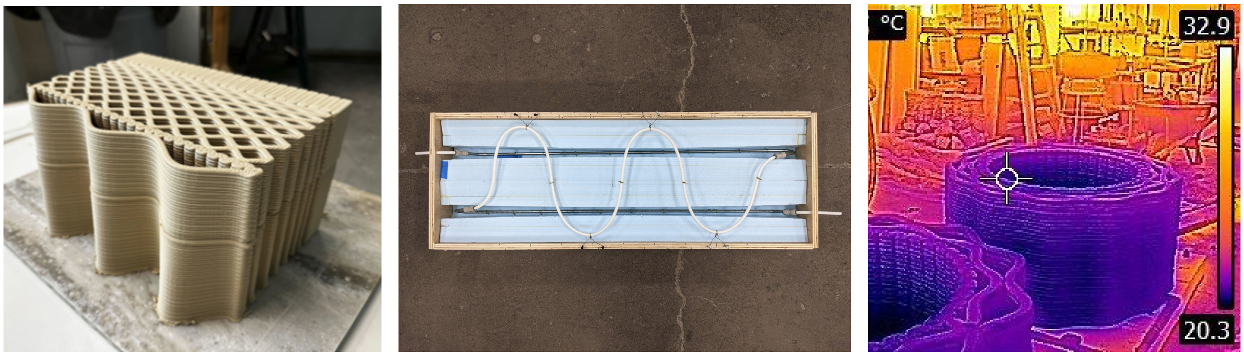
4.s43 Shaping Thermal Performance in Architectural Enclosures // Spring 2024
Instructor: Caitlin Mueller
TA: Eduardo (Edu) Gascón Alvarez
Collaborators: Professor Les Norford, PhD candidate Sandy Curth

Subject Overview



Prototypes of low-carbon, thermally-optimized building components: clay bricks, concrete slabs, earthen walls (Curth, Gascón Alvarez, Ismail, Mueller, Norford, Stamler)

Subject Description

In the context of the climate crisis and rising temperatures, building enclosure technologies must respond to a plurality of requirements--including solar radiation control, thermal insulation, and heat storage--ideally, with minimal embodied carbon and at low cost. While contemporary normative approaches tackle this with assemblies of highly specialized layers, alternative solutions are emerging that use geometric specificity and variation to integrate multiple high-performance behaviors in a humble and simplified material palette. Shape-forward wall systems are well situated to leverage advances in digital fabrication, such as additive manufacturing of low-carbon materials like minimally processed earth, but can also be materialized with a range of traditional and emerging assembly and fabrication methods. In this workshop, students will first study historical and contemporary precedents of relevant multifunctional enclosure components. They will then learn to use state-of-the-art digital tools for designing, modeling, simulating, and optimizing these types of wall systems, accounting for the described thermal requirements along with embodied carbon and structural behavior. The workshop will also include hands-on physical prototyping and experimental tests. The final project will be an evidence-based design proposal, supported by digital simulations and physical experiments, for novel thermally performative enclosure systems and their potential impact on architectural expression.

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Meeting Times*

Textbook

Lecture+Lab: Tuesday, 9-12, in 5-216 Office Hours: TBD *see below for more details **Units and Level** 3-0-6, Graduate	Readings will be provided via Canvas website

Subject Canvas Website
https://canvas.mit.edu/courses/25186

Subject Zoom Room*
https://mit.zoom.us/j/94365211969
* All classes will be held in person, but we have a Zoom room as a backup if necessary.

Target Audience and Prerequisites
Graduate and advanced undergraduate students in architecture and related engineering disciplines. Expected (but not strictly required) background includes familiarity with introductory building physics (e.g. through 4.401J/4.464J/1.564J) and building enclosures (e.g. through 4.463), along with architectural drawing and 3D modeling skills.

Semester Schedule

Week	**Lecture** Tuesdays. 9-10:30, 5-216	**Lab** Tuesdays. 10:30-12, 5-216	Deadlines
01	T 2/6 **MODULE 1: ENCLOSURES FOR A CHANGING CLIMATE** Workshop introduction: motivation, content, and objectives [all]	HW1: precedent analysis Analysis framework introduction	
02	T 2/13 Passive and low-energy cooling strategies in enclosures [EGA]	*Student presentations: precedent analysis*	Interim precedent presentation
03	T 2/20 No class (Monday schedule)		
04	T 2/27 **MODULE 2: SHAPING THERMAL PERFORMANCE** Design for multi-domain performance [CM]	HW2: optimal thermal mass Tool (I): DSE + Karamba	HW1 due
05	T 3/5 Building thermal dynamics: principles and design opportunities [LN]	Tool (II): RC models + EP	
06	T 3/12 Shaped surfaces for enhanced thermal performance	HW3: design for fabrication	HW2 due (3/15)

	[EGA]	Tool (III): Simscale	
07	T 3/19 Low-carbon fabrication methods for climate-resilient enclosures [SC]	Tool (IV): Toolpathing	
08	T 3/26 No class (Spring break)		
09	T 4/2 *Students presentations: HW3*		HW3 due + presentation
10	T 4/9 **MODULE 3: FINAL DESIGN PROJECT** Prototype design and fabrication [EGA+SC]	Final project introduction	
11	T 4/16 Measurement tools and data collection/interpretation [LN]	Tools demonstration	Prototype complete
12	T 4/23 *Student presentations: project proposal*		Final project proposal + presentation
13	T 4/30 Scientific writing and research communication [CM]	In-class exercise	
14	T 5/7 Guest lecture / field trip (TBD)	Desk crits	
15	T 5/14 FINAL REVIEW		Final project report and presentation

Subject Meeting Structure, Schedule and Content
This workshop will be offered fully in person for the Spring 2024 semester. Students will be expected to attend and participate live in the classroom during our weekly meetings. Additional office hours with the instructors will be available mostly in person but occasionally on Zoom (see below for details). If students are not able to attend in-person class due to medical or personal reasons, they will be able to access presented slides and class recordings on the Canvas site, but recordings will not be made by default this semester. See below for more details on the attendance policy.

Tuesdays 9:00-10:30: Lecture that students should attend and respond to with questions, discussion, etc.

Tuesdays 10:30-12:00: In-class lab session. These include tools demos, hands-on exercises, desk crits, among others.

Assignments and Project

The main focus of this workshop is the design and prototyping of a low-carbon, heat-resilient wall system. Through simulations and experimental data, students will be able to guide their design process in an evidence-based manner, tying thermal performance with fabrication constraints and aesthetic goals. Three initial homework assignments serve as an introduction to relevant computational design and simulation tools, as well as important concepts around the structural and thermal performance of enclosures and available low-carbon construction methods. See the last page of the syllabus for a preview of the content of each assignment and the final project, subject to minor changes.

While intermediary assignments are to be submitted individually, students are encouraged to work in groups of 2-3 for the final design project. Late assignments will not be accepted, unless circumstances warrant an extension (must be arranged with instructors 24 hours before deadline). Homeworks will typically be assigned in class on Tuesdays.

Grading Breakdown
Assignments: 45% (15% each)
Project: 45%
Attendance and Participation: 10%

Office Hours
Instructors will hold weekly office hours in person (or on Zoom if necessary) for students to ask questions about the class's content, assignments, etc, by appointment. There will also be ample opportunities to ask questions in class. Students will be polled during the first day of the class to arrange the schedule for office hours.

Absence Policy
Attendance and participation are mandatory and part of this subject's grade (10%). Missed lectures, discussion sessions, or labs will be counted against the grade unless special arrangements are made with the instructors in advance of class. Excused absences will always be granted for medical or personal reasons, but must be arranged ahead of time with the instructors via email. Please do not come to class if you feel unwell. The instructors will make reasonable efforts to work with students to access missed material for excused absences.

Learning objectives
At the end of the class, students will be able to:

- Understand basic and advanced concepts related to heat transfer phenomena within building enclosures and their impact on the buildings' thermal comfort conditions and energy consumption.
- Comprehensively analyze new and existing enclosure systems, evaluating their performance across domains while accounting for their environmental impact and resilience to heat.
- Apply contemporary simulation methods to assess the thermal performance of building enclosures using tools that are relevant to the scale and scope of analysis.
- Formulate multi-objective optimization problems that allow exploring enclosure designs in an iterative and performance-driven manner
- Coordinate data measuring campaigns for the experimental validation of specific features of the envelope through small-scale prototypes.

- Design a new low-carbon, heat-resilient enclosure that responds to the specificities of its climate and program by creatively deploying the learned concepts in class.

Assignment and project preview (NB: details are subject to minor changes)

Homework 1: Precedent analysis (individual)
This first assignment asks you to select two to three examples of enclosure systems specifically designed for cooling purposes to then analyze them under a common evaluation framework. The goal is to create an initial library of relevant precedents while objectively evaluating (and comparing) their performance across domains. Emphasis will be put on identifying the tradeoffs between their embodied carbon impact and thermal performance.

Homework 2: Lightweight thermal mass (individual)
The second assignment focuses on the design of a prefabricated SIP (Structural Insulated Panel) for optimal structural-thermal performance accounting for specific local climate conditions and building program. The assignment's objective is to familiarize students with computational design workflows that allow them to explore design alternatives iteratively and optimize for multiple performance objectives. The structural panels will be analyzed for their dynamic thermal performance as well as their structural integrity against vertical and horizontal loading conditions.

Homework 3: Surface activation (groups of two to four)
The last assignment invites students to explore the potential of shaping enclosure surfaces for enhanced heat transfer through combined design, simulation, and fabrication exercises. Firstly, the surface of a 3D-printed earthen wall system is designed using available theory on extended surfaces as guidance. This process is conducted while keeping its fabrication constraints in mind - for this exercise, those constraints will be set by the robotic arm at N-51. Small prototypes will allow students to test their designs' fabrication feasibility and aesthetics.

Final project (groups of two to four)
In groups of two to four people, students are asked to design and prototype a low-carbon, heat-resilient wall system for a climate previously assigned. Simulations and experimental data should guide the design process in an evidence-based manner, tying thermal performance with fabrication constraints and aesthetic goals. The fabrication of a small prototype will allow testing and validating specific thermal properties of the designed enclosure, which will then be extrapolated to different contexts and climates using the computational tools presented throughout the semester. Architectural drawings and visualizations will be used as an opportunity to speculate about the system's application at a full-building scale.