

O SCALE MODEL RAILROADING IN ARCHITECTURAL EDUCATION

*A Vertically Integrated 5-Year STEM Curriculum
Structures & Building Systems · Environmental Systems*

Physical Model Building as the Primary Medium of Inquiry

Years 1–5 | Bachelor of Architecture (B.Arch) / Master of Architecture (M.Arch)

O Scale STEM Education Initiative

Curriculum Title	The Station and the City: Architectural STEM Education Through O Scale Model Railroading
Program Type	Bachelor of Architecture (B.Arch) 5-year / Master of Architecture (M.Arch) with undergraduate preparation
Primary Threads	Structures & Building Systems · Environmental Systems (Daylighting, Acoustics, Thermal)
Primary Medium	Physical model building with O Scale components — supplemented by hand drawing and basic computation
Vertical Integration	Each year builds on the previous; O Scale vocabulary and technical skills accumulate across all 5 years
Year 1 Theme	Material & Making — first principles of structure, load, and light through physical experiment
Year 2 Theme	Assembly & System — how components combine into structural and environmental systems
Year 3 Theme	Performance & Measurement — quantifying structural capacity and environmental quality
Year 4 Theme	Integration & Optimization — reconciling structural, environmental, and architectural intent
Year 5 Theme	Thesis — independent investigation culminating in a professionally presented design research project
Accreditation	Addresses NAAB (National Architectural Accrediting Board) Student Performance Criteria (SPC) across all five student achievement areas
Scale	O Scale (1:48) — the most architecturally versatile scale: 1 inch = 4 feet, enabling direct translation between model and full-scale architectural dimensions
Contact	O Scale STEM Education Initiative

Why O Scale for Architecture? O Scale (1:48) is uniquely suited to architectural education. The 1-inch-to-4-feet ratio is directly convertible to architectural drawing conventions. O Scale spaces are large enough to model interior environments with furnishings, daylighting, and occupant figures at a legible scale. The rail infrastructure — stations, bridges, tunnels, retaining walls, viaducts, yards, and depots — represents the full vocabulary of civic and industrial architecture. The railroad building type has been central to architectural history from the Crystal Palace to Louis Sullivan's train stations to Renzo Piano's Kansai International Airport. Students are not building toys — they are building scaled laboratories for architectural investigation.

Why the Railroad is an Architectural Subject

Railroad architecture is among the most consequential building typology in the history of the built environment. The 19th-century railway station invented the large-span iron and glass enclosure — a structural and environmental achievement that prefigured every modern airport, stadium, and convention center. The railroad viaduct defined a new relationship between infrastructure and landscape. The depot anchored the American small town. The rail yard created the industrial urbanism that shaped Chicago, Pittsburgh, and Newark. The tunnel through the mountain demonstrated masonry and engineering at a scale previously unimaginable.

For contemporary architecture students, the railroad offers three irreplaceable pedagogical assets: (1) a complete range of structural types — arches, trusses, long-span beams, retaining walls, foundations on difficult ground; (2) a complete range of environmental challenges — large volumes requiring daylighting without glare, acoustic separation between noisy rail operations and quiet waiting areas, thermal management of spaces open to the elements; and (3) a direct connection between building performance and human experience — the traveler in a great train station is acutely aware of light, sound, temperature, and structure in a way that makes architectural performance viscerally legible.

NAAB Student Performance Criteria Coverage

NAAB SPC	Student Achievement Area	How This Curriculum Addresses It
PC.3	Precedent: ability to examine and comprehend the built environment	Years 1–2 precedent studies of great railroad stations; measured drawings from O Scale models
PC.4	Site & Climate: climate-responsive design	Year 3 solar analysis, daylighting, and thermal modeling using O Scale station models
PC.5	Life Safety: structure, fire, egress	Year 2 load path tracing; Year 3 structural calculation; Year 4 integrated systems coordination
SC.1	Structural Systems: how forces are resolved	Core thread across all 5 years; from load and gravity Year 1 through optimization Year 4
SC.2	Environmental Systems: mechanical, lighting, acoustics	Core thread across all 5 years; from light and shadow Year 1 through full system integration Year 4
SC.3	Building Envelope: performance of exterior	Year 3 thermal resistance; Year 4 envelope integration; Year 5 thesis application

	enclosure	
PC.2	Design Thinking: problem framing and iterative design	Studio project in every year uses the O Scale model as the primary design and testing medium
EC.1	Research: investigate complex problems using multiple information sources	Year 5 thesis requires original research contribution using O Scale as a research instrument

Vertical Curriculum Map

Year	Theme	Structures Thread	Environmental Thread	O Scale Medium
1	Material & Making	Force, load path, compression vs. tension — first principles through model experiments	Light and shadow, sun angles, glare vs. illuminance — observatory model	Kit-bashing and scratch-building O Scale structural components; load testing balsa bridges
2	Assembly & System	Structural hierarchy: primary/secondary/tertiary members; load transfer through connections	Thermal envelope: insulation, thermal bridging, U-value; acoustic separation	Building a complete O Scale station interior with structural framing and daylighting model
3	Performance & Measurement	Section modulus, moment of inertia, beam deflection formulas; measured vs. calculated	Daylighting factor (DF), reverberation time (RT60), solar heat gain coefficient (SHGC)	Instrumented O Scale model with lux meters, microphones, and thermocouples for data collection
4	Integration & Optimization	Structural system selection across building typologies; coordination with envelope and systems	Passive vs. active environmental strategies; integrated design; life-cycle energy analysis	Design-build of a fully coordinated O Scale transit building model with all systems resolved
5	Thesis	Structural innovation: student-selected structural research question applied to thesis project	Environmental performance: thesis building modeled and analyzed for environmental quality	O Scale thesis model as the primary research instrument; professional presentation standards

YEAR 1

Material & Making

First Principles of Structure and Environment Through Physical Experiment

Year Context	First year of a 5-year B.Arch or 4+2 M.Arch program; students have no prior architecture coursework
Prerequisite	High school physics (forces, energy); basic geometry; no prior model-building experience required
Studio Integration	Coordinates with: ARCH 101 Design Studio I; ARCH 111 Structures I (Statics); ARCH 121 Environmental Systems I
Duration	Full academic year (two semesters): Structures thread in Fall; Environmental thread in Spring
Structures Focus	Force, load, compression, tension, equilibrium, load path — the physical logic of how buildings stand up
Environmental Focus	Light and shadow, sun path geometry, glare vs. diffuse illuminance, acoustic reflection and absorption — the physical behavior of light and sound in space
O Scale Medium	Kit-bashing O Scale components; scratch-building from balsa, chipboard, and wire; first exposure to 1:48 scale conventions
NAAB SPCs	PC.3 (Precedent); SC.1 (Structural Systems — introduction); SC.2 (Environmental Systems — introduction)

Year 1 — Curriculum Philosophy

First-year architecture students arrive with diverse backgrounds and a single shared quality: they have never been asked to think rigorously about why buildings stand up or why some spaces feel luminous and others oppressive. Year 1 uses the O Scale model as a laboratory for discovering physical principles through making and testing — not through equations, but through the direct experience of load, failure, light, and shadow at a manageable scale. The emphasis is on observation, description, and hypothesis: what happens when I add weight here? Why does this space feel dark even though the sun is shining? The O Scale railroad station provides the building type, and the student provides the curiosity.

The Pedagogical Argument: Architecture students learn structures and environmental systems best when they can touch, test, break, and rebuild the models they are analyzing. The O Scale station — with its long spans, glass roofs, and large interior volumes — is a structures and environmental systems problem of extraordinary richness compressed to a scale that fits on a drafting table. The failure of a balsa truss under increasing load is more instructive than any diagram in a textbook. The shadow cast by a cardboard wall across an interior floor at the winter solstice sun angle is more memorable than any daylighting formula.

Fall Semester — Structures Thread: Force, Load & Load Path

Unit 1.S.1 — What is a Force? (Weeks 1–3)

Students begin by building the simplest possible O Scale structural element: a beam spanning two supports, carrying a locomotive. Before any formulas, they develop physical intuition:

STUDIO PROJECT

Project 1S — The Span Problem

How long can a beam span before it fails — and what does failure tell us?

Project Duration	3 weeks
Structures Concepts	Dead load, live load, span-to-depth ratio, bending vs. shear failure, ductile vs. brittle failure
Building Type	O Scale railway bridge — the most direct structural type in the railroad vocabulary
Materials	Balsa wood strips (1/8", 1/4", 3/8" square), chipboard, basswood; O Scale locomotive as the calibrated live load
Deliverables	(1) Load-test log with failure load and failure mode sketches; (2) Series of 8 comparative study models; (3) Written reflection: "What did failure teach you?"

Students build 8 identical span beams from 1/8" square balsa, each with a different depth (1/8", 1/4", 3/8", 1/2") and two different materials (balsa vs. chipboard). They load each beam with calibrated weights (using the O Scale locomotive as a reference — approximately 200g) until failure. They record: failure load, failure mode (bending at center, shear near support, crushing at bearing point), and the sound and appearance of failure.

The critical observation: depth matters more than width. A beam twice as deep carries approximately four times the load. Students discover the span-to-depth ratio intuitively before they encounter the formula. The lesson: structure is geometry before it is material.

Beam Depth	Material	Failure Load (g)	Failure Mode	Sketch of Failure Pattern
1/8"	Balsa			
1/4"	Balsa			
3/8"	Balsa			
1/2"	Balsa			
1/8"	Chipboard			
1/4"	Chipboard			
3/8"	Chipboard			
1/2"	Chipboard			

Unit 1.S.2 — Compression, Tension & Triangulation (Weeks 4–7)

Students build a series of O Scale railway bridge trusses, exploring how triangulation converts bending into axial forces — the fundamental structural logic of the truss.

STUDIO PROJECT

Project 2S — The Truss Studies

Why is a triangle the basic unit of structural stability?

Three sequential model experiments:

1. Build a rectangular frame from balsa sticks pinned at corners. Apply a lateral load. Observe: the frame collapses (no triangulation = unstable). Sketch the deformation.
2. Add a diagonal to the rectangular frame. Apply the same lateral load. Observe: the frame is now stable. Identify which members are in compression (shortened) and which are in tension (elongated) by touch — compressed members bow slightly; tension members stretch taut.
3. Build a full Pratt truss spanning 24 inches (representing a 96-foot prototype span in O Scale). Apply the O Scale locomotive as a live load. Identify the load path from the wheel, to the rail, to the stringer, to the floor beam, to the panel point, through the truss members, to the abutment. Sketch the load path with arrows on a section drawing.

Precedent study: Students study the Firth of Forth Rail Bridge (1890, Scotland) — the first major cantilever truss bridge, still one of the largest in the world. They sketch the structural logic at 1:48 scale, identifying how the cantilever arms balance each other and where the tension and compression chords are.

Unit 1.S.3 — The Arch: Compression in Curve (Weeks 8–11)

The masonry arch is the oldest large-span structural form in railroad architecture — thousands of Victorian railway viaducts use brick arches to carry trains over valleys, rivers, and streets. Students build a series of arch models exploring how the arch converts vertical load into horizontal thrust.

STUDIO PROJECT

Project 3S — The Arch & the Abutment

How does a curved form carry a load — and what must resist it?

Students cut arch shapes from chipboard (semicircular, segmental, and pointed) and place them between two vertical supports. They discover: the arch stands only when the supports are prevented from spreading apart. Add a tie rod (a piece of thread connecting the two feet of the arch) — the arch can now stand without spreading supports. This is the tied arch: the structural logic of many modern bridges and stadium roofs.

The horizontal thrust H of a semicircular arch under uniform load w per unit length, with span L :

$H = w \cdot L^2 / (8 \cdot f)$ where f = rise of arch (horizontal thrust inversely proportional to rise)

Students do not yet solve this equation — they discover it physically. A flat arch (small f) spreads wildly; a steep arch (large f) barely spreads. The equation is introduced as a description of what they have already observed.

Precedent: Students study the Glenfinnan Viaduct, Scotland (1901) — 21 concrete arches carrying the West Highland Line through the Scottish Highlands. They build a 1:48 scale section model in air-dry clay and photograph it in raking light to reveal the three-dimensional geometry of the arch barrel.

Unit 1.S.4 — Semester Review: The Station as a Structural Problem (Weeks 12–15)

STUDIO PROJECT

End-of-Semester Project 4S — Station Structure Study

Analyze and model the structural system of a great railway station

Students select one great railway station from a provided list (King's Cross, London; Union Station Chicago; Penn Station original; Grand Central Terminal New York; Gare d'Austerlitz Paris; Chhatrapati Shivaji Terminus Mumbai) and produce:

4. A 1:48 scale structural study model showing only the primary structural system — columns, beams, arches, or trusses — stripped of all architectural finish. Minimum footprint: 12"×12".
5. A set of three structural analysis drawings (plan, section, axonometric) with load path arrows showing how gravity loads travel from roof to foundation.
6. A 500-word structural narrative: what structural type is used, why it is appropriate for the span and program, and what would happen if one primary member were removed.

Spring Semester — Environmental Thread: Light, Shadow & Sound

Unit 1.E.1 — The Sun and the Building (Weeks 1–4)

STUDIO PROJECT

Project 1E — The Light Observatory

How does the position of the sun determine the quality of light inside a space?

Students build a simple O Scale station waiting room model (12"×8"×4" tall, representing a 48'×32'×16' space at 1:48 scale) from white chipboard with a single south-facing window opening. The model has a removable roof so the interior can be photographed and observed.

Using a heliodon (a simple adjustable-angle lamp stand simulating sun position) or outdoor sunlight, students observe the interior at four conditions:

- Summer solstice, noon — sun angle approximately 72° above horizon at 40°N latitude
- Winter solstice, noon — sun angle approximately 26° above horizon

- Spring/fall equinox, noon — sun angle approximately 49°
- Winter solstice, 3pm — low sun from the southwest

For each condition: photograph the interior; sketch the shadow pattern on the floor and walls; describe in words the quality of light (direct vs. diffuse, harsh vs. gentle, depth of penetration). Students discover that low winter sun penetrates deeply into the space — useful for winter solar gain — but also creates glare and harsh shadows. High summer sun barely enters the south window at all. The station's deep overhanging eave is both a structural and an environmental element.

The Sun Path Geometry: At latitude 40°N (approximately the latitude of Philadelphia, Denver, or Beijing): Summer solstice noon altitude = $90^\circ - 40^\circ + 23.5^\circ = 73.5^\circ$. Winter solstice noon altitude = $90^\circ - 40^\circ - 23.5^\circ = 26.5^\circ$. Equinox noon altitude = $90^\circ - 40^\circ = 50^\circ$. Students calculate the depth of sun penetration at each altitude: penetration depth $d = H / \tan(\text{altitude})$, where H = ceiling height. At 26.5° winter altitude with a 16' ceiling: $d = 16 / \tan(26.5^\circ) = 16 / 0.499 = 32$ feet. In O Scale: $32/4 = 8$ inches of penetration. Students verify by measuring the actual shadow edge in their model.

Unit 1.E.2 — Sound in Space (Weeks 5–9)

STUDIO PROJECT

Project 2E — The Echo Chamber

Why do some spaces sound alive and others dead — and what controls the difference?

Students modify their station waiting room model by lining the interior surfaces with different materials: bare chipboard (hard, reflective), cork sheet (absorptive), fabric (absorptive), and aluminum foil (highly reflective). Using a small piezo buzzer as the sound source and a basic smartphone decibel meter app as the receiver, they measure the relative sound level decay in each configuration.

The key concept: reverberation. A hard-surfaced space (stone cathedral, marble train station concourse) has long reverberation — sound bounces repeatedly before dying away, creating a sense of grandeur but poor speech intelligibility. An absorptive space (carpeted office, padded recording studio) has short reverberation — sound dies quickly, creating clarity but a sense of deadness.

The Sabine equation for reverberation time RT60 (time for sound to decay 60 dB):

$$RT60 = 0.161 * V / A \quad [\text{seconds}]$$

Where V = room volume (m^3); A = total absorption ($m^2 \cdot \text{sabin}$) = sum of surface area \times absorption coefficient for each surface. Students calculate the theoretical RT60 for their model room (scaled to prototype dimensions) and compare to the measured decay. For a great railway concourse ($V \approx 100,000 m^3$, hard stone surfaces with average absorption coefficient ≈ 0.05): $RT60 = 0.161 \times 100,000 / (5,000) \approx 3.2$ seconds — consistent with the famous reverberant acoustic quality of Union Station.

Unit 1.E.3 — Thermal Comfort & the Envelope (Weeks 10–15)

STUDIO PROJECT

Project 3E — Hot Box / Cold Box

How does a building envelope control the flow of heat?

Students build two identical O Scale station pavilion models — one with a single-layer chipboard wall (representing no insulation) and one with a double-layer chipboard wall with a 1/4" air gap filled with cotton batting (representing insulation). Using a heat lamp as the exterior heat source and a small thermometer inside each model, they measure the interior temperature rise over 20 minutes.

The thermal resistance R-value concept: $R = \text{thickness} / \text{thermal conductivity (t/k)}$. Materials with lower k (conductivity) resist heat flow better. Air gaps slow conduction. Students discover that the insulated model heats up more slowly — and that when the lamp is removed, it also cools more slowly. Thermal mass and insulation are complementary strategies, not identical ones.

Precedent: Students study the Great Conservatory at Chatsworth (1836, Paxton) — the direct structural and environmental ancestor of the great railway station train shed. Its iron and glass envelope maximized solar gain in winter but overheated in summer — an environmental design failure that prefigures contemporary debates about all-glass buildings.

Year 1 Assessment

Criterion	4 – Distinction	3 – Proficient	2 – Developing	1 – Beginning
Structural Model Quality	All 8 beam study models built to consistent craft standard; truss load path clearly readable; arch model demonstrates thrust behavior; station structure study model correctly represents primary structure without secondary elements	7 models at consistent craft; truss partially readable; arch model present; station model mostly correct	5–6 models; truss and arch present but craft inconsistent; station model has significant omissions	Fewer than 5 models; no truss or arch; station model represents finish rather than structure
Environmental Observation	Light observatory: 4 sun conditions documented with photographs, shadow sketches, and qualitative descriptions; RT60 calculated and compared to measured; thermal model	3 sun conditions documented; RT60 calculated; thermal data recorded	2 sun conditions documented; RT60 not calculated; thermal data partially recorded	1 sun condition; no RT60 calculation; no thermal data

	temperature data recorded over full 20-min period			
Structural Narrative	500-word narrative correctly identifies structural type; accurately describes load path; thoughtfully discusses consequence of member removal; demonstrates emerging structural intuition	Structural type correct; load path described; member removal discussed with minor inaccuracy	Structural type correct; load path partially described; member removal discussed superficially	Structural type identified; load path not described; no member removal analysis
Precedent Research	Precedent station correctly identified in structural type and historical context; model accurately represents primary structure; drawings correctly show load path; connection to O Scale railroad building type is explicit	Precedent correct; model mostly accurate; drawings show load path; railroad connection mentioned	Precedent identified; model partially accurate; load path partially shown	Precedent identified; model does not represent structure; no load path analysis
Craft & Drawing Quality	All models built with consistent craft; all drawings at appropriate scale with title block, north arrow (where applicable), and scale bar; sketches labeled; photographs well-composed and clearly labeled	Consistent craft; drawings at scale with most required elements; sketches labeled	Variable craft; drawings partially at scale; some labels missing	Craft highly variable; drawings not at scale; labels absent

YEAR 2

Assembly & System

How Components Combine into Structural and Environmental Systems

Year Context	Second year; students have completed Year 1 foundations; beginning to think systematically
Prerequisites	Year 1 structures and environmental threads; ARCH 111 Structures I; concurrent with ARCH 211 Structures II
Studio Integration	Coordinates with: ARCH 201 Design Studio II; ARCH 211 Structures II (indeterminate structures); ARCH 221 Environmental Systems II
Structures Focus	Structural hierarchy (primary/secondary/tertiary systems); connections and joints; lateral stability systems; foundation types; material properties at a system level
Environmental Focus	Thermal envelope assembly: U-value, thermal bridging, vapor barriers, air barriers; acoustic separation between spaces; daylighting systems beyond the simple window
O Scale Medium	Building a complete O Scale station interior — structural framing, glazing system, roof assembly — as a coordinated physical model representing all building systems simultaneously
NAAB SPCs	SC.1 (Structural Systems — intermediate); SC.2 (Environmental Systems — intermediate); PC.5 (Life Safety — introduction)

Year 2 — Curriculum Philosophy

Year 2 moves from the isolated experiment to the integrated system. Students now ask not "how does a beam work?" but "how does a complete structural system hold a building together?" The shift is from element to assembly, from component to connection, from material to system. The O Scale station building type provides the full range of structural and environmental systems in a single, coherent building: a heavy timber or steel primary frame carrying long-span roof trusses, with a masonry or concrete envelope, a glazed clerestory for daylighting, and a complex acoustic environment separating the noisy train hall from the quiet waiting room.

Fall Semester — Structures Thread: Hierarchy, Connections & Lateral Stability

Unit 2.S.1 — Structural Hierarchy (Weeks 1–4)

STUDIO PROJECT

Project 1S — Dissecting a Structure

Map the complete structural hierarchy of a real railroad building

Students receive a set of measured drawings (provided by instructor) of a real O Scale-proportioned railroad station building. They produce a structural hierarchy diagram identifying every structural member and classifying it as:

- Primary structure: columns, major beams, trusses — carries loads to the ground
- Secondary structure: purlins, girts, floor beams — spans between primary members
- Tertiary structure: roof decking, wall panels, floor planking — spans between secondary members

They then build a 1:48 scale model of the structural skeleton alone — no walls, no roof covering, no windows — just the bare structural frame. The model must be self-standing without temporary supports. This forces students to solve the lateral stability problem: a frame of beams and columns is not stable without bracing, moment connections, or shear walls.

Three lateral stability strategies are modeled and compared:

7. Diagonal bracing: add wire diagonals in selected bays. Identify which bays need bracing and which can remain open (for doors, windows, platforms).
8. Shear wall: substitute a solid chipboard panel for one bay of the frame. Measure the improvement in lateral stiffness by applying a lateral load and measuring drift.
9. Moment frame: glue (rather than pin) the beam-column connections in selected bays. Observe the difference in lateral behavior compared to pinned connections.

Unit 2.S.2 — The Connection (Weeks 5–8)

A structure is only as strong as its connections. Students study the three primary connection types in railroad building construction — pinned (moment-free), semi-rigid (partial moment transfer), and rigid (full moment transfer) — and build model connections that physically demonstrate each behavior.

STUDIO PROJECT

Project 2S — The Joint Detail

How does a connection determine the behavior of a structure?

Using O Scale-appropriate materials (balsa, basswood, brass wire, small nuts and bolts from hobby suppliers), students build:

- A pinned beam-column connection: the beam rests on a small pin through the column — it can rotate freely. Under load, the beam sags symmetrically and the connection does not develop moment.
- A rigid welded connection: the beam is glued to the column with epoxy — it cannot rotate. Under load, the column develops bending stress at the connection, and the beam sags less (because the fixed end reduces the effective span).
- A bolted clip angle connection (semi-rigid): the beam is connected to the column with a small L-shaped chipboard bracket. Under load, the bracket deforms slightly — partial moment transfer.

Students photograph each connection under load, sketch the deformed shape, and write a comparison: which connection transfers moment? Which allows rotation? Which would you choose for the base of a station platform canopy column, and why?

Historical precedent: The great iron train sheds of the Victorian era (Paddington Station, London, 1854; St. Pancras Station, London, 1868) used wrought iron ribs with pinned bases and rigid apex connections — a specific structural logic that allowed the shed to behave as a three-hinged arch while appearing as a continuous vault.

Unit 2.S.3 — Foundation Types & Soil-Structure Interaction (Weeks 9–12)

STUDIO PROJECT

Project 3S — What the Ground Holds

How do different foundation types respond to different ground conditions?

Students build O Scale foundation models in three ground conditions simulated with different materials: dense sand (fine modeling sand), soft clay (water-saturated pottery clay), and rock (a chipboard sheet representing bedrock). Foundation types modeled:

- Spread footing: a square pad of chipboard loaded with the O Scale locomotive. Measure settlement in each ground material.
- Strip footing under a masonry wall: a continuous chipboard strip. Observe differential settlement when one end of the strip is on clay and the other on sand.
- Pile foundation: toothpick piles driven into the clay until they reach the chipboard bedrock. Load the same way. Observe: piles eliminate settlement by transferring load to rock.

This directly connects to railroad engineering: the choice of foundation for a railroad bridge or station building is determined by the soil conditions. The great railroad viaducts of the northeastern US (many built in the 1840s–1870s) used stone masonry piers founded on bedrock wherever possible and timber piles in soft ground — a decision students can now understand from physical experience.

Unit 2.S.4 — Year Project: The Station Skeleton (Weeks 13–15)

STUDIO PROJECT

Year Project 2S — Complete Structural System Model

Design and build the complete structural system of an O Scale transit building

Working in pairs, students design and build the complete structural skeleton of a small O Scale transit building (minimum footprint 18"×12", representing a 72'×48' building at prototype). The building must include:

- A primary structural system (steel frame, timber frame, or masonry load-bearing walls) — chosen and justified
- A long-span roof structure (truss, arch, or space frame) spanning the main waiting hall
- A lateral stability system (bracing, shear walls, or moment frames) — identified and modeled
- At least two foundation types responding to a defined ground condition
- All connections modeled at an appropriate level of abstraction

The model is evaluated by a structural jury including the instructor and at least one practicing structural engineer (invited from the local ASCE or SEI chapter). Each pair presents their structural logic in a 10-minute oral presentation.

Spring Semester — Environmental Thread: Envelope Performance & Acoustic Design

Unit 2.E.1 — The Building Envelope as a Filter (Weeks 1–5)

STUDIO PROJECT

Project 1E — The Envelope Assembly

How do multiple layers work together to control heat, moisture, and air?

Students build a series of wall assembly models at 1:48 scale — each representing a different approach to the building envelope in a cold climate (simulating a northeastern US railroad station in winter). The wall assemblies modeled:

- Mass masonry (brick or stone): single-material wall with high thermal mass but no insulation layer. High U-value (poor insulator) but high thermal mass (delays peak temperature swing).
- Cavity wall with insulation: outer wythe + air gap + insulation + inner wythe. Low U-value, moderate thermal mass.
- Curtain wall with thermal break: aluminum frame + double-pane glazing + thermal break at mullion. Very low thermal mass; U-value depends on glazing specification.

For each assembly, students calculate the total U-value (overall heat transmission coefficient) from the layer-by-layer R-values:

$$U_{total} = 1 / (R1 + R2 + R3 + \dots + Rn) \quad [W/m^2 \cdot K \text{ or } BTU/hr \cdot ft^2 \cdot F]$$

Typical R-values per inch: brick = 0.20; concrete = 0.08; wood = 1.25; fiberglass batt = 3.14; still air = 0.68. Students compare their calculated U-values to ASHRAE 90.1 minimum requirements for Climate Zone 5 (northeastern US).

Unit 2.E.2 — Thermal Bridging (Weeks 6–8)

A thermal bridge is a conductive path through the insulation layer — a point of weakness in the thermal envelope. In real buildings, structural steel columns penetrating the insulation layer are common thermal bridges. Students model this by inserting a copper wire (high conductivity) through the insulated wall assembly of their Year 1 hot box model. With a heat lamp on the outside and a thermometer on the inside, they measure the temperature increase near the copper bridge vs. away from it, quantifying the effect of a thermal bridge on interior comfort.

Unit 2.E.3 — Acoustic Separation Between Spaces (Weeks 9–12)

STUDIO PROJECT

Project 2E — The Partition Problem

How do we separate the noisy train hall from the quiet waiting room?

Students build a two-room O Scale model: a train hall (representing the track and platform area — noisy) and a waiting room (representing the passenger concourse — desired quiet). The partition between the rooms is modeled in three configurations:

- Single layer chipboard: thin, lightweight — low sound isolation. Measure: sound level in waiting room with buzzer active in train hall.
- Double layer chipboard with air gap: mass-air-mass — improved isolation. Measure and compare.
- Double layer chipboard with air gap filled with cotton (acoustic insulation) and resilient connection (rubber gasket): decoupled assembly — best isolation. Measure and compare.

The Sound Transmission Class (STC) concept: STC is a single-number rating of a wall's sound isolation performance. STC 25 means normal speech is clearly audible through the wall; STC 50 means loud speech is barely audible. Students estimate the STC of each partition from their measured level differences and compare to ASHRAE handbook recommendations for train station acoustic separation (typically STC 45–55 between platform and passenger areas).

Unit 2.E.4 — Integrated Daylighting System Design (Weeks 13–15)

STUDIO PROJECT

Project 3E — Daylighting the Great Hall

Design a daylighting system for a large O Scale station concourse that avoids glare and achieves target illuminance

Students design and test a daylighting strategy for the main waiting hall of their Year Project structural model. The target: achieve a minimum Daylight Factor (DF) of 2% throughout the hall with no direct beam sunlight on the floor or seating areas between 9am and 3pm on the summer solstice. Students test three daylighting strategies:

- Clerestory windows (high side windows): good for even distribution, limited direct sun penetration
- Monitor roof (raised central roof section with north-facing glazing): excellent diffuse daylighting, zero direct sun
- Sawtooth roof (repeated asymmetric profiles with north-facing glazing): used in Victorian-era train sheds; excellent for long buildings

Each strategy is tested using the heliodon or direct sunlight. Photographs document interior light quality. The preferred strategy is incorporated into the structural model, creating for the first time a model that simultaneously represents structure and environment.

Year 2 Assessment

Criterion	4 – Distinction	3 – Proficient	2 – Developing	1 – Beginning
Structural Skeleton Model	Model self-standing without	Model self-standing;	Model self-standing with	Model requires support;

	temporary supports; all three structural levels (primary/secondary/tertiary) identifiable; lateral stability system correctly implemented and demonstrable; connections modeled at appropriate abstraction	primary and secondary structure identifiable; lateral stability present; connections present	assistance; primary structure identifiable; lateral stability present	structural levels not distinguishable
Connection Demonstrations	All three connection types built and loaded; photographs show deformed shapes; written comparison correctly identifies moment-transfer behavior of each; historical precedent connected	3 connection types built and loaded; photographs present; comparison correct; precedent mentioned	2 connection types built; comparison partially correct; no precedent	1 connection type; no loaded photograph; comparison absent
Envelope U-Value Calculation	U-value calculated correctly for all 3 assemblies using layer-by-layer R-values; compared to ASHRAE 90.1 limits; thermal bridge experiment conducted with temperature measurements; STC partition comparison documented	U-value for 2 assemblies; ASHRAE compared; thermal bridge conducted; STC measured	U-value for 1 assembly; ASHRAE not compared; thermal bridge conducted without measurement	U-value formula stated; not calculated; no thermal bridge or STC measurement
Daylighting System	Daylighting strategy selected and tested with heliodon or sunlight; 3 strategies compared; preferred strategy	2 strategies compared; preferred strategy integrated into model; solstice test documented	1 strategy tested and integrated; no comparison	Daylighting considered in model design but not tested or documented

	integrated into structural model; summer solstice direct sun test documented			
Jury Presentation	10-minute presentation clearly communicates structural logic; correctly answers structural jury questions; demonstrates understanding of system-level thinking; model supports the argument	10-minute presentation; most questions answered correctly; system-level thinking evident	Presentation present; some questions answered; element-level rather than system-level thinking	Presentation significantly over/under time; structural logic not clearly communicated

YEAR 3

Performance & Measurement

Quantifying Structural Capacity and Environmental Quality

Year Context	Third year; students now think systematically; ready for quantitative analysis
Prerequisites	Years 1–2; ARCH 211 Structures II; ARCH 221 Environmental Systems II; concurrent with ARCH 311 Structures III (steel and concrete) and ARCH 321 Environmental Systems III
Structures Focus	Quantitative structural analysis: section modulus, moment of inertia, beam deflection formulas, column buckling (Euler), steel member sizing, concrete basics
Environmental Focus	Quantitative environmental analysis: Daylight Factor calculation, RT60 from Sabine equation, SHGC and solar heat gain calculation, thermal load calculation, energy use intensity (EUI)
O Scale Medium	Instrumented O Scale models: lux meters measure interior illuminance; smartphone apps measure RT60; thermocouples measure temperature gradients across envelope assemblies; all data compared to calculated predictions
NAAB SPCs	SC.1 (Structural Systems — advanced); SC.2 (Environmental Systems — advanced); SC.3 (Building Envelope — intermediate)
Key Shift	Students produce quantitative predictions before building models, then compare measured results to predictions and explain discrepancies — the discipline of engineering validation

Year 3 — Curriculum Philosophy

Year 3 introduces the discipline of prediction and validation: before testing, calculate. Before measuring, predict. After measuring, compare and explain discrepancies. This is the intellectual discipline that separates the engineer from the maker, and the architect who can defend their environmental and structural decisions from the one who cannot. The O Scale model becomes an instrument of measurement — equipped with sensors, calibrated, and used to generate data that is compared to analytical predictions derived from first principles.

Fall Semester — Structures Thread: Quantitative Analysis

Unit 3.S.1 — Section Properties & Bending Stress (Weeks 1–5)

Students learn to calculate the moment of inertia I and section modulus S for the cross-sections they have been using intuitively in Years 1 and 2. For a rectangular cross-section of width b and depth d :

$$I = b \cdot d^3 / 12 \quad [\text{moment of inertia, in}^4 \text{ or mm}^4]$$

$$S = I / c = b \cdot d^2 / 6 \quad [\text{section modulus, } c = d/2 \text{ for symmetric section}]$$

$$\sigma_{\max} = M / S \quad [\text{maximum bending stress, psi or MPa}]$$

Students calculate these values for each of their 8 beam study models from Year 1 (now revisited with formulas) and verify that the failure loads are consistent with the material's modulus of rupture (f_r). For balsa wood, $f_r \approx 4,000\text{--}6,000$ psi. Students calculate the theoretical failure load and compare to the measured failure load from Year 1. Percent error is calculated and sources of discrepancy are identified (grain orientation, glue joints, imperfect support conditions).

STUDIO PROJECT

Project 1S — The Calculation Validates the Model

Predict failure load for 5 beam configurations, then test

Before building or testing, students calculate the predicted failure load for 5 specified beam configurations (different spans, depths, and materials). They build the beams, test them, and calculate percent error. The goal: predictions within $\pm 20\%$ of measured values. Students who achieve this demonstrate that their structural intuition from Years 1–2 has been correctly formalized.

Unit 3.S.2 — Beam Deflection & Serviceability (Weeks 6–9)

$$\Delta_{\max} = 5 \cdot w \cdot L^4 / (384 \cdot E \cdot I) \quad [\text{midspan deflection, uniform load}]$$

$$\Delta_{\max} = P \cdot L^3 / (48 \cdot E \cdot I) \quad [\text{midspan deflection, center point load}]$$

Students measure the modulus of elasticity E for each material used in their models (using the cantilever coupon method from earlier years) and calculate predicted deflection under the O Scale locomotive load. They measure actual deflection using a dial indicator or laser pointer reflection method. Serviceability limit: deflection must not exceed $L/360$ for floor beams or $L/240$ for roof beams (standard architectural practice). Students check their model bridges against these limits.

Unit 3.S.3 — Column Buckling (Weeks 10–12)

Students return to the vertical elements of their structural frames and analyze them as columns subject to buckling. Euler's critical buckling load:

$$P_{\text{cr}} = \pi^2 \cdot E \cdot I / (K \cdot L)^2$$

Where K = effective length factor ($K=1.0$ for pin-pin; $K=0.5$ for fixed-fixed; $K=0.7$ for fixed-pin; $K=2.0$ for fixed-free cantilever). Students test columns with different boundary conditions — the same column carries dramatically different loads depending on how its ends are restrained. This directly connects to their connection work from Year 2: a rigid moment connection at the column base doubles the buckling load compared to a pinned base.

Spring Semester — Environmental Thread: Quantitative Measurement

Unit 3.E.1 — Daylight Factor Measurement (Weeks 1–5)

STUDIO PROJECT

Project 1E — The Daylight Factor Survey

Measure and map the Daylight Factor across the floor of an O Scale station interior

The Daylight Factor (DF) is the ratio of interior horizontal illuminance to simultaneous exterior horizontal illuminance under an overcast sky:

$$DF = (E_{\text{interior}} / E_{\text{exterior}}) * 100\% \quad [\text{percent}]$$

Target values: DF > 5% = well daylit; DF 2–5% = adequately daylit; DF < 2% = supplementary artificial lighting required. Students measure DF at a 1-inch grid across the floor of their O Scale station model using a calibrated lux meter (or a smartphone lux app) indoors under overcast conditions. They produce a DF contour map of the interior. They then calculate the predicted DF using the British Building Research Establishment (BRE) simple formula:

$$DF_{\text{avg}} = W * \tau * \theta / [A * (1 - R^2)]$$

Where W = glazing area; tau = glass transmittance; theta = angle subtended by sky from window; A = total room surface area; R = average room surface reflectance. Students compare measured to predicted DF values and identify locations of under-performance.

Unit 3.E.2 — Reverberation Time Measurement (Weeks 6–9)

STUDIO PROJECT

Project 2E — The Acoustic Survey

Measure RT60 in an O Scale station model and compare to Sabine prediction

Students use the impulse response method: clap sharply inside the O Scale model (or use a small piezo click) while recording with a smartphone. Using free acoustic analysis software (Audacity), they measure the time for the recorded sound to decay by 60 dB — the RT60. They compare to the Sabine equation prediction:

$$RT60 = 0.161 * V / A$$

Where V = room volume (m³, scaled from model); A = total absorption (m²·sabin) calculated from surface areas and absorption coefficients of each material. Students test three surface configurations and compare all three measured RT60 values to Sabine predictions. They then specify the surface treatment required to achieve a target RT60 of 1.5–2.0 seconds for the main waiting hall — appropriate for a space requiring both acoustic presence and speech intelligibility.

Unit 3.E.3 — Solar Heat Gain Calculation (Weeks 10–13)

Students calculate the solar heat gain through the glazed clerestory of their station model for the peak cooling day (July 21 in the northern hemisphere):

$$Q_{\text{solar}} = A_{\text{glass}} * SHGC * I_{\text{solar}} \quad [\text{BTU/hr or Watts}]$$

Where A_{glass} = glazed area; SHGC = Solar Heat Gain Coefficient of glazing (0.25–0.87 depending on glass type); I_{solar} = incident solar radiation (from ASHRAE climatic data for the project location). Students compare three glazing types (clear single, low-e double, spectrally selective triple) and calculate the difference in cooling load. They then specify the glazing that achieves the best balance of daylighting (high visible transmittance) and solar control (low SHGC).

Unit 3.E.4 — Year Project: The Instrumented Station Model (Weeks 14–15)

STUDIO PROJECT

Year Project 3 — Full Performance Analysis Report

Produce a complete structural and environmental performance analysis of your O Scale station model

The Year 3 capstone requires a formal Performance Analysis Report documenting:

10. Structural analysis: moment of inertia and section modulus for primary beams; predicted vs. measured deflection at design load; column buckling check; load rating in Cooper equivalent units (a structural joke connecting back to railroad engineering).
11. Daylighting analysis: DF contour map from measurement; comparison to predicted DF; identification of under-daylit zones; proposed design modification with re-calculated DF.
12. Acoustic analysis: measured RT60 in three surface configurations; Sabine prediction for each; discrepancy analysis; specification for target RT60 with required absorption area.
13. Thermal analysis: U-value of envelope assembly; solar heat gain calculation for peak cooling day; specification for glazing type achieving balanced daylighting and solar control.

Year 3 Assessment

Criterion	4 – Distinction	3 – Proficient	2 – Developing	1 – Beginning
Structural Calculations	All beam failure predictions within $\pm 20\%$ of measured; deflection calculated with correct formula and measured E; column buckling analysis with correct K-factor; percent errors calculated and discrepancies explained	Predictions within $\pm 30\%$; deflection calculated; buckling analyzed; errors calculated	Predictions within $\pm 50\%$; deflection or buckling calculated; errors not analyzed	Calculations present but predictions consistently outside $\pm 50\%$; no error analysis
Daylight Factor Survey	DF measured at 1-inch grid; contour map produced; BRE formula prediction calculated and compared; under-daylit zones identified; design modification proposed with re-calculated DF	DF measured at 2-inch grid; contour map produced; BRE prediction calculated; under-daylit zones identified	DF measured at several points; no contour map; BRE prediction calculated	DF measured at one or two points; no contour map; no prediction

RT60 Measurement & Sabine	RT60 measured for 3 surface configurations; Sabine prediction for each calculated with correct absorption coefficients; measured vs. predicted compared; target RT60 specification with required absorption area	RT60 for 2 configurations; Sabine for each; comparison made; target specified	RT60 for 1 configuration; Sabine calculated; target specified	RT60 measured; Sabine formula stated but not calculated
Solar Heat Gain	Q_solar calculated for all 3 glazing types with correct SHGC and I_solar; glazing selection justified by balance of VT and SHGC; comparison to comfort threshold; ASHRAE data source cited	Q_solar for 2 glazing types; selection justified; ASHRAE cited	Q_solar for 1 glazing type; selection stated without calculation	Formula stated; not calculated for specific glazing options
Performance Analysis Report	Report in professional format: executive summary, all four analysis sections, all calculations shown, all measured data tabulated, all figures captioned, conclusions with specific design recommendations; professional language throughout	All sections present; calculations shown; data tabulated; figures captioned; recommendations present	All sections present; calculations partially shown; some figures uncaptioned; recommendations generic	Report incomplete; calculations absent; no professional format

YEAR 4

Integration & Optimization

Reconciling Structural, Environmental, and Architectural Intent

Year Context	Fourth year; students can analyze structure and environment independently; now must integrate them in design
Prerequisites	Years 1–3; all structures and environmental courses; concurrent with ARCH 411 Advanced Structural Systems; ARCH 421 Integrated Building Systems; ARCH 431 Professional Practice
Structures Focus	Structural system selection for complex building programs; coordination of structure with envelope; long-span systems (space frames, cable structures, tensile structures); seismic and wind resistance
Environmental Focus	Passive vs. active environmental strategies; integrated design process; life-cycle energy analysis; post-occupancy evaluation methodology; LEED/BREEAM framework applied to transit buildings
O Scale Medium	Design-build of a fully coordinated O Scale transit building model — all structural, environmental, and architectural systems resolved simultaneously — constructed to exhibition quality
NAAB SPCs	SC.1 (Structural Systems — comprehensive); SC.2 (Environmental Systems — comprehensive); SC.3 (Building Envelope — advanced); PC.5 (Life Safety — comprehensive)
Key Challenge	The integration problem: structural systems that serve environmental goals; envelope systems that express structural logic; spaces that are simultaneously structurally efficient and environmentally responsive

Year 4 — Curriculum Philosophy

Year 4 confronts the central difficulty of architectural practice: that the most structurally efficient solution is rarely the most environmentally responsive, and the most environmentally optimal form is rarely the most structurally elegant. The student architect must navigate these tensions through design — making decisions that are simultaneously structural, environmental, and spatial. The O Scale transit building becomes a complex design problem where every decision has structural and environmental consequences, and the model is the medium through which those consequences are discovered and resolved.

Year Project — The Integrated Transit Building

STUDIO PROJECT

Year 4 Design-Build — The Pocono Summit Station

Design and build a fully integrated O Scale transit building for a mountain railroad

Project Scope	Full-year design-build project; individual students or pairs; minimum model footprint 24"×16"
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Program	Pocono Summit Station: a mountain railroad depot serving 200 daily passengers; includes waiting hall, ticketing, baggage handling, platform shelter, and landscape
Site	A sloping mountain site with 8" (32' prototype) of grade change across the 24" model footprint; east-west orientation with ridge to the north
Structural Requirement	Must include at least 2 different structural systems (e.g., masonry bearing walls for the platform canopy + steel frame for the waiting hall); all structural members sized and documented
Environmental Requirement	Must meet Year 3 targets: DF > 2% throughout waiting hall; RT60 1.5–2.0 seconds; winter solar heat gain positive (net heating benefit from south glazing); summer solar heat gain controlled (DF retained with SHGC appropriate for cooling climate)
Model Standard	Exhibition quality — to be displayed in a public architecture school exhibition at year end; model presented on a topographic baseboard with landscape context

Phase 1 — Site Analysis & Structural Strategy (Weeks 1–4)

Students analyze the topographic site model (provided) for:

- Foundation requirements: where does grade change create bearing pressure differences? Where are retaining walls needed?
- Solar orientation: south-facing facade for winter solar gain; north-facing for diffuse daylighting; east/west glazing requiring shading strategy
- Prevailing wind direction (provided as site data): impacts natural ventilation strategy and structural wind load direction
- Acoustic context: the train tracks are on the west; the passenger drop-off is on the east; acoustic separation strategy is required

Students produce a Site Analysis Model — the topographic base with site forces annotated — before beginning building design. No building design is permitted until the site analysis is complete and reviewed.

Phase 2 — Structural System Design (Weeks 5–9)

Students select, justify, and size the structural system for each building element. Required documentation for each structural system:

14. Structural type selection rationale: why this system for this span, program, and site?
15. Approximate member sizing: using the rules of thumb from Year 3 calculations, estimate beam depths ($L/20$ for steel beams; $L/15$ for timber) and column sizes. Verify with moment of inertia calculation for the governing member.
16. Connection strategy: pinned or rigid? Where and why?
17. Lateral stability system: how does the building resist wind and seismic forces in both orthogonal directions?
18. Foundation type: based on site analysis, specify the foundation approach for each portion of the building.

The Integration Test: Every structural decision must be evaluated against the environmental program. A solid masonry wall provides lateral stability — but does it block the south solar access needed for winter heating? A moment frame allows an open glazed facade — but does the unbraced column require a larger section that intrudes on the interior space? A long-span roof truss frees the interior — but does the truss depth block the clerestory glazing needed for daylighting? Students must navigate these conflicts through design, not eliminate them.

Phase 3 — Environmental System Design & Verification (Weeks 10–13)

Students specify and model the complete environmental systems:

- Daylighting: glazing type (VT and SHGC); window-to-wall ratio; shading devices (overhang depth calculated to block summer sun and admit winter sun)
- Acoustic: surface finish specification for each room; STC rating specification for each partition; RT60 target and required absorption area
- Thermal envelope: U-value calculation for each wall and roof assembly; glazing SHGC; thermal bridge locations and mitigation strategy

The shading overhang design calculation — one of the most elegant integrations of structural and environmental thinking in architecture:

$$\text{Overhang depth } D = H_{\text{window}} / \tan(\text{altitude}_{\text{summer_noon}}) \quad [\text{blocks summer sun}]$$

$$\text{Verify: } D / H_{\text{sill}} * \tan(\text{altitude}_{\text{winter_noon}}) < H_{\text{window}} \quad [\text{admits winter sun}]$$

Where H_{window} = height of window head above floor; H_{sill} = height of window sill above floor; $\text{altitude}_{\text{summer_noon}}$ and $\text{altitude}_{\text{winter_noon}}$ = solar altitude at noon on solstices. This single equation integrates solar geometry, structural depth (the overhang is a structural cantilever), and environmental performance.

Phase 4 — Life-Cycle Energy Analysis (Weeks 14–15)

Students perform a simplified life-cycle energy analysis of their building, comparing the energy performance of their integrated design to a baseline (an equivalent building with no passive strategies — double-pane clear glass throughout, no shading, no thermal mass strategy). Using the degree-day method:

$$\text{Annual heating load} = U * A * \text{HDD} * 24 \quad [\text{BTU/year}]$$

$$\text{Annual cooling load} = U * A * \text{CDD} * 24 + Q_{\text{solar_gain}} * \text{cooling_hours} \quad [\text{BTU/year}]$$

Where HDD = heating degree days for the project location; CDD = cooling degree days; A = envelope area; U = overall U-value. Students calculate the energy savings of their passive strategies and express the result as Energy Use Intensity (EUI) in kBtu/sf/year. They compare their EUI to ASHRAE 90.1 code minimum and to LEED Platinum energy performance thresholds for the building type.

Year 4 Assessment

Criterion	4 – Distinction	3 – Proficient	2 – Developing	1 – Beginning
Structural Integration	All structural systems	All structural systems	Primary structure	Structure present in

	<p>specified with sizing calculations; lateral stability documented in both directions; foundations matched to site analysis; structural decisions explicitly evaluated against environmental consequences; no unresolved conflicts between structure and environment</p>	<p>specified; lateral stability documented; foundations matched; most conflicts resolved</p>	<p>specified with calculations; lateral stability present; some conflicts unresolved</p>	<p>model; not specified or calculated; no conflict analysis</p>
<p>Environmental Performance</p>	<p>All three environmental targets met (DF, RT60, solar); overhang designed and verified with shading calculation; envelope U-value and SHGC specified; acoustic STC ratings specified</p>	<p>2 of 3 targets met; overhang calculated; U-value and STC specified</p>	<p>1 of 3 targets met; overhang present without calculation; U-value specified</p>	<p>No targets verified; no performance calculations</p>
<p>Life-Cycle Energy Analysis</p>	<p>Annual heating and cooling loads calculated; passive strategy savings quantified; EUI calculated; comparison to ASHRAE 90.1 and LEED Platinum made; design modification proposed if EUI exceeds target</p>	<p>Annual loads calculated; savings quantified; EUI calculated; ASHRAE compared</p>	<p>Annual loads calculated; EUI stated; no LEED comparison</p>	<p>Energy analysis attempted; major formula errors; EUI not calculated</p>
<p>Model Quality</p>	<p>Exhibition quality: all materials carefully chosen and crafted; topographic</p>	<p>High craft quality; most materials appropriate; site represented; structural and</p>	<p>Good craft; some materials inappropriate; site partially represented; structural OR</p>	<p>Craft acceptable; site not represented; structure and environment not simultaneously</p>

	base accurately represents site; model communicates structural logic and environmental strategy simultaneously; landscape context included	environmental logic readable	environmental logic readable	readable in model
Design Coherence	Structural system, environmental strategy, and spatial quality are mutually reinforcing — each decision serves multiple goals; student can articulate this integration verbally and in writing	Most decisions serve multiple goals; integration partially articulated	Some integration of structure and environment; mostly independent systems	Structure and environment designed independently; no integration demonstrated

YEAR 5

Thesis — Independent Investigation

Original Research Using O Scale as the Primary Research Instrument

Year Context	Fifth and final year; B.Arch capstone or M.Arch thesis year; students work independently with faculty advisors
Prerequisites	All Years 1–4 coursework; professional internship hours (if required by program); concurrent with ARCH 501 Thesis Seminar
Format	Two-semester independent design research project; individual; advised by faculty committee of at least two members
Thesis Type	Design Research — the O Scale model is used as a primary research instrument to investigate a question at the intersection of architectural structures, environmental systems, and spatial quality
Deliverables	(1) Written thesis (minimum 15,000 words) with original research contribution; (2) O Scale thesis model(s) as research artifacts; (3) Complete set of architectural drawings; (4) Final presentation to public jury; (5) Exhibition-quality installation
NAAB SPCs	All SPC areas addressed at thesis level; EC.1 (Research) is the primary criterion

Year 5 — Thesis Framework

The Year 5 thesis is not a design project with a research component — it is a research project expressed through design. The distinction matters: a thesis makes an original contribution to architectural knowledge that can be stated as a proposition and tested through evidence. The O Scale model is not a design representation — it is a research instrument that generates data in response to a research question about the performance of architectural form.

The Thesis Proposition: Every thesis begins with a proposition — a falsifiable claim about the relationship between architectural form and structural or environmental performance. Example propositions: "A double-skin facade with a specific cavity depth can simultaneously achieve target Daylight Factor and reduce solar heat gain by 40% compared to a single-skin alternative in a northern climate." OR: "A catenary cable roof for a transit platform can achieve 30% material savings over an equivalent truss roof while meeting FRA loading requirements." OR: "Sawtooth daylighting in a long-span station hall produces more uniform Daylight Factor distribution than monitor roof configurations of equivalent glazing area." The O Scale model tests the proposition. The thesis records the test.

Thesis Structure

Semester 1 — Research & Proposition Development

Students spend the first semester developing their thesis proposition and building the research apparatus:

19. Literature Review: minimum 40 scholarly sources; demonstrates knowledge of existing research on the chosen structural and environmental topic; identifies the gap that the thesis will address.
20. Precedent Analysis: three built precedents analyzed in depth at structural and environmental performance levels; O Scale study models built for each precedent.
21. Research Design: the methodology — what models will be built, what will be measured, what variables will be changed, what constitutes confirmation or refutation of the proposition.
22. Instrumentation Plan: what measurement tools are needed, how will they be calibrated, what scale factors apply when converting model measurements to prototype values.
23. Preliminary Model: a first iteration model built to test whether the research methodology is viable; data from the preliminary model informs the final model design.

Semester 2 — Design, Testing & Documentation

Students build, test, and document the thesis investigation:

24. Thesis Model(s): the primary O Scale research artifact(s); built to the highest craft standard; instrumented for measurement; capable of modification between test iterations.
25. Experimental Series: minimum three experimental iterations — each modifying one variable, keeping all others constant, and measuring the effect on structural or environmental performance.
26. Data Analysis: quantitative comparison of all iterations; statistical analysis where appropriate; comparison to theoretical predictions; assessment of whether the proposition is confirmed, refuted, or requires qualification.
27. Architectural Drawings: a complete set of drawings for the thesis building at prototype scale, drawn to professional standards — the design that emerges from the research.
28. Thesis Document: the written thesis in final form; written to a standard appropriate for submission to the ACSA (Association of Collegiate Schools of Architecture) annual meeting or equivalent peer-reviewed venue.

Thesis Research Areas — Suggested Topics

Structures Research Topics

- Adaptive reuse of historic railroad stations: structural assessment methodology using O Scale documentation and load rating
- Long-span timber roof systems for transit buildings: comparison of glulam, CLT, and LVL systems at O Scale with structural efficiency metrics
- Tensile fabric canopies for platform shelters: geometry, drainage, and structural performance at O Scale with scaled tension testing
- Seismic performance of unreinforced masonry station buildings: scale model shake table testing using O Scale masonry construction
- Hybrid structural systems combining old masonry fabric with new steel insertions: structural compatibility and connection design

Environmental Systems Research Topics

- Daylighting performance of Victorian train shed typologies: comparison of ridge-and-furrow, monitor, and sawtooth configurations at O Scale
- Natural ventilation in enclosed train halls: stack effect ventilation through clerestory openings modeled and measured at O Scale with smoke visualization
- Acoustic design for high-speed rail stations: reverberation time optimization across the full frequency spectrum, measured in O Scale models with impulse response method
- Passive cooling strategies for underground transit stations: earth-coupling, cool tube ventilation, and thermal mass strategies modeled and measured
- Building-integrated photovoltaics on transit building roofs: daylighting impact of PV canopy geometry modeled at O Scale

Integration Research Topics (Structures + Environment)

- The structurally expressed daylighting system: investigations into structural configurations that simultaneously optimize daylighting distribution
- Thermal mass as structural system: the dual role of masonry and concrete in railroad building types
- The acoustics of structural form: how the curvature of vaulted and domed station roofs affects reverberation time and spatial sound distribution
- Life-cycle carbon of structural system selection for transit buildings: embodied carbon vs. operational energy across 50-year building life

Thesis Scale Modeling Protocol

The following protocol applies to all thesis research involving O Scale physical models as measurement instruments:

Measurement Type	Scale Factor (Model to Prototype)	Instrumentation & Calibration
Linear dimensions	1:48 (1 inch model = 4 ft prototype)	Steel rule to ± 0.5 mm; verify against known O Scale reference dimensions
Area	1:2304 ($1:48^2$)	Calculate from linear measurements; verify with planimeter for irregular shapes
Volume	1:110,592 ($1:48^3$)	Calculate from dimensions; verify by water displacement for complex forms
Illuminance (lux)	1:1 (scale-invariant for DF calculation)	Calibrated lux meter; compare exterior and interior simultaneously; overcast sky condition required
Reverberation time (RT60)	$RT60_{\text{prototype}} \approx RT60_{\text{model}} * (L_{\text{proto}}/L_{\text{model}})^{(1/2)} = RT60_{\text{model}} * \sqrt{48}$	Impulse response method; Audacity software; verify with Sabine equation

Temperature (C or F)	1:1 (scale-invariant)	K-type thermocouple or calibrated digital thermometer; $\pm 0.5^{\circ}\text{C}$ accuracy
Structural load	Scales as $(1:48)^3 = 1:110,592$ for weight	Digital scale to $\pm 1\text{g}$; O Scale locomotive as calibration reference (weigh before each session)
Deflection	1:48 (linear)	Dial indicator to $\pm 0.01\text{ mm}$; laser pointer reflection method for remote measurement

Critical Calibration Note: Reverberation time does NOT scale linearly with the linear dimension ratio. Sound wavelengths at model scale do not scale — a 1 kHz tone has the same wavelength in a model as in a prototype. RT60 measured in an O Scale model is approximately $1/\sqrt{48} = 1/6.9$ of the prototype RT60 for the same surface absorption coefficients. Students must apply this correction factor in all acoustic research and clearly document the assumption in their thesis methodology chapter.

Year 5 Thesis Assessment

Criterion	4 – Distinction	3 – Proficient	2 – Developing	1 – Beginning
Research Proposition & Design	Proposition is clearly stated, falsifiable, and architecturally significant; research design specifies variables, constants, measurement methods, and success criteria; literature review demonstrates genuine gap in existing knowledge; methodology is rigorous and reproducible	Proposition clear and falsifiable; research design mostly specified; literature review adequate; methodology mostly rigorous	Proposition present but vague; research design partially specified; literature review covers main sources; methodology has gaps	Proposition not falsifiable or not architecturally significant; research design absent; literature review insufficient
O Scale Model Quality & Rigor	Thesis model(s) built to exhibition quality; all three experimental iterations documented with before/after photographs; all measurements recorded with uncertainty; scale conversion factors applied and	Exhibition quality; 2 iterations documented; measurements recorded; scale factors applied	High craft quality; 3 iterations present but 1 poorly documented; most measurements recorded	Good craft; fewer than 3 iterations; measurements incomplete; scale factors not documented

	documented; data is reproducible			
Data Analysis & Proposition Evaluation	All data presented in tabular and graphical form; statistical comparison of iterations; comparison to theoretical predictions; honest assessment of whether proposition is confirmed, refuted, or requires qualification; implications for architectural practice stated	Data tabulated and graphed; comparison of iterations; comparison to theory; proposition evaluated	Data tabulated; limited graphical presentation; comparison of iterations; proposition assessment vague	Data listed; no graphs; no comparison to theory; proposition not evaluated against data
Architectural Drawings	Complete set to professional standard: site plan, all floor plans, all building sections, key details at 1:12 or larger, perspective or axonometric; all drawings at consistent scale with title block and graphic scale bar; drawings are the design that the research produced	Complete set; most drawings at professional standard; title blocks present; design responds to research findings	Most drawings present; variable quality; title blocks present; design partially responds to findings	Drawing set incomplete; below professional standard; design not clearly connected to research findings
Written Thesis & Presentation	Written thesis meets minimum 15,000 words; original contribution clearly articulated; research methodology chapter is replicable; conclusions are	Written thesis complete; contribution articulated; methodology replicable; conclusions honest; presentation confident	Written thesis complete; contribution stated; methodology partially replicable; presentation adequate	Written thesis below minimum length; contribution vague; methodology not replicable; presentation underprepared

	honest about limitations; written to standard appropriate for academic publication; public jury presentation is confident, clear, and responsive to jury questions			
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Appendix A — O Scale Materials Kit by Year

Year	Structural Materials	Environmental Measurement Tools	O Scale Reference Items
1	Balsa wood (1/8", 1/4", 3/8" square); chipboard; balsa sheet; wood glue; wire	Heliodon or adjustable desk lamp; smartphone camera; simple thermometers	O Scale locomotive (calibration weight ~200g); O Scale figures; ruler and scale rule
2	Basswood; brass wire; small nuts/bolts; epoxy; cork sheet; cotton batting; aluminum foil	Smartphone decibel meter app; K-type thermometer; heat lamp	O Scale building kit (any style station or freight house); O Scale trees and accessories
3	All Year 2 materials; air-dry clay; fine modeling sand; pottery clay; toothpicks	Calibrated lux meter; logic analyzer or Audacity software; thermocouple + multimeter; dial indicator	O Scale scale figures (to verify 1:48 human proportion in daylight studies)
4	All prior materials; museum board; architectural chipboard; foam core; metal mesh	Full lux meter; laptop with Audacity; thermocouple data logger; laser level	O Scale locomotive, freight cars, passenger cars (for operational context of station design)
5	Student-specified per research program	Calibrated instruments per thesis methodology; RTL-SDR for acoustic spectrum analysis (optional)	O Scale track and operating railroad (thesis models may be placed on operational layout for contextual photography)

Appendix B — Key Formulas by Year and Thread

Year	Thread	Concept	Formula
1	Structures	Arch horizontal thrust	$H = w \cdot L^2 / (8 \cdot f)$
1	Environ.	Sun altitude at latitude phi	$Alt_{noon} = 90 - \phi \pm 23.5$ (+ summer, - winter)
1	Environ.	Sun penetration depth	$d = H_{ceiling} / \tan(\text{solar_altitude})$
1	Environ.	Sabine RT60 (introduced)	$RT60 = 0.161 \cdot V / A$
2	Structures	Total U-value of assembly	$U = 1 / (R_1 + R_2 + \dots + R_n)$
2	Environ.	Solar heat gain	$Q = A \cdot SHGC \cdot I_{solar}$
3	Structures	Moment of inertia (rectangle)	$I = b \cdot d^3 / 12$
3	Structures	Section modulus	$S = I / c = b \cdot d^2 / 6$

3	Structures	Maximum bending stress	$\sigma = M/S$
3	Structures	Midspan deflection (UDL)	$\delta = 5*w*L^4/(384*E*I)$
3	Structures	Euler buckling	$P_{cr} = \pi^2*E*I/(K*L)^2$
3	Environ.	Daylight Factor	$DF = E_{interior}/E_{exterior} * 100\%$
3	Environ.	BRE DF formula	$DF_{avg} = W*\tau*\theta/(A*(1-R^2))$
3	Environ.	Sabine RT60 (applied)	$RT60 = 0.161*V/A$ (SI); $0.049*V/A$ (imperial)
4	Structures	Steel beam depth rule	$d \approx L/20$ for steel; $L/15$ for timber
4	Environ.	Overhang for solar control	$D = H_{window}/\tan(\text{alt}_{summer})$; verify winter admission
4	Environ.	Annual heating load	$Q_{heat} = U*A*HDD*24$
5	Environ.	RT60 model-to-prototype	$RT60_{proto} = RT60_{model} * \sqrt{48}$
5	Structures	Load model-to-prototype	$F_{proto} = F_{model} * 48^3 = F_{model} * 110,592$

Appendix C — O Scale Architectural Reference Data

O Scale Dimension	Prototype Equivalent	Architectural Reference
1 inch	4 feet	Standard module in timber and masonry construction
6 inches	24 feet (7.3 m)	Typical urban block structural bay
1 foot	48 feet (14.6 m)	Long span for modest station hall
18 inches	72 feet (21.9 m)	Mid-range train hall span (many Victorian stations)
24 inches	96 feet (29.3 m)	Large station hall span (Grand Central main concourse ~160 ft)
1/4 inch	1 foot	Brick coursing (standard US brick = 2-2/3" = 0.056" in O Scale)
O Scale figure height: 1.5 inches	6 feet (1.83 m)	Standard human figure for scale reference
O Scale door opening: 0.75" wide x 1.5" tall	3 ft wide x 6 ft tall	Standard ADA-compliant single door
O Scale window: 1" wide x 1.25" tall	4 ft wide x 5 ft tall	Typical commercial window unit
Track gauge: 1.25 inches	5 feet (1.524 m)	Slightly wider than standard

		gauge — useful reference for platform width
Platform height: 0.25 inches	1 foot (305 mm)	Low-level platform; ADA high platform = 1 foot (0.25" model)
Minimum platform width: 2.5 inches	10 feet (3.05 m)	APTA minimum for low-volume platforms

Appendix D — Great Railroad Station Precedents for Study

Station	Date	Structural Type	Environmental / Architectural Significance
King's Cross, London (Cubitt)	1852	Twin semicircular brick arches (laminated timber ribs)	Original iron and timber roof — first great railway arch; recently restored
Paddington Station, London (Brunel/Wyatt)	1854	Three-span wrought iron transept arches	Oriels (bay windows) in the arch spandrels for daylighting; the first truly architectural train shed
St. Pancras Station, London (Barlow/Scott)	1868	Single-span wrought iron arch, 243 ft	Widest single-span roof of its time; tied arch; hotel facade by Gilbert Scott
Grand Central Terminal, New York (Reed & Stem)	1913	Steel Beaux-Arts structure	The celestial ceiling; clerestory daylighting of the main concourse; underground platforms
Union Station, Washington DC (Burnham)	1907	Steel frame with masonry cladding	Coffered barrel vault; acoustic properties of the great hall; Beaux-Arts civic architecture
Union Station, Chicago (Graham, Anderson, Probst & White)	1925	Steel frame	The great light well; natural ventilation through the concourse
Gare de Lyon, Paris	1900	Iron and glass train shed + stone office building	Classic French combination of utilitarian shed and monumental head building
Antwerp Central Station (de la Censerie)	1905	Steel dome over main hall	One of the most elaborate station interiors; stone and iron hybrid structure
Chhatrapati Shivaji Terminus, Mumbai (Stevens)	1888	Gothic Revival stone and iron	UNESCO World Heritage; fusion of Victorian Gothic and Indian decorative traditions
Kansai International Airport (Piano)	1994	Steel roof structure	Long-span curved roof for daylighting; contemporary airport as successor to the train shed

Gare do Oriente, Lisbon (Calatrava)	1998	Concrete palm-tree columns	Structural expressionism; integrated daylighting through structural form; O Scale model is iconic
High Speed Rail Stations, Spain (various)	2000s	Various long-span steel	Contemporary high-speed rail architecture; structural and environmental performance benchmarks

Appendix E — Integration with Operational O Scale Railroad

Throughout the 5-year curriculum, the architectural models produced by students can be integrated with an operational O Scale railroad layout to create a living architectural exhibition. Practical integration notes:

- All student models are built to O Scale standards (1:48, track gauge 1.25 inches) — any model can potentially be placed adjacent to an operational O Scale track.
- Station models should incorporate standard O Scale platform heights (0.25 inches above track level for low platforms; 0.375 inches for ADA high platforms).
- Building footprints should respect O Scale minimum curve radii (O36 = 18 inch radius minimum for full-size equipment) if positioned adjacent to operating track.
- The operational layout provides irreplaceable contextual photographs of student models in a realistic railroad environment — powerful for portfolio and exhibition documentation.
- Model railroad clubs can serve as community partners: students present their architectural models at club events, connecting academic work to the enthusiast community and potential STEM education outreach.

O Scale Architectural STEM Curriculum

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