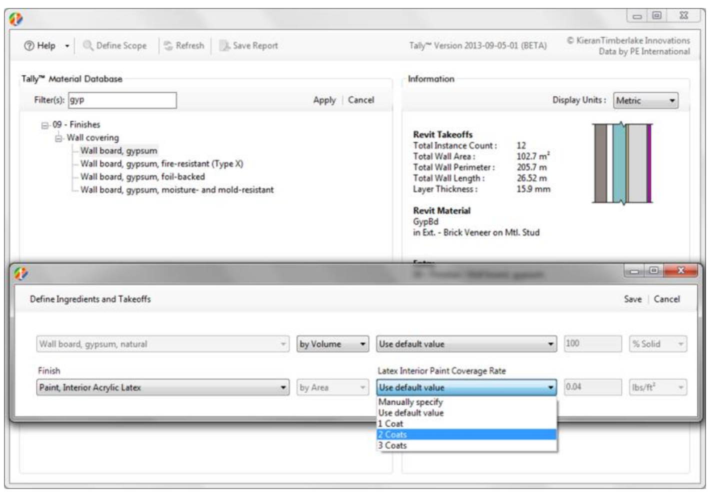
3. Link to database



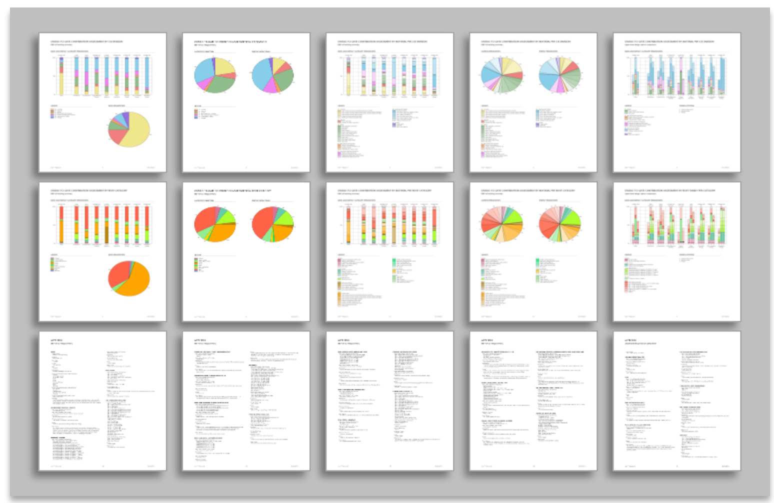
1. Revit materials take-off



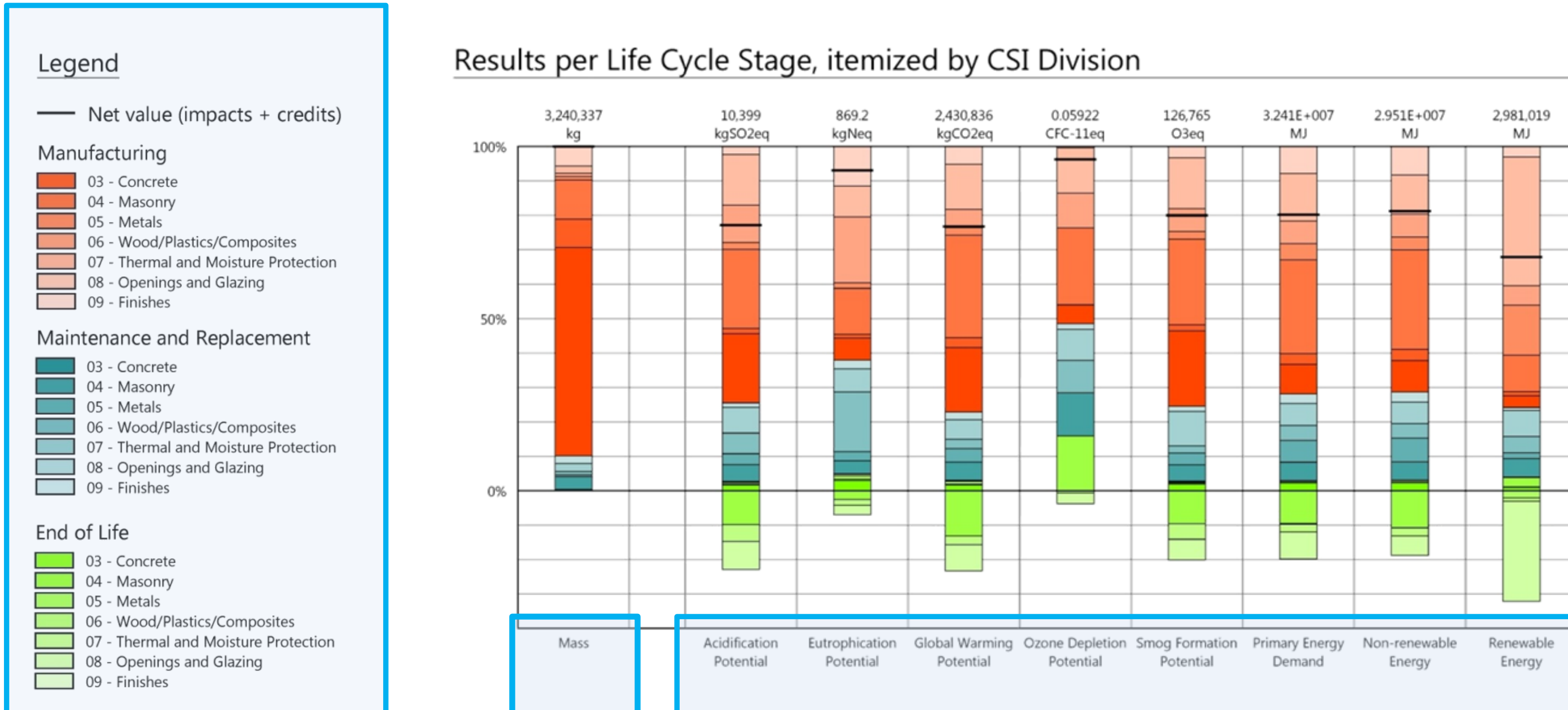
2. Create bill of materials



3. Link to database



4. Generate reports



Building materials organized by CSI Division and life cycle stage

Mass by Materials

8 Impact Categories

Primary Energy

renewable

non-renewable

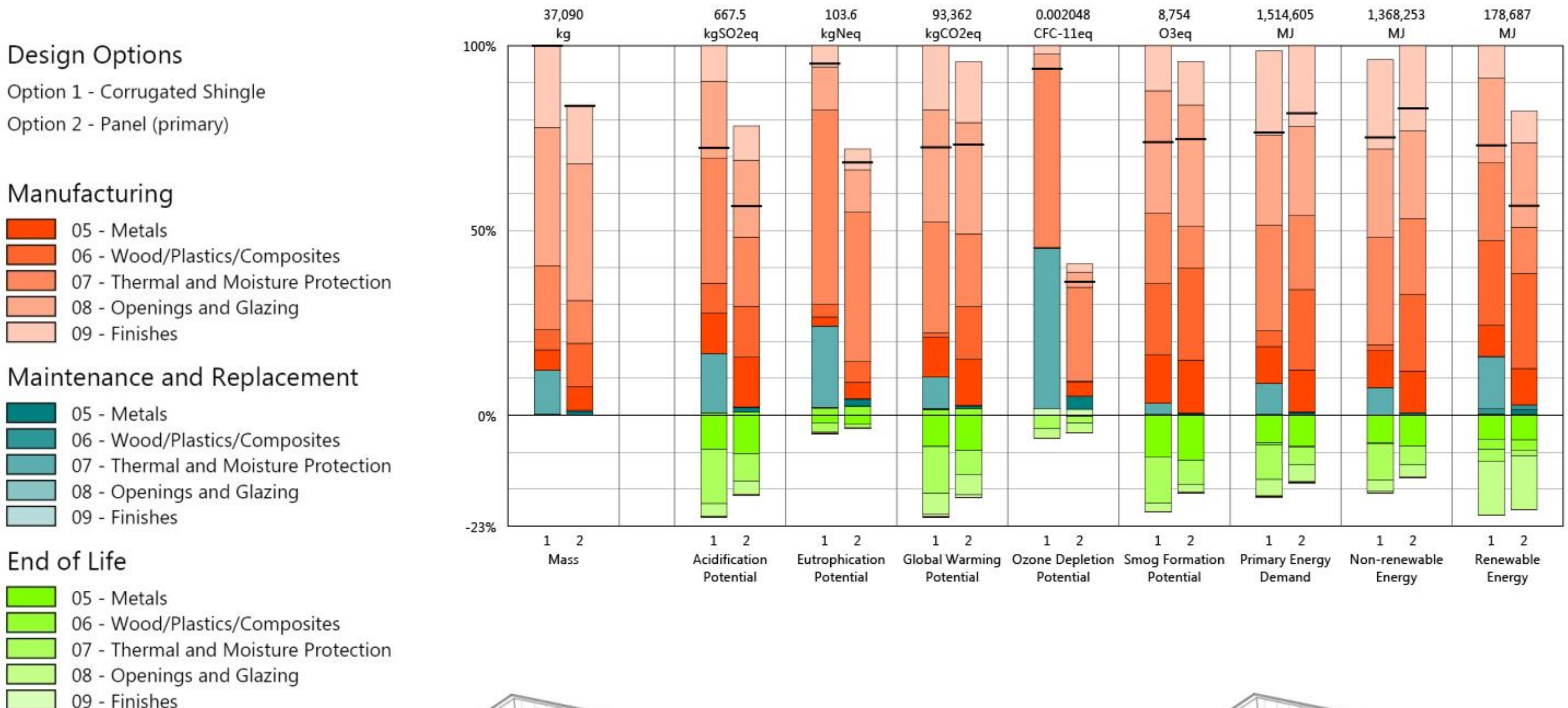
Acidification

Eutrophication

Global Warming Potential

Ozone Depletion

Smog Formation

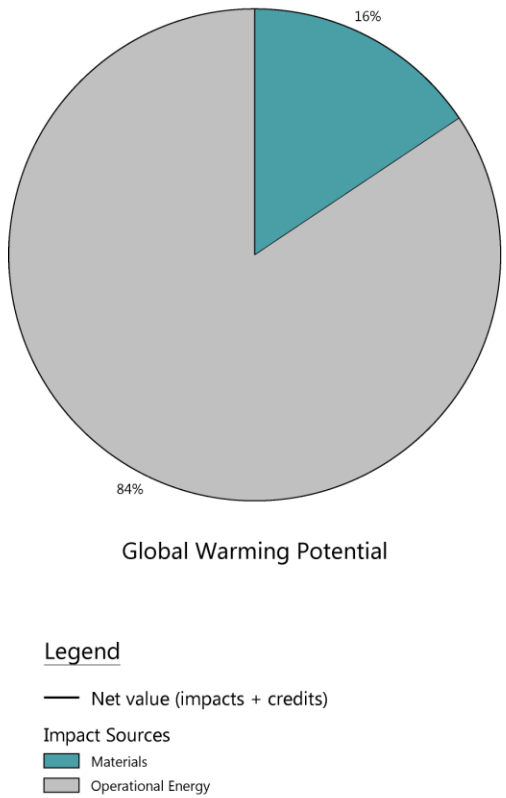


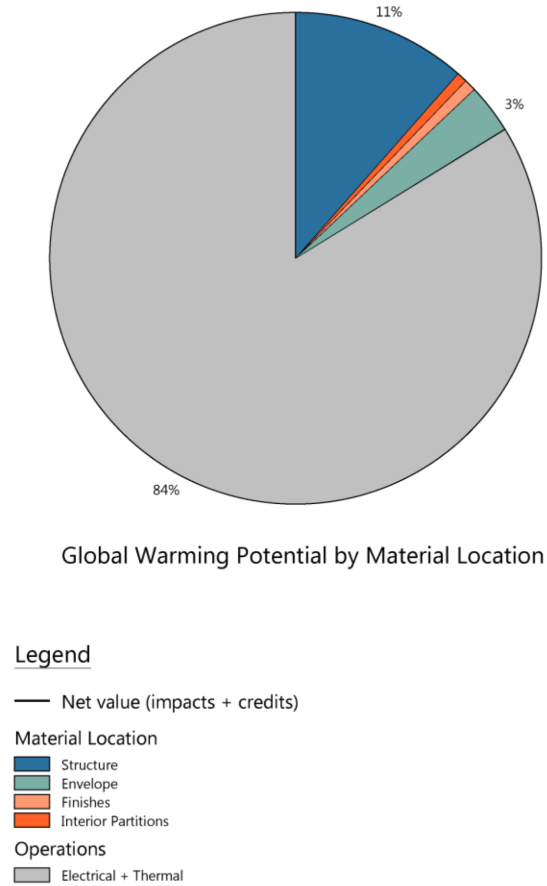
Option 1 – Corrugated Shingle Cladding

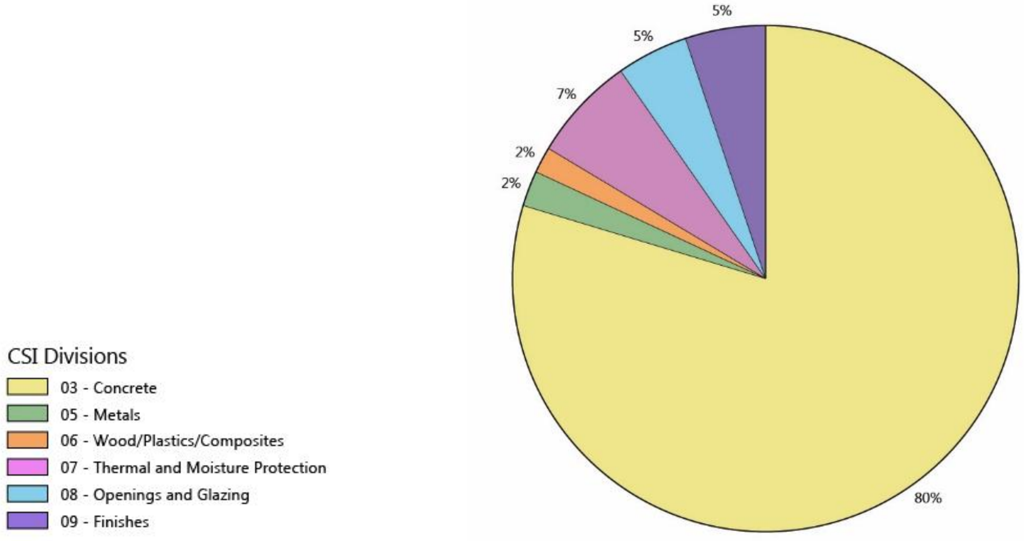
Option 2 – Translucent Panel Cladding

FULL BUILDING ASSESSMENT CHARLES DAVID KEELING APARTMENTS, UCSD

Which elements of building design have the largest carbon footprint?

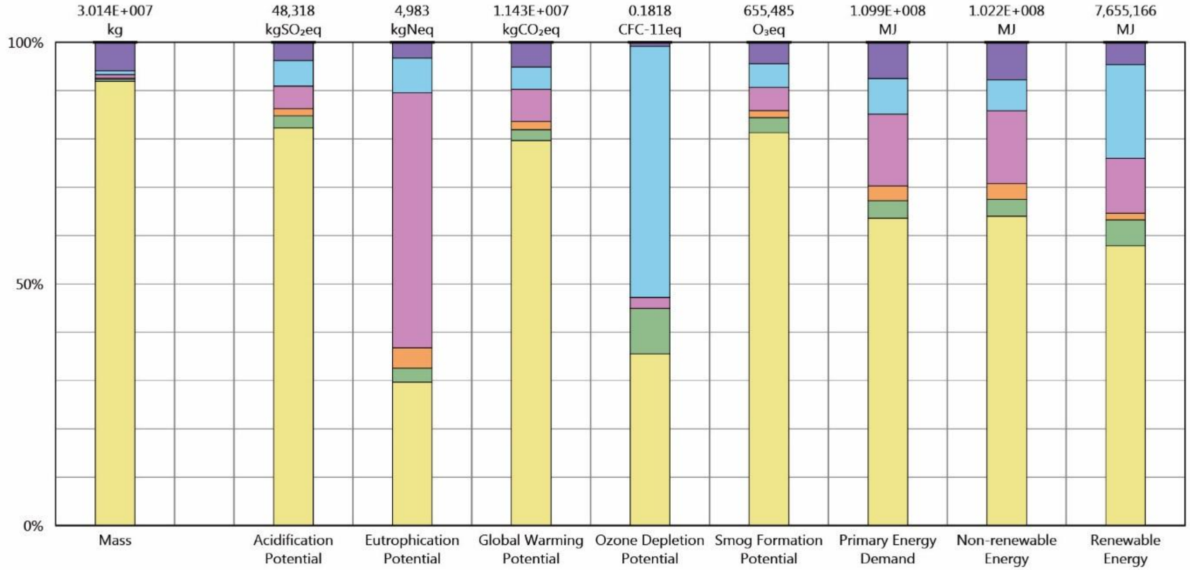






Global Warming Potential

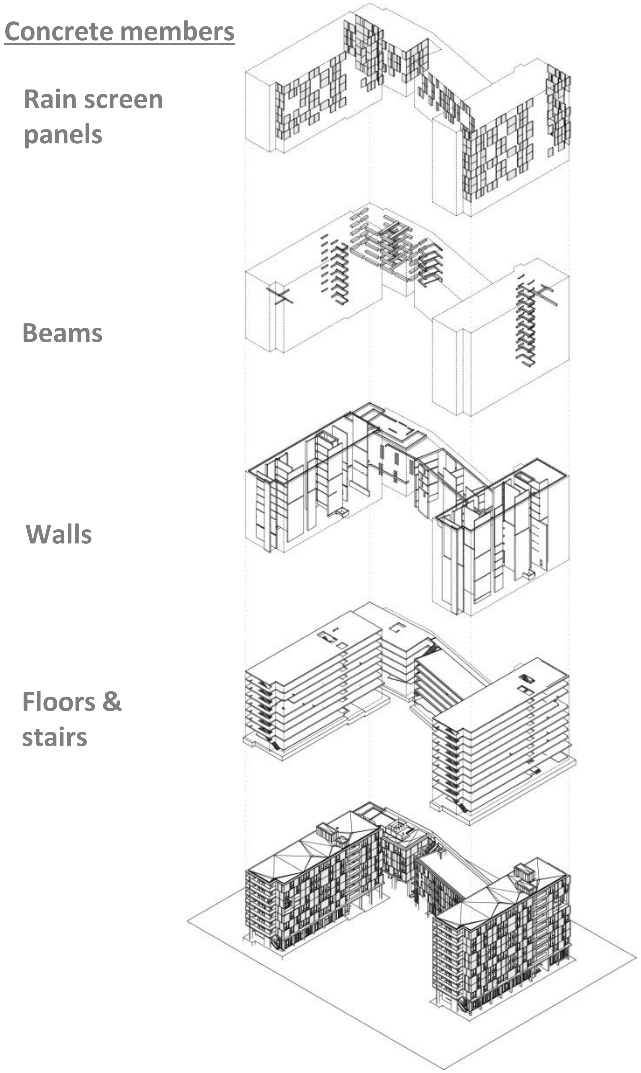
Results per CSI Division



FULL BUILDING ASSESSMENT CHARLES DAVID KEELING APARTMENTS, UCSD

FULL BUILDING ASSESSMENT IDENTIFYING MOST SIGNIFICANT CONTRIBUTORS

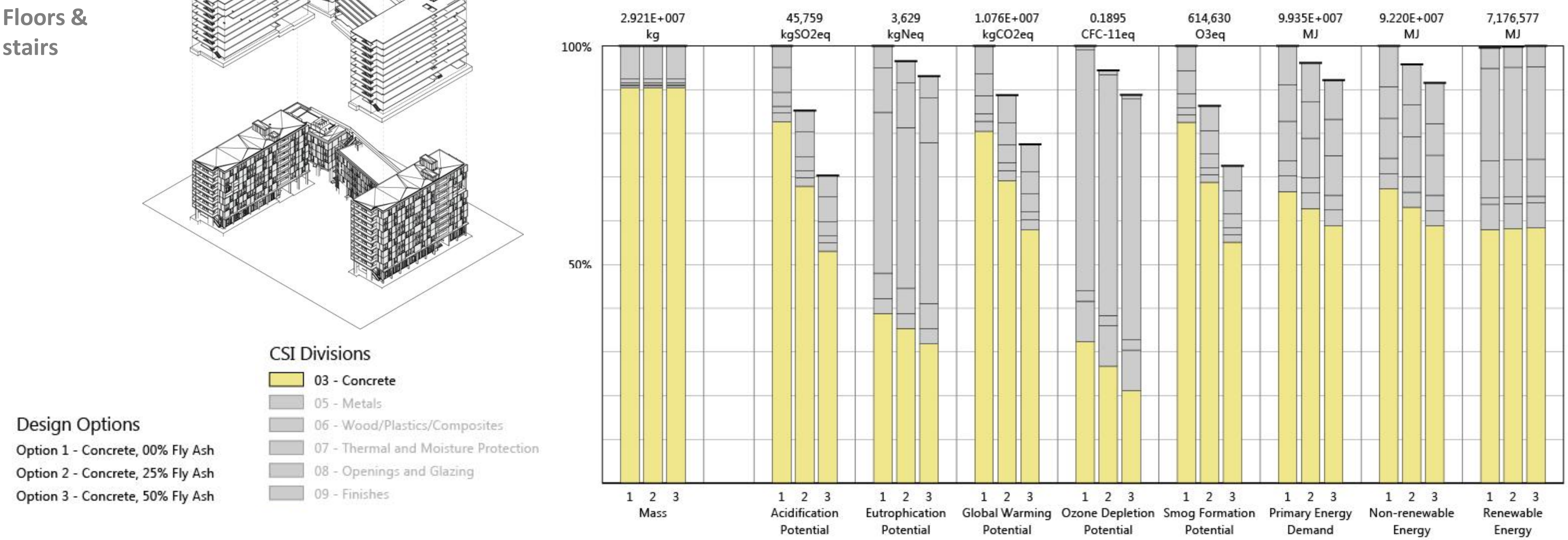
MATERIAL COMPARISONS



Does it matter what type of concrete the project specifies (% fly ash) ?

Can the structural system be optimized to minimize resource use and construction time?

Results per CSI Division



FULL BUILDING ASSESSMENT CHARLES DAVID KEELING APARTMENTS, UCSD

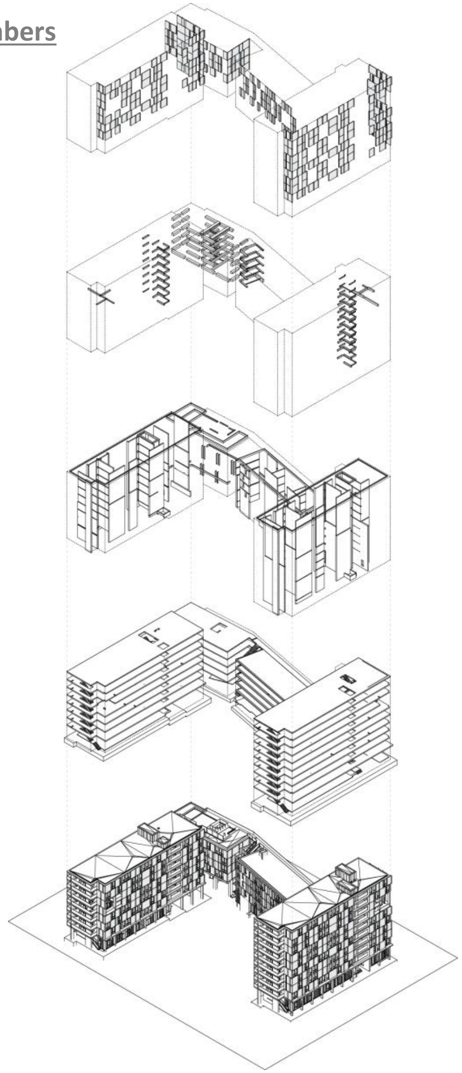
<u>Concrete members</u>

Rain screen panels

Beams

Walls

Floors & stairs

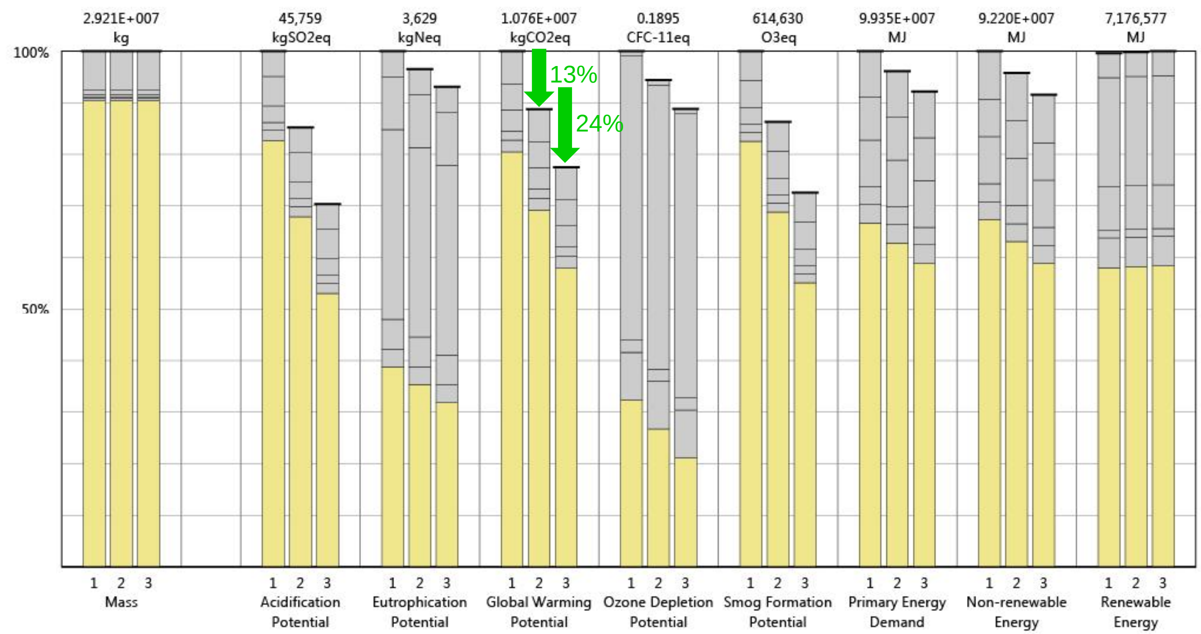


MATERIAL COMPARISONS

Does it matter what type of concrete the project specifies (% fly ash) ?

Can the structural system be optimized to minimize resource use and construction time?

Results per CSI Division



CSI Divisions

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Design Options

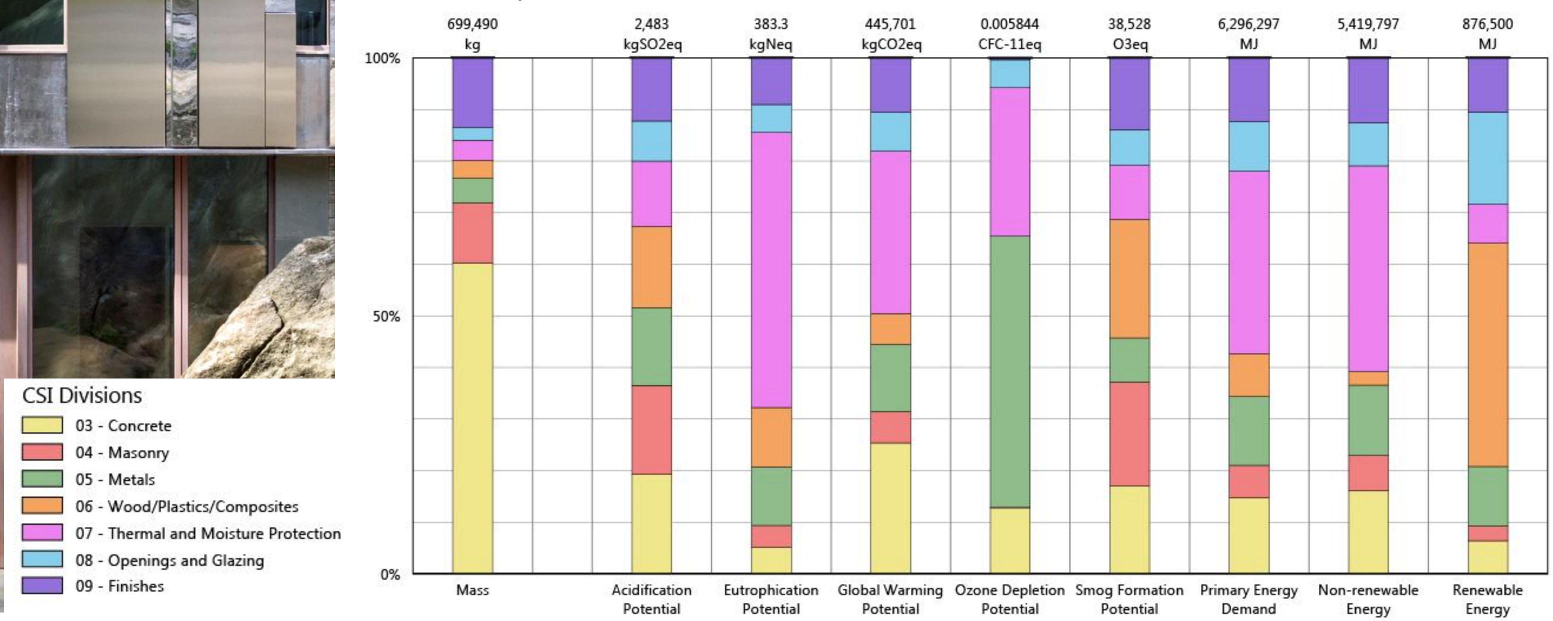
- Option 1 - Concrete, 00% Fly Ash
- Option 2 - Concrete, 25% Fly Ash
- Option 3 - Concrete, 50% Fly Ash

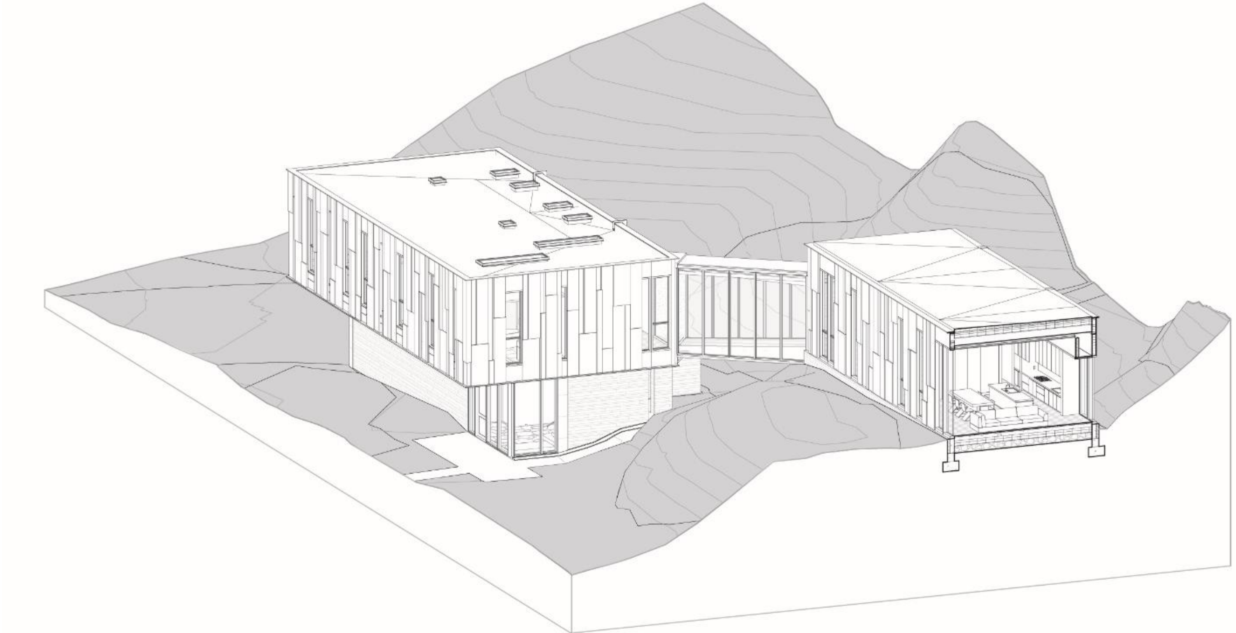
LCA & Energy Efficient Buildings

What is the relative importance of building elements tied to increased energy efficiency?

How can I evaluate novel assemblies or materials?

Results per CSI Division





03 - Concrete
- Cast-in-place concrete, reinforced structural, 4000 psi
- Reinforced concrete footing
- Reinforced slab, exclusive of deck

04 - Masonry
- Limestone veneer wall, grouted

05 - Metals
- Aluminum, extrusion
- Aluminum, honeycomb backer / substrate
- Aluminum, sheet
- Copper sheet
- Steel, composite form deck
- Steel, C-stud metal framing
- Steel, furring channel
- Steel, hollow structural section
- Steel, MC section
- Steel, plate
- Steel, round tubing
- Steel, sheet, stainless
- Steel, wide flange shape

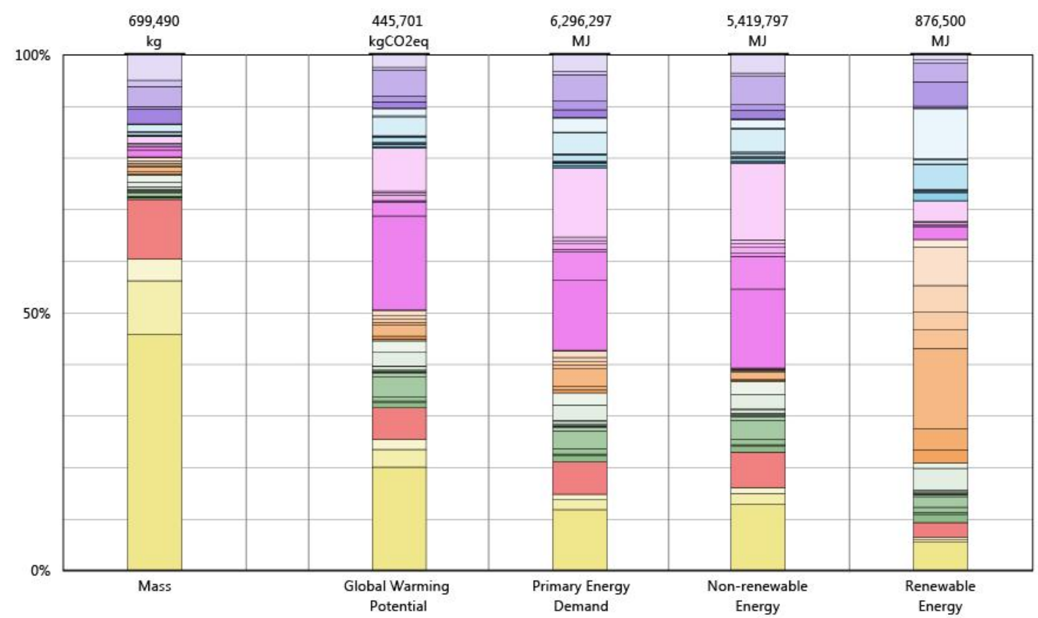
06 - Wood/Plastics/Composites
- Composite wood I-joist
- Domestic hardwood
- Oriented strandboard (OSB)
- Paneling, interior
- Parallel strand lumber (PSL)
- Plywood, exterior grade
- Plywood, interior grade
- Wood framing

07 - Thermal and Moisture Protection
- Closed cell, polyurethane foam, spray-applied
- Expanded polystyrene (EPS), board
- Fluid applied synthetic polymer air barrier
- Fluoropolymer-coated aluminum flashing
- Mineral wool, board, generic
- Open cell, polyurethane foam, spray-applied
- Polyethelene sheet vapor barrier (HDPE)
- Polyisocyanurate (PIR), board
- PVC roofing membrane, sheet
- Waterproofing, modified bituminous sheet

08 - Openings and Glazing
- Door frame, steel, galvanized
- Door frame, wood
- Door, exterior, steel
- Door, exterior, wood, solid core
- Door, interior, glass
- Door, interior, steel
- Door, interior, wood, structural composite core
- Glazing, double pane IGU
- Glazing, monolithic sheet
- Glazing, triple pane IGU
- Window frame, aluminum
- Window frame, wood

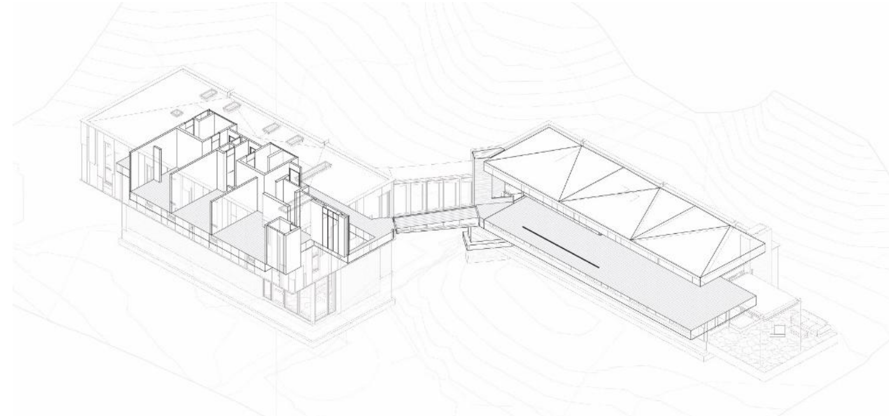
09 - Finishes
- Acoustic ceiling system, fabric faced fiberglass
- Ceramic tile, glazed
- Flooring, solid wood plank
- Stone tile
- Tile backer board
- Wall board, gypsum

Results per CSI Division, itemized by material

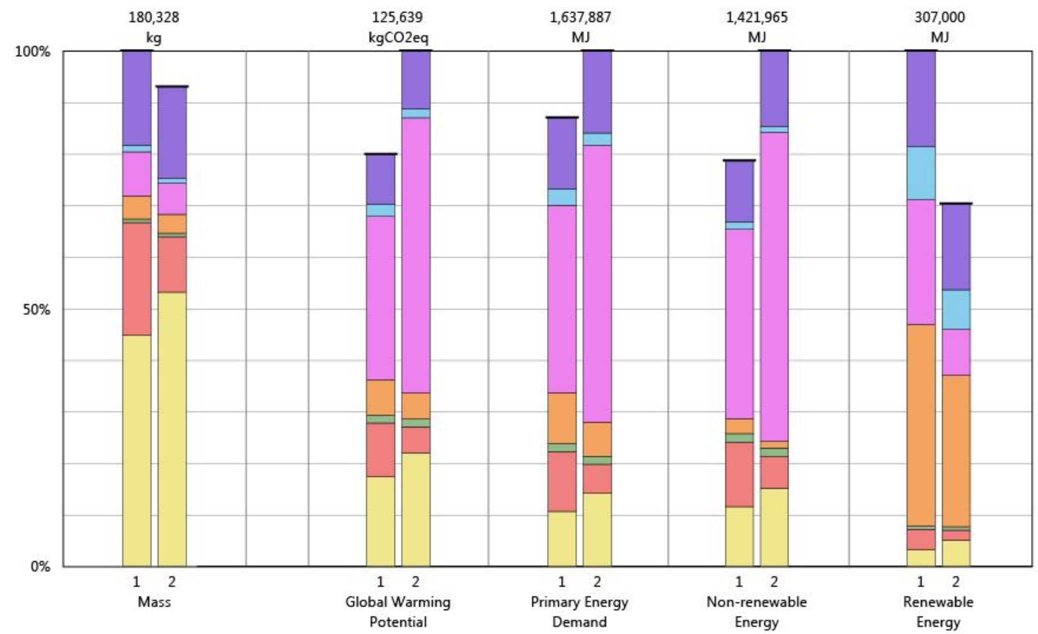


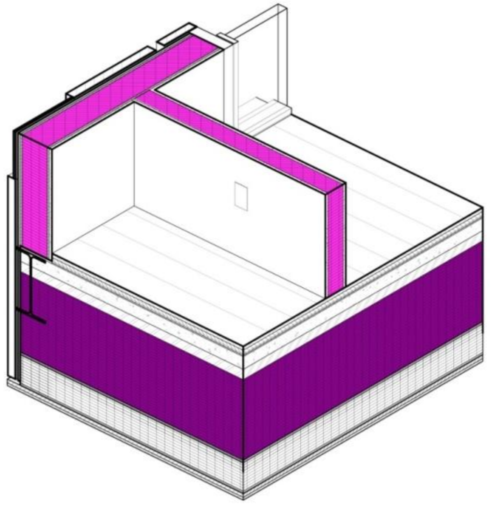
Changes between project phases

How do changes made during construction affect building performance and embodied impacts?



Results per CSI Division



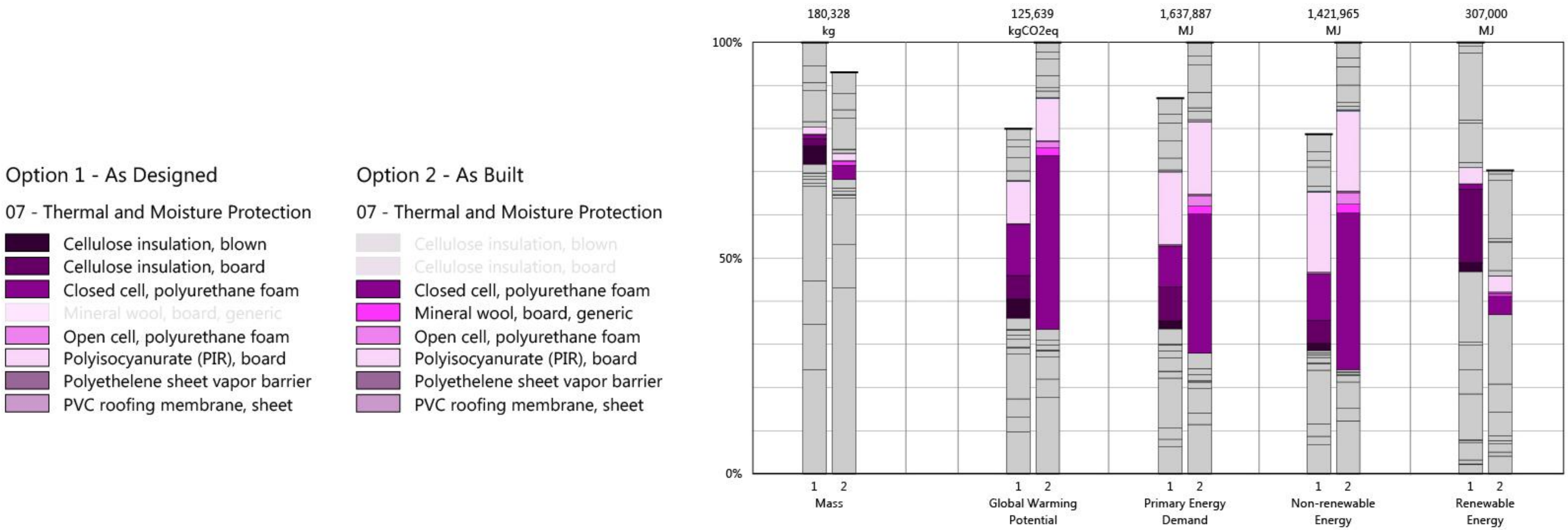


Changes between project phases

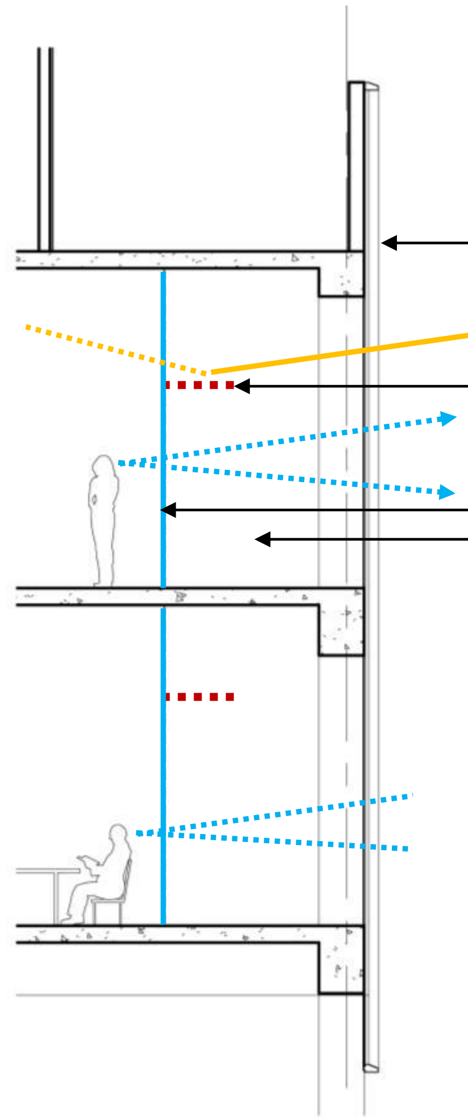
How do changes made during construction affect building performance and embodied impacts?

What are the trade offs between material choices (embodied impacts, cost, performance, constructability)?

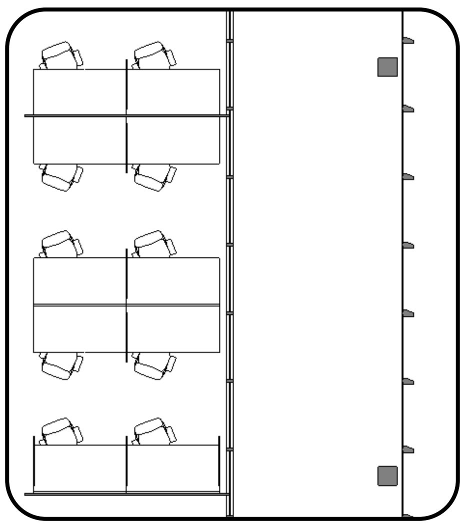
Results per CSI Division, itemized by material



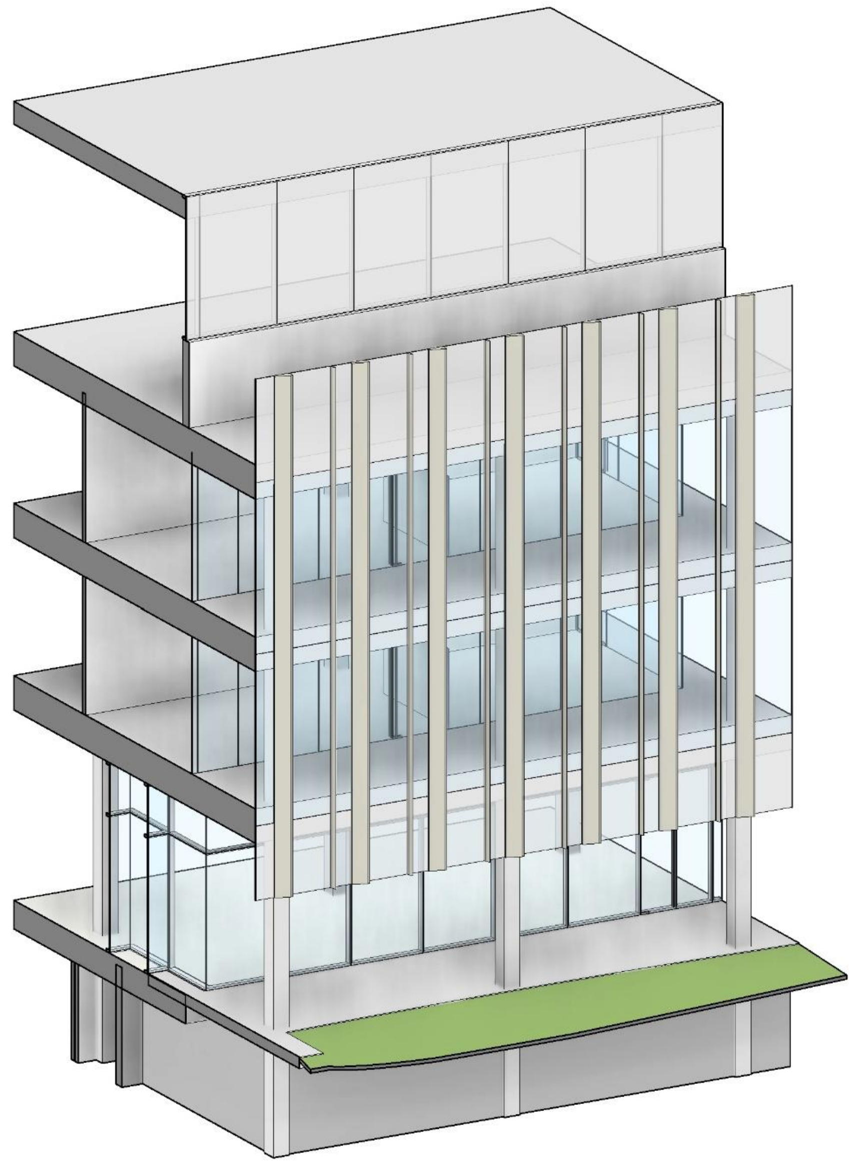
CASE STUDY NEW SCHOOL OF ENGINEERING, BROWN UNIVERSITY



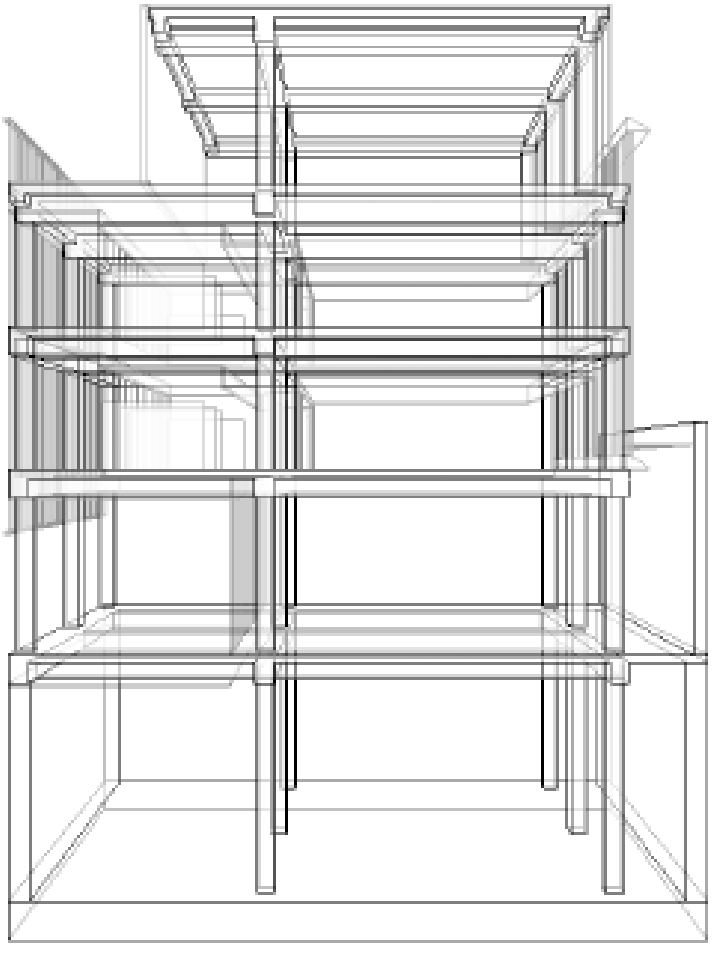
SECTION AT WEST FACADE



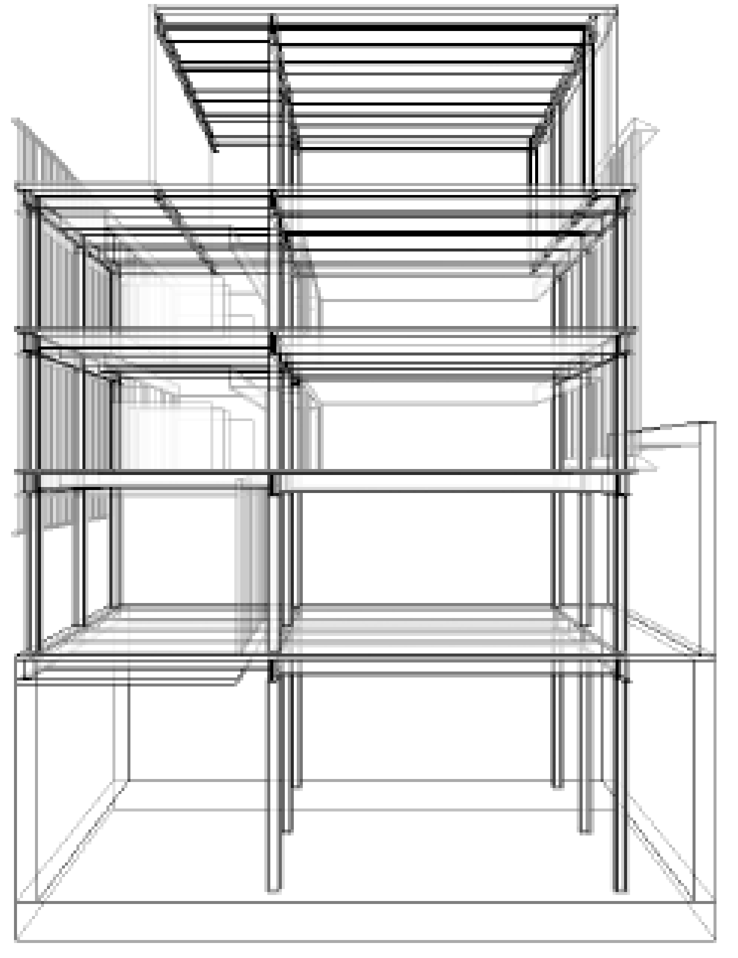
PLAN



FACADE DIAGRAM AXONOMETRIC SECTION

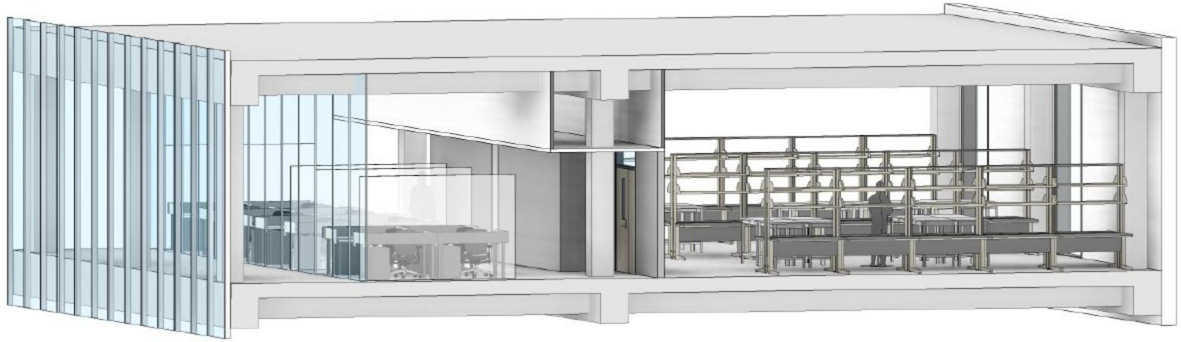


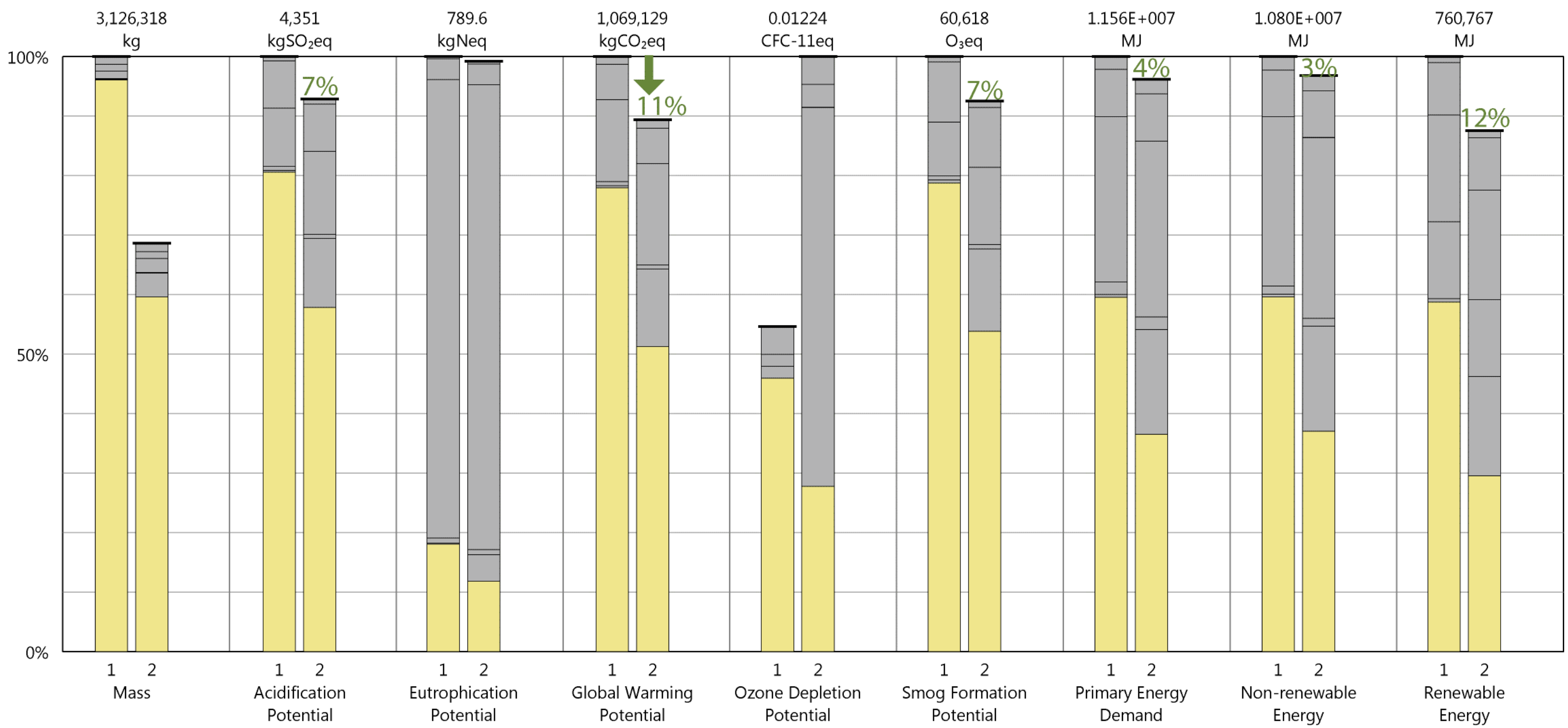
Option 1: Concrete



Option 2: Steel

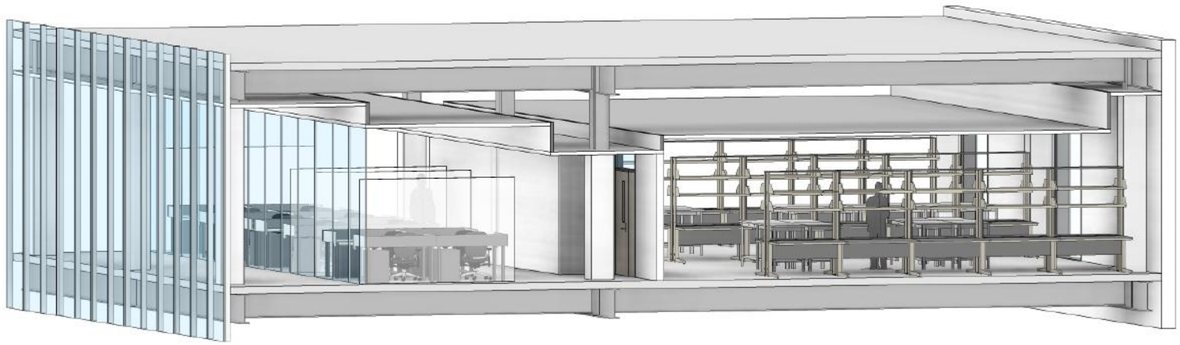
STRUCTURAL SYSTEM COMPARISON

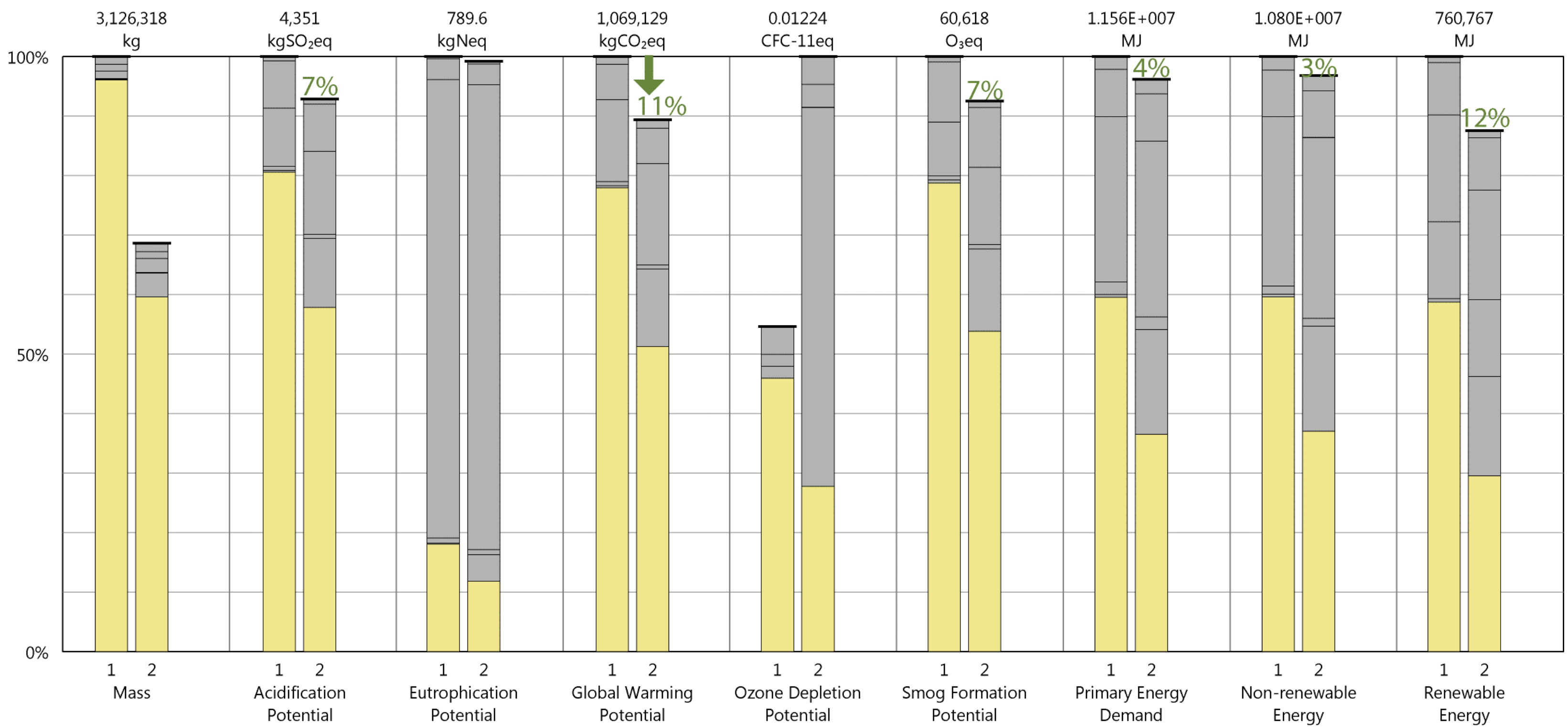




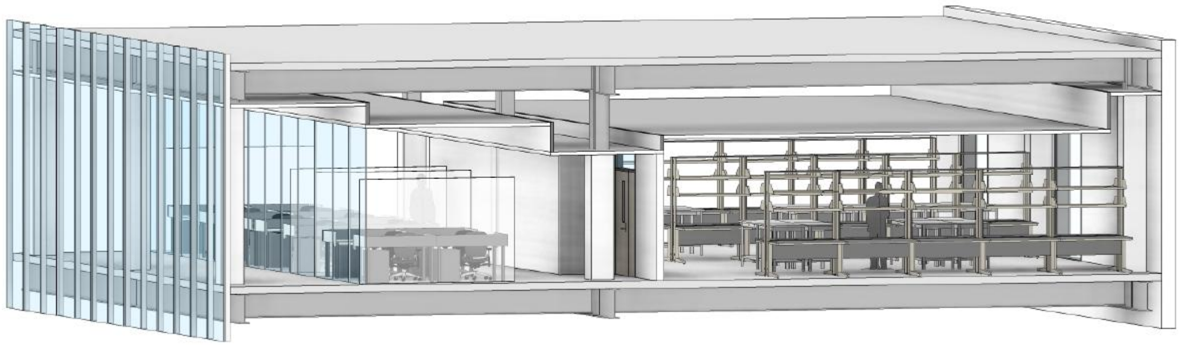
STRUCTURAL SYSTEM COMPARISON

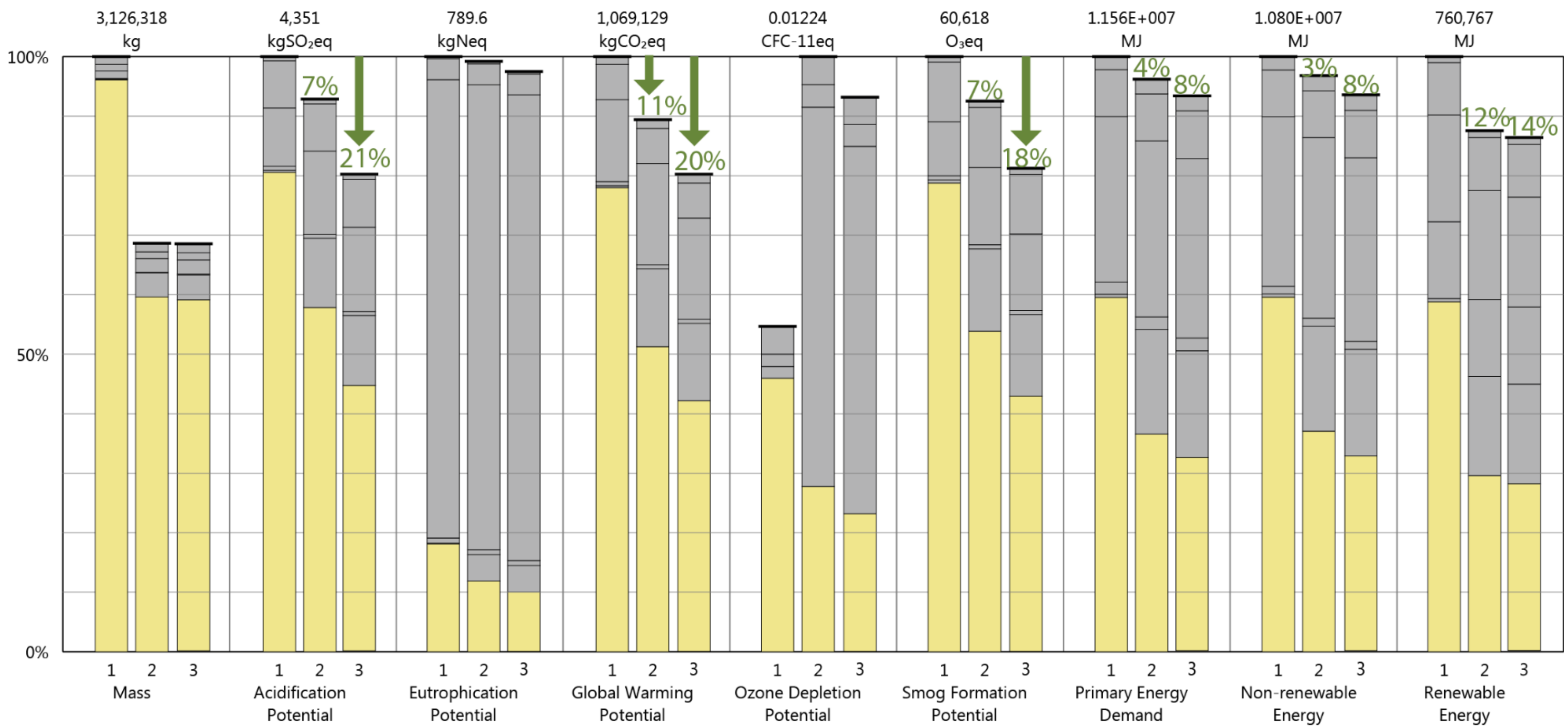
LIFECYCLE ASSESSMENT FOR BUILDINGS AND CONSTRUCTION



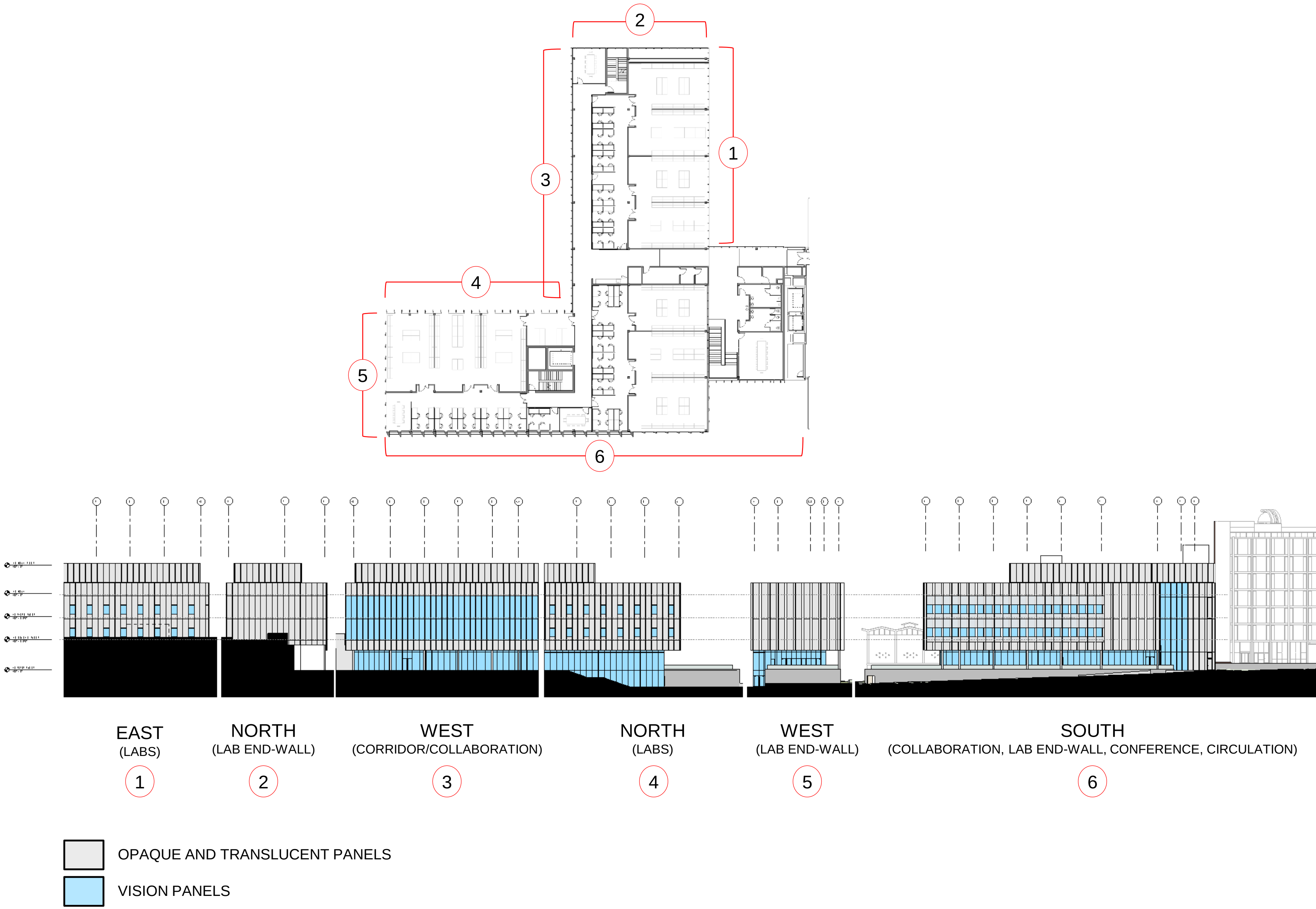


STRUCTURAL SYSTEM COMPARISON





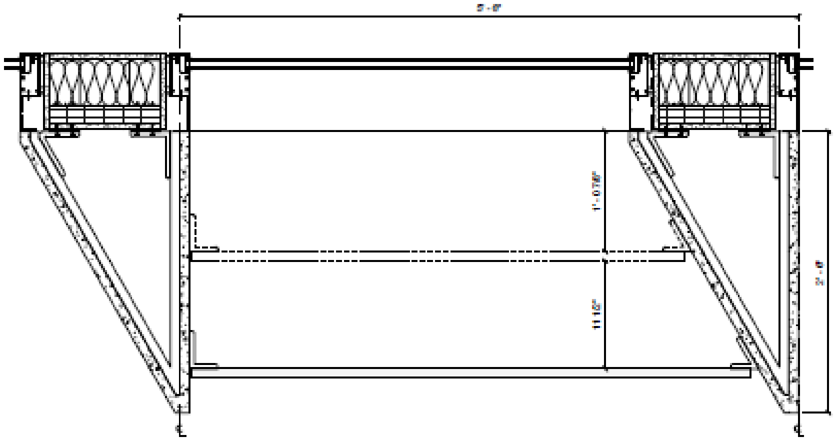
STRUCTURAL SYSTEM COMPARISON

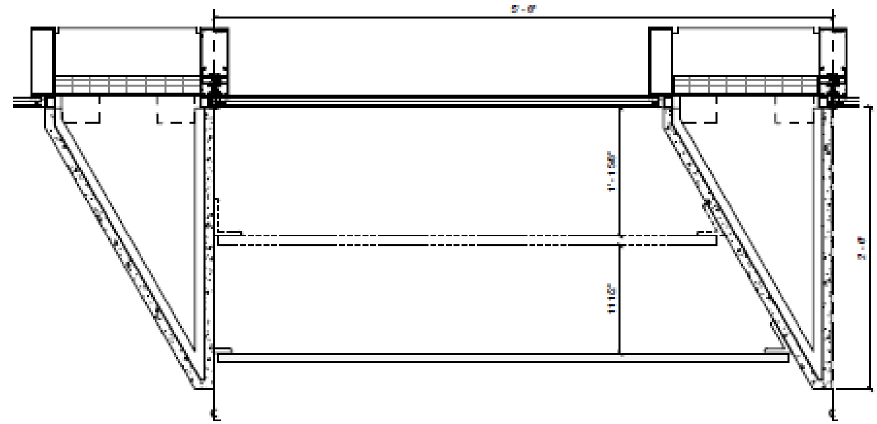


UNFOLDED ELEVATIONS

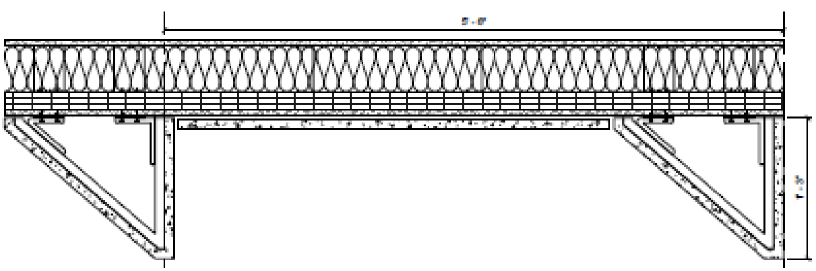
LIFECYCLE ASSESSMENT FOR BUILDINGS AND CONSTRUCTION

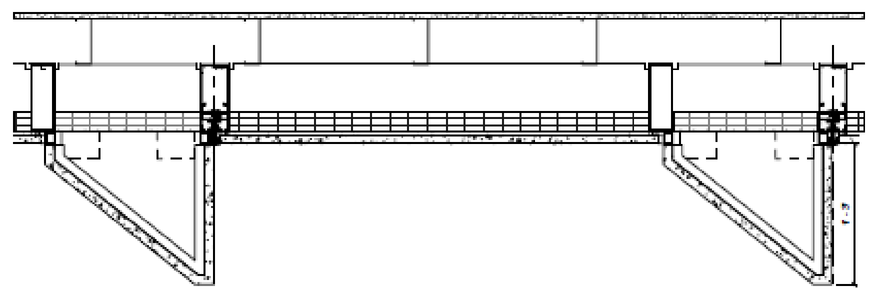
South Facade





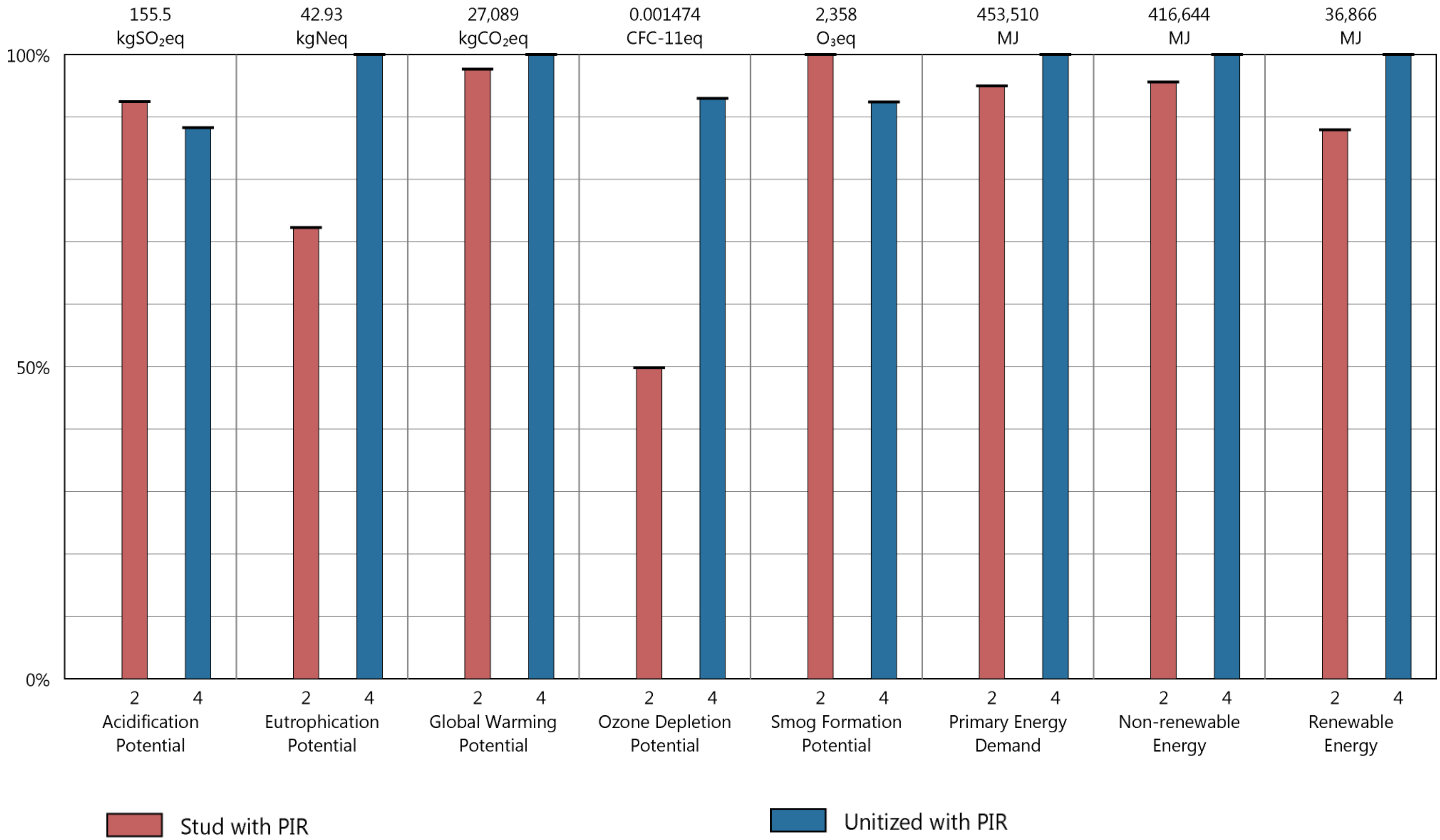
Opaque Facade

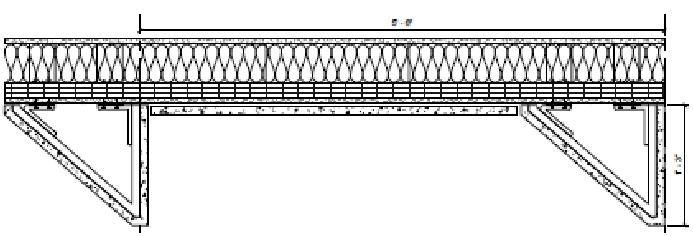


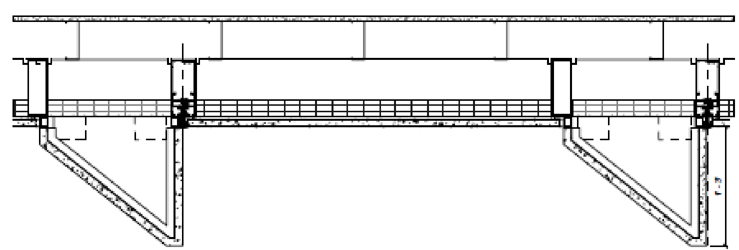


Option 1: Storefront and Frame

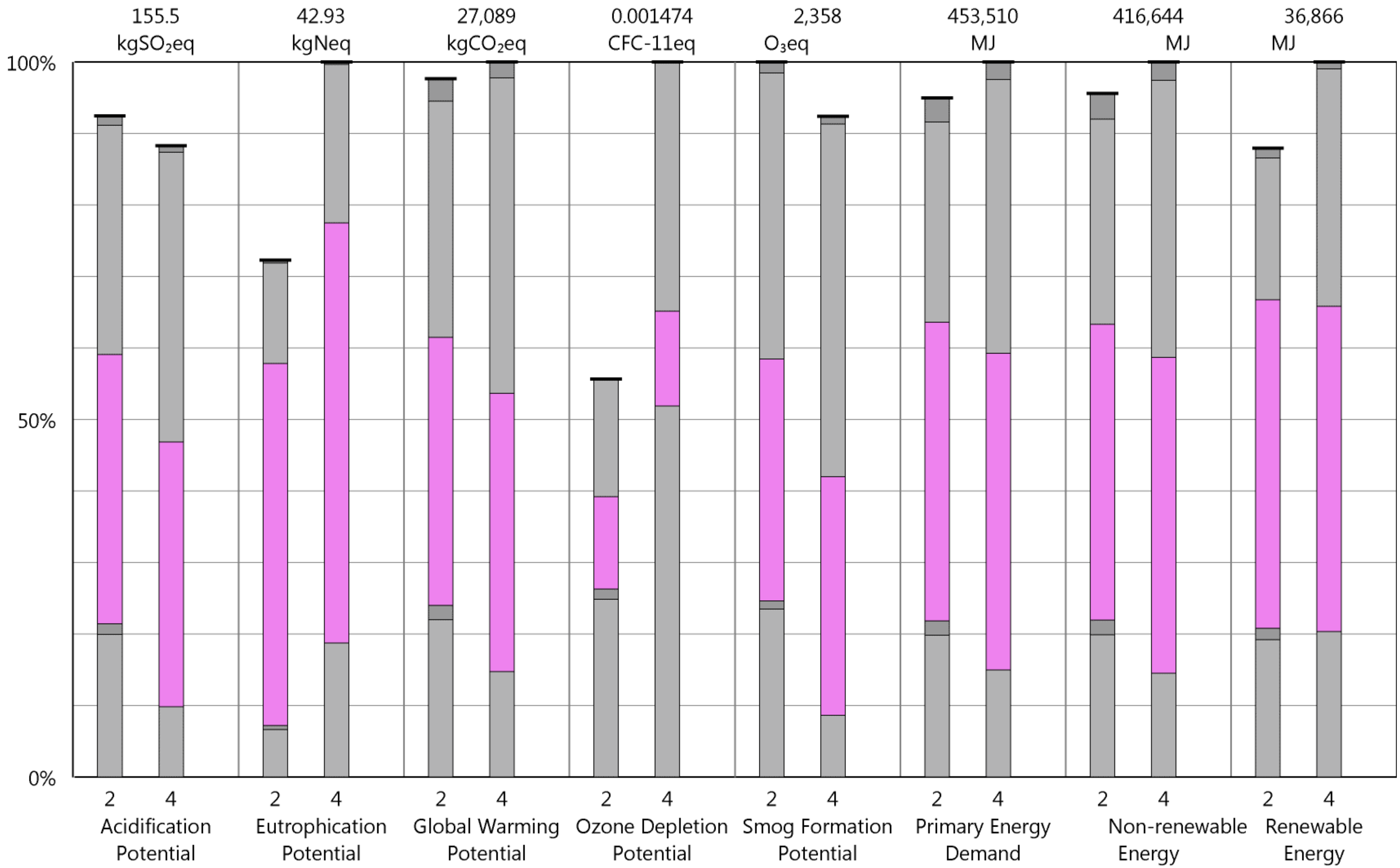
Option 2: Unitized Curtainwall







FACADE SYSTEM COMPARISONS



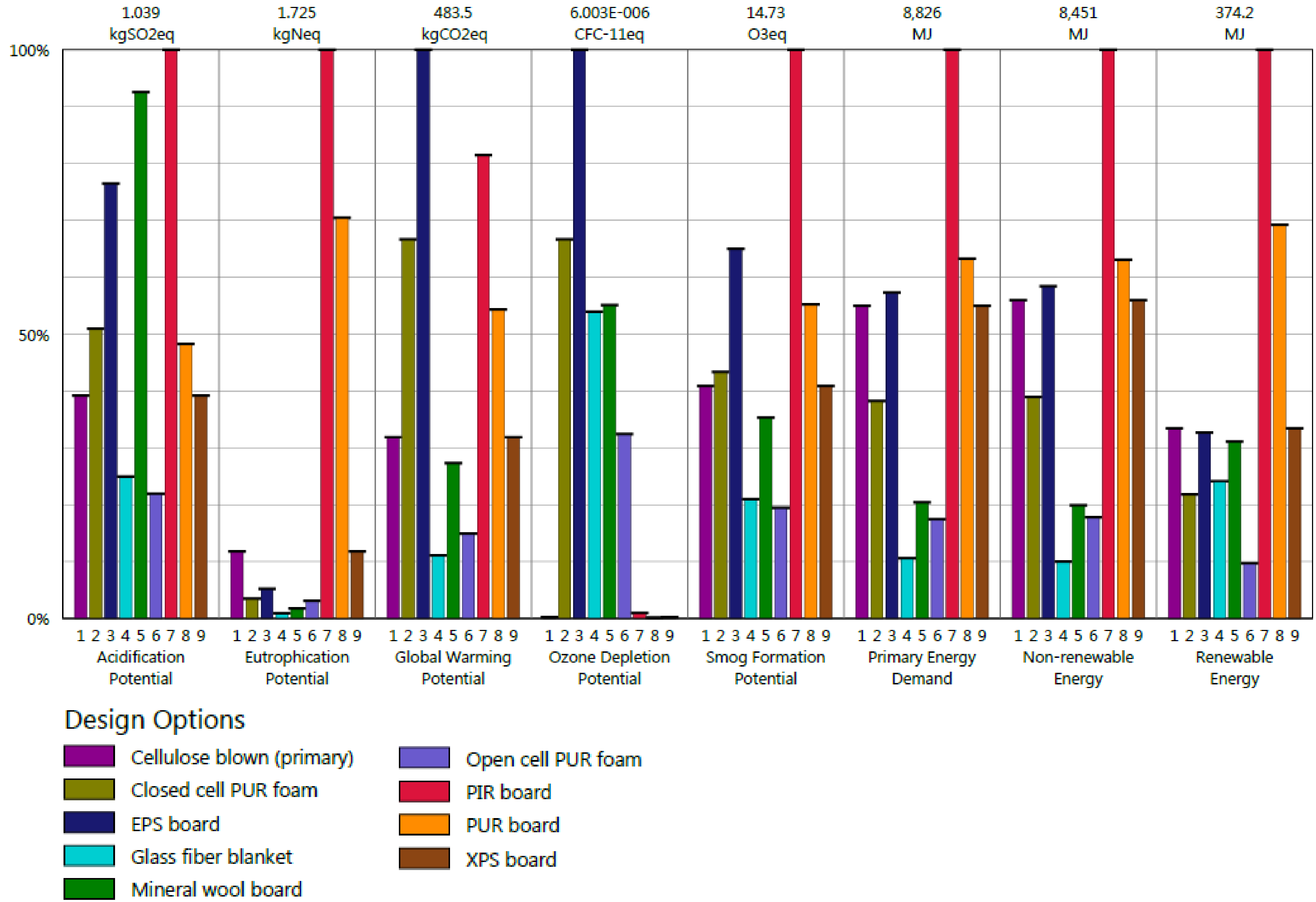
CSI Divisions

- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

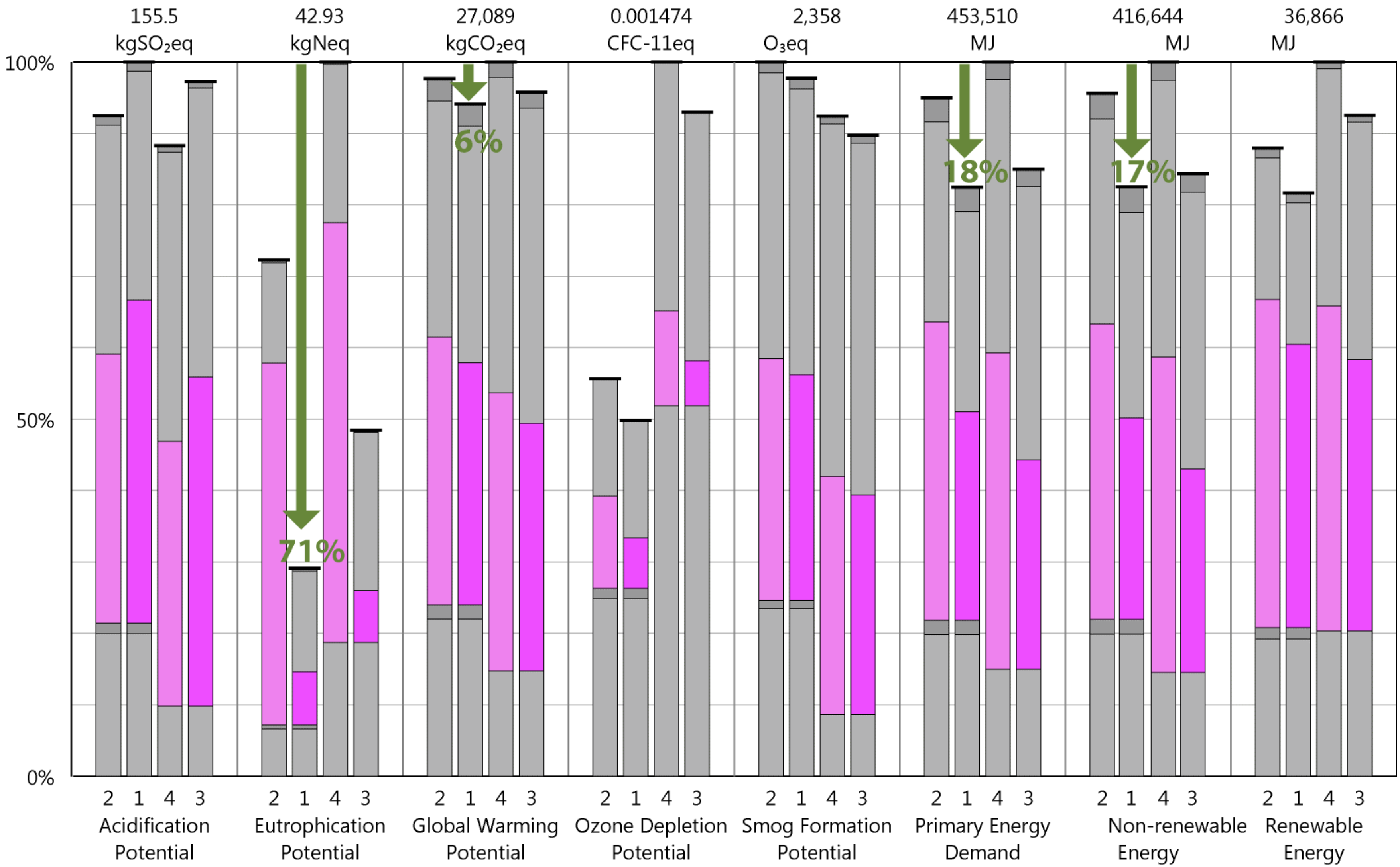
Design Options

Option 1 - Stud with Mineral
Option 2 - Stud with PIR
Option 3 - Unitized with Mineral
Option 4 - Unitized with PIR

FACADE SYSTEM COMPARISONS MAJOR CONTRIBUTORS



COMPARING INSULATION TYPES



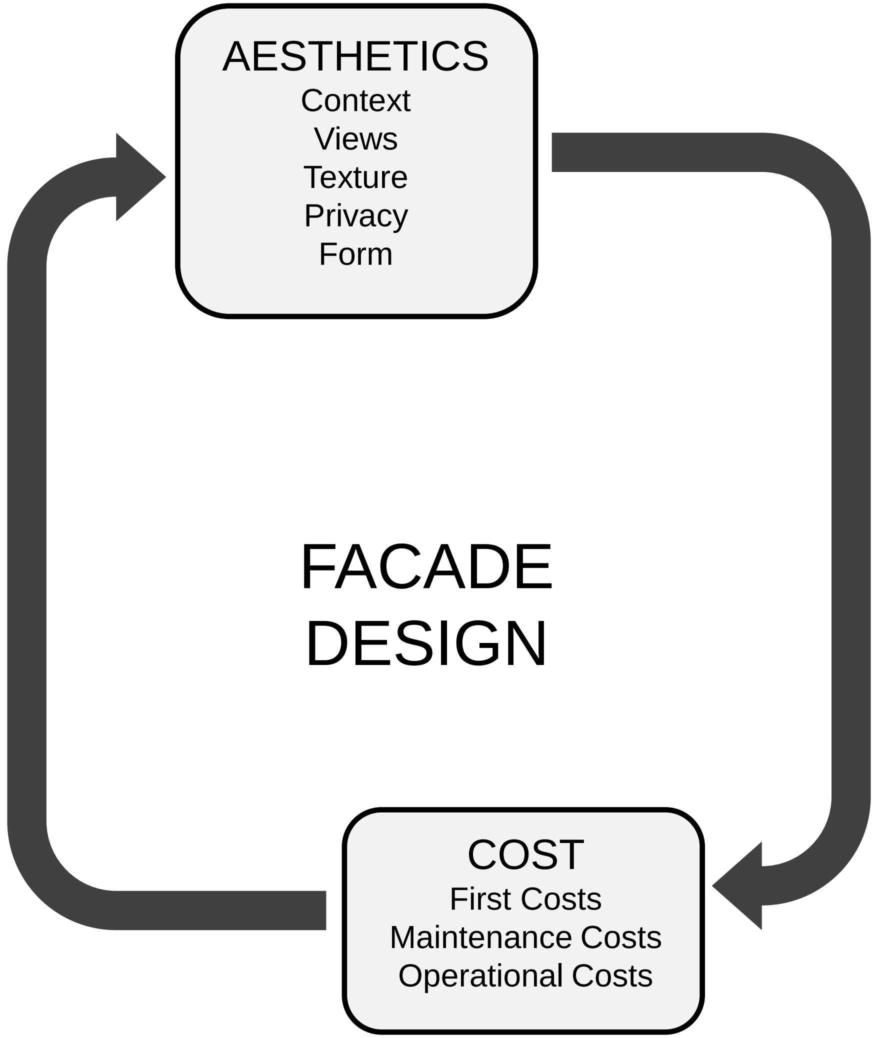
CSI Divisions

- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

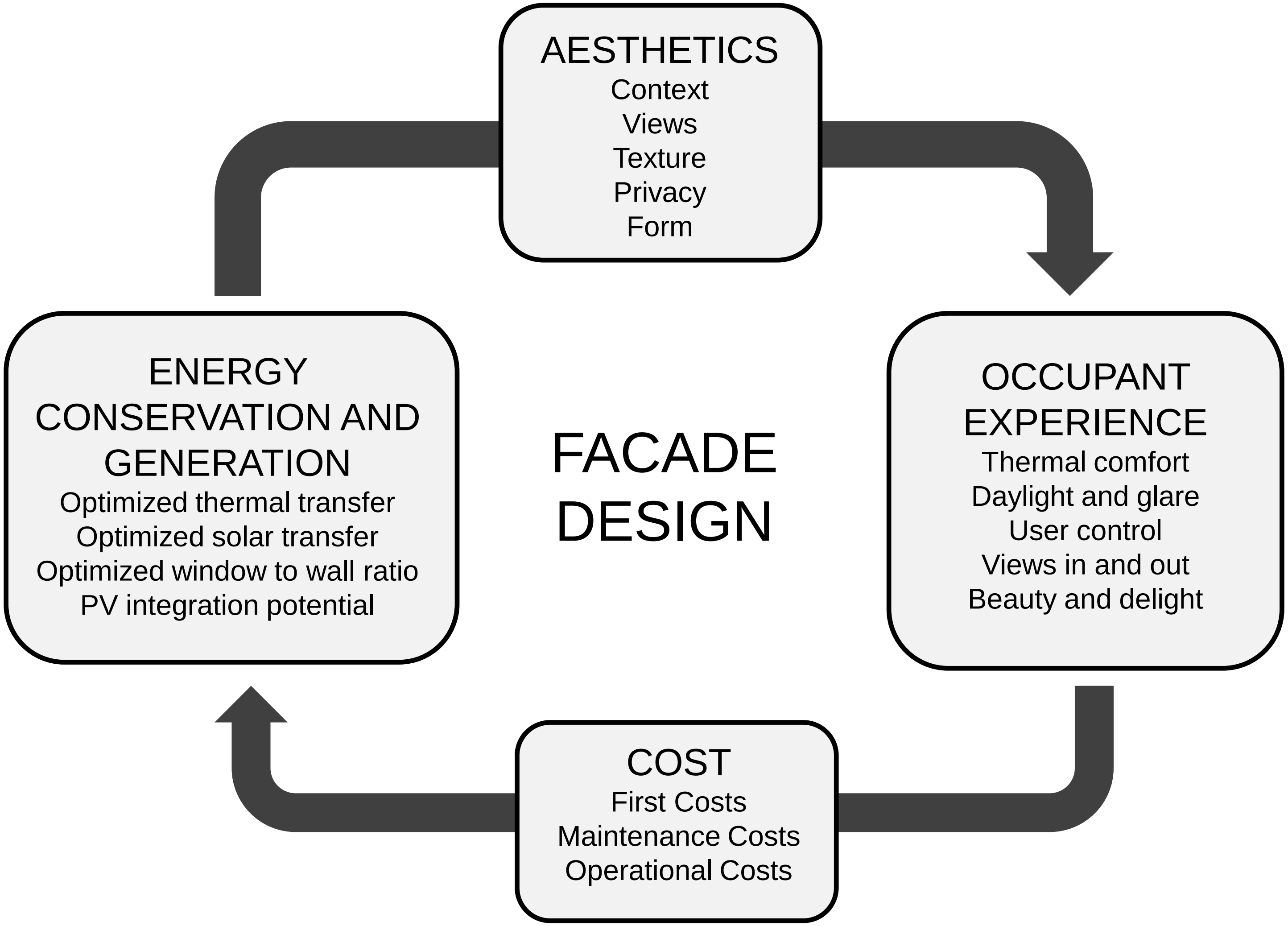
Design Options

- Option 1 - Stud with Mineral
- Option 2 - Stud with PIR
- Option 3 - Unitized with Mineral
- Option 4 - Unitized with PIR

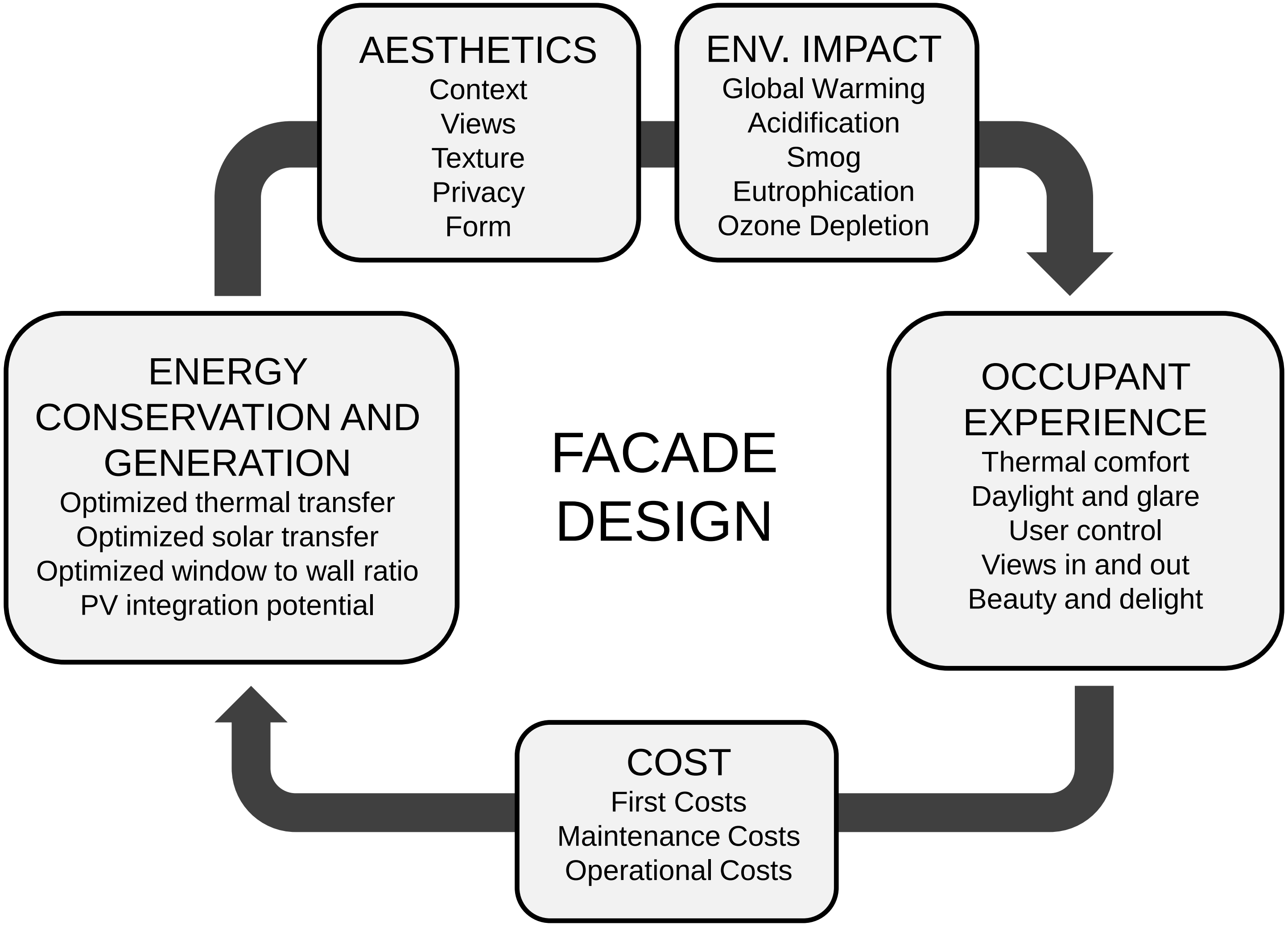
COMPARING INSULATION TYPES



DESIGN DRIVERS



DESIGN DRIVERS



DESIGN DRIVERS

Opportunities

- Designers should be taking a leadership position on understanding environmental impacts of their designs
- **Every impact** associated with a building **is the result of a design decision**
- New tools and workflows are making LCA more efficient and assessable to designers.

Challenges

- **Interpretation** of results is still difficult
- LCA will always be **data intensive**.
- Low availability of high-quality data on products and assemblies
- Benchmarking is a huge challenge!
- LCA community is small, poorly funded
- LCA isn't a perfect methodology (doesn't cover all of our concerns)

KNOW YOUR IMPACT

Introducing Tally

The first LCA app that lets you calculate the environmental impacts of your building material selections directly in an Autodesk® Revit® model.

Click to download a free trial

WHOLE BUILDING LCA

Assess the embodied environmental impact of your entire building. Benchmark your impact throughout design.

DESIGN OPTION COMPARISON

Compare two or more distinct sets of building components side by side.

MATERIAL SELECTION

Compare LCA impacts and ingredients of materials and assemblies, including information from manufacturer EPDs.