ASEE-EOP AE 444 Building Envelope Systems

Ideas in this document:

- **Building envelope systems mapping**
- **Embodied carbon & Envelope materials**
- **Designing (envelopes) for resilience today and tomorrow**
- **Autodesk Forma and passive design**
- **Building Envelope & Ecosystem services**

➢ Building design systems mapping

Introduce students to causal loop diagramming using tools like Loopy to map interactions between water, daylight, air, heat, materials, and energy in the building envelope. Students identify how their design choices in one system can affect the others. This is practiced in class through a class game, and incorporated as one of the project deliverables.

Example of prompt: Create a simple causal loop diagram illustrating how your proposed redesign solutions affect the systems reviewed in the class (water, air, heat, etc). For each solution, explore the tradeoffs and synergies between systems (for example, how a MATERIAL choice to improve HEAT properties will result in ENERGY savings but might reduce the amount of DAYLIGHT in the building). Use Loopy or a similar tool. Reflect in one paragraph on how this influenced your design direction.

Deliverable examples: Slide with diagram + short written reflection (first deliverable).

Resources: See this page for examples on how to map the whole system. This causal loop diagram handbook by the Cascade Institute can be useful to learn the concepts and how to build a causal loop diagram, while this short article by The Systems Thinker has a great table/figure summary on the topic. This free online tool (Loopy) lets you build simple causal loop diagrams and create gifs to see how increasing or decreasing a variable can affect the whole system.

EOP Learning outcomes:

- **Systems Thinking:**
  - **Advanced 3**: *Create visual system maps (e.g., causal loop diagramming, system dynamic simulations, etc.)*
- **Design**
  - *Advanced 5. Design with systems dynamics concepts in mind (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, etc.*

➢ Designing for Resilience Today and Tomorrow

Students assess future climate and hazard risks using resources like NOAA Climate Explorer and FEMA National Risk Index. They evaluate how their project can adapt to long-term risks like heat, flooding, or hurricanes. This could be introduced as part of the expectations for the Structural and Geotechnical deliverable, or early on with each deliverable having an element of climate resilience.

Example of Prompt: Use NOAA Climate Explorer and FEMA's National Risk Index to identify a key climate hazard for your site (e.g., extreme heat, flooding) and how the risk is expected to increase in the future. Describe one change or addition you would make to your design to enhance resilience, OR write a short reflection explaining how your design already supports climate adaptation (first deliverable). Use the temperature projections in NOAA Climate Explorer to calculate how your current design will perform in the future (calculate the heat transfer or redo energy modeling for the projected temperature at your site). Include this calculation in your final deliverables.

Resources:

- Students can access the FEMA's National Risk through the PolicyMap's "Dig Deeper" tool (Quality of Life > Environment and Disaster Risk > FEMA National Risk Index). As an option, the same tool allows them to layer in social vulnerability.
- NOAA Climate Explorer

- This page from Project Drawdown lets students explore possible alternatives and solutions to climate resilience.

EOP Learning outcomes:

- **Systems Thinking:**
  - Core 1. *Explain interconnectedness (e.g., intersecting, related and/or connected systems; human actions and global environmental and social impacts and consequences; synergies and rebound effects) and how all human-made designs and activities rely upon and are embedded within ecological and social systems*
- **Environmental Literacy:**
  - Core 1: *Recognize opportunities (i.e., social, economic, and environmental benefits, etc.) to solve environmental challenges*
  - Core 5: *Examine data about environmental issues (e.g., climate change, energy and water use, scarcity and pollution, air quality, waste management, toxicity, etc.) including consideration for past/current/future and local/regional/global impacts*
- **Critical thinking**
  - Advanced 2. *Identify issues and actions of environmental and social priority*
- **Design**
  - *Core 1. Execute technical analyses to choose strategies that maximize the positive and minimize the negative environmental and social impacts in order to achieve design goals*
  - Core 3. *Create long-term approaches for tackling environmental problems (e.g. climate mitigation and adaptation) or preventing negative environmental and/or social impacts including creative solutions within supply chains*
  - *Advanced 3. Design with approaches that incorporate whole life-cycle and systems thinking*
  - *Advanced 5: Design with systems dynamics concepts in mind (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, etc.)*

➢ Autodesk Forma and Passive Design

Students use Autodesk Forma to evaluate environmental site conditions and adopt passive design strategies (e.g., orientation, daylighting, natural ventilation).

Example of Prompt: (As part of the first deliverable) Run an analysis in Forma for your current preliminary design/building mass. Identify at least one passive strategy informed by solar, wind, or daylight data. Describe how you plan to adapt your design in response. Examples of adaptations include changing the building orientation, adjusting façade and window area, adding shading and vegetation, and reconsidering entrances and program zones according to daylight, wind, noise, and microclimate. This is a great opportunity to adapt your building orientation, mass, and architectural features to environmental conditions during early design! (As part of the final deliverable): Show before and after Forma simulations that provide evidence of how your proposed redesign improve the envelope conditions.

Resources:

- Autodesk Forma (free for Drexel students, intuitive, integrated with Revit).

EOP Learning outcomes:

- **Systems Thinking:**
  - Core 1. *Explain interconnectedness (e.g., intersecting, related and/or connected systems; human actions and global environmental and social impacts and consequences; synergies and rebound effects) and how all human-made designs and activities rely upon and are embedded within ecological and social systems*
  - Core 2. *Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations)*
- **Environmental Literacy:**
  - Core 1: *Recognize opportunities (i.e., social, economic, and environmental benefits, etc.) to solve environmental challenges*
- **Critical thinking**
  - Advanced 2. *Identify issues and actions of environmental and social priority*
- **Design**
  - *Core 1. Execute technical analyses to choose strategies that maximize the positive and minimize the negative environmental and social impacts in order to achieve design goals*
  - Core 2. *Design for the environment and society based on discipline-specific technical skills (e.g., lightweighting, design for repairability and durability, design for upgradeability, design for disassembly, flexibility, and reuse, design for part or whole recovery, etc.)*
  - *Advanced 3. Design with approaches that incorporate whole life-cycle and systems thinking*
  - *Advanced 5: Design with systems dynamics concepts in mind (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, etc.)*

- **Embodied Carbon and Materials Tradeoffs**

Students compare material options for key structural elements using embodied carbon data from resources like Kaleidoscope (simple, intuitive online tool), ICE database (Excel spreadsheet with embodied energy and carbon data for materials), or similar sources. They weigh carbon impacts against performance, cost, or availability. The concept of embodied carbon and energy could be introduced in the material selection lecture, and this can be a deliverable expected for the Structural and Geotechnical assignment.

Example of Prompt: (First deliverable) Use the Kaleidoscope tool to compare different options of material for your building envelope design. Reflect on tradeoffs (cost, performance) and recommend a material to move forward with the redesign. (Final deliverable) Using tools like the ICE database, EPDs, Kaleidoscope and/or the Tally plugin for

Revit (preferred), estimate the embodied carbon of your building envelope before and after redesign.

Resources:

- ICE database
- Kaleidoscope
- Environmental Product Declarations
- Recommended reading: World Green Building Council's Bringing Carbon Upfront (Executive Summary, Our Vision, and Call to Action – Designers)

EOP Learning outcomes:

- **Systems Thinking:**
  - Core 2. *Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations)*
- **Environmental Impact Assessment:**
  - Core 2. *Recognize current eco-labelling systems and certificates (i.e., EPEAT, Energy Star) for sustainable production and consumption.*
  - Core 3: *Interpret broader energy, climate, water, wastewater, air pollution, and land-use implications of their work by conducting basic environmental impact assessments (e.g., Life-Cycle Assessments, carbon footprints, etc.)*
- **Responsible Business and Economy**
  - Advanced 6: *Weigh economic trade-offs in sustainability efforts; these economic trade-offs may happen for a variety of stakeholders within each unique value chain, so students must be able to identify, quantify, and compare the financial trade-offs in sustainable initiatives*
- **Materials Selection**
  - Core 4. *Compare materials properties (e.g., chemical, physical, and structural properties) and performance aligned with end-use application*
  - Core 5. *Design with lower impact, natural materials (e.g., earth, bamboo, agro-waste, etc.) with an aligned degree of knowledge of industrial materials (e.g., iron, steel, aluminum, etc.)*
  - Advanced 1. *Implement tools and resources for identifying potential social and environmental impacts of materials supply chain throughout the entire life-cycle — from raw material extraction through processing, manufacturing, use, reuse/recycling and end of life — with a zero waste and restorative perspective*
  - Advanced 6: *Apply systems perspective and calculate embodied energy of materials to make informed decisions*
  - Advanced 8: *Weigh trade-offs that guide selection of design-appropriate materials (e.g., technical considerations including strength, weight, cost, toxicity, extraction impacts, material compatibility, and thermal properties, among others)*
- **Design**
  - Core 1. *Execute technical analyses to choose strategies that maximize the positive and minimize the negative environmental and social impacts to achieve design goals*
  - Advanced 3. *Design with approaches that incorporate whole life-cycle and systems thinking*
- **Critical Thinking:**
  - Advanced 3. *Implement relevant qualitative and quantitative research into decision-making processes*

➢ Multi-benefit evaluation of envelope design

Engineers are often asked to design for building performance, but sustainable infrastructure must deliver broader value. We might consider asking students to evaluate their design using different, more subjective criteria (co-benefits).

Prompt example: (first deliverable) Read the Ecosystem Services in Urban Management (Section 1). Use the table below to score your initial design against each ecosystem service listed. Choose at least three benefit areas where your design is currently weak or unaddressed. Consider how your redesign could support both ecological and community benefits, and propose changes for your redesign that could improve those areas.

Benefit Area	Score (1–5)	Brief Justification (1–2 sentences)
Thermal Regulation		Envelope features like green roofs, ventilated façades, or shading reduce indoor heat gain and cooling loads.
Stormwater Management		Roof design, permeable surfaces, and rainwater harvesting contribute to runoff reduction and infiltration.
Air Quality Regulation		Material choices, operable windows, and integrated vegetation can improve indoor/outdoor air quality.
Noise Attenuation		Envelope thickness, materials, and vegetated barriers reduce indoor noise from urban surroundings.
Habitat Provision		Façade systems or green roofs can support bird, insect, or plant life, especially native or pollinator species.
Carbon Sequestration		Use of biogenic materials (e.g., timber, hempcrete) or living systems (e.g., vegetated façades) can contribute to embodied or operational carbon drawdown.
Well-being & Aesthetics		Views, natural light, and access to greenery via façade or roof elements support mental health and visual comfort.
Energy Efficiency		Passive systems, thermal insulation, and climate-adapted envelope strategies lower energy consumption.

EOP Learning outcomes:

- **Systems Thinking:**
  - Core 1. *Explain interconnectedness (e.g., intersecting, related and/or connected systems; human actions and global environmental and social impacts and consequences; synergies and rebound effects) and how all human-made designs and activities rely upon and are embedded within ecological and social systems*
  - Core 2. *Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations)*
  - Core 3. *Apply relevant concepts from required disciplines to the study of real-world problems and their solutions with empathic and ethical consideration for communities/societies, environmental justice, and cultural awareness*
- **Environmental literacy:**
  - Core 1. *Recognize opportunities (i.e., social, economic, and environmental benefits, etc.) to solve environmental challenges*
  - Advanced 2. *Describe key ecosystem services and functions including provisioning services, regulating and maintenance services, cultural services, and supporting services (e.g., material cycles, energy cycles)*
  - Advanced 4. *Apply key ecosystem services and functions to their design solutions*
- **Social responsibility:**
  - Core 2. *Recognize and be empathetic to ethical implications relative to the social impact of their work*
  - Core 3. *Describe how engineering activities directly and indirectly cause positive and negative social/cultural impacts throughout the design life-cycle, both to workers producing the products (i.e., labor practices, livelihood, health, etc.) and to communities, society, and non-human life (i.e., resources acquisition, waste production and management, traditional/cultural methodologies, etc.)*
- **Design**
  - Core 2. *Design for the environment and society based on discipline-specific technical skills*
  - Core 3. *Create long-term approaches for tackling environmental problems (e.g. climate mitigation and adaptation) or preventing negative environmental and/or social impacts, including creative solutions within supply chains*
  - Advanced 3. *Design with approaches that incorporate whole life-cycle and systems thinking*
- **Critical thinking**
  - Core 1. *Define problems comprehensively with consideration of consequences, unintended and intended*
  - Core 6. *Critique complex ethical and values-based choices, employing empathy when evaluating conflicts of interest, trade-offs, and uncertain knowledge and contradictions within problem constraints*
  - Advanced 2. *Identify issues and actions of environmental and social priority*
  - Advanced 3. *Implement relevant qualitative and quantitative research into decision-making processes*