

ARCH 7326

Embodied Carbon and Architecture:

Understanding the Built Environment's Contribution to Climate Change

In June 2019, both the AIA and RIBA Council voted overwhelming to join the global declaration of a climate emergency and to call for architects to take urgent and sustained climate action. Across the world, governments have recommitted to bringing greenhouse emissions to zero by 2050. Much of this renewed action has been propelled by the publication of the UN Intergovernmental Panel on Climate Change's 2018 report *Global Warming of 1.5°C*, (IPCC 2018). The picture presented is bleak – widespread ecosystem destruction, financial instability, growing social inequity, conflict and unrest, the disappearance of landmasses and nations. The scenarios are so clearly articulated, the models so robust, and the science so well documented that they have ignited new urgency to find pathways across all sectors to meet the targets of the Paris Commitment and accelerate our progress towards a 1.5°C pathway. Unfortunately, we are nowhere near meeting these targets. All projections that give us a chance of staying on a 1.5°C pathway mandate that we must radically cut carbon emissions immediately.

Architecture has a vital role to play. Presently, **buildings account for 39% of global carbon emissions**. Though it has become mainstream to discuss energy efficiency and advocate for minimizing environmental impacts, architects, engineers, and planners have yet to truly reckon with the magnitude of that number. Architectural education has yet to reflect this concern in the way we study and judge design projects. The global climate crisis demands that we radically rethink global models of consumption and emissions – a staggering amount of which is tied to the design of our built environment.

Broadly speaking, there are two ways of measuring the emissions caused by buildings: operational carbon (the emissions associated with energy used to operate the building) and embodied carbon (the emissions associated with materials and construction processes throughout the whole lifecycle of a building). Despite laudable programs such as LEED, Passive House, and the Living Building Challenge, we've now come to recognize that it is not enough for architects and engineers to focus only on decreasing operational carbon. Currently, building operations account for roughly 28% of global carbon emissions (WGBC, 2019). These emissions can be addressed by improving the energy efficiency of buildings, through widespread electrification, and through decarbonization of the energy grid. This work is essential. However, for decades, we have been ignoring the role of embodied carbon in global carbon budgets and the opportunities for innovation and decarbonization in this arena.

The embodied carbon emissions of building products and construction represent a significant portion of global emissions: concrete, iron, and steel alone produce ~9% of annual global GHG emissions; embodied carbon emissions from the building sector produce 11% of annual global GHG emissions (UN Environmental Global Status Report, 2017, EIA Outlook 2018). Every year, 6.13 billion square meters of buildings are constructed, with global building stock expected to double in the next thirty years. The carbon footprint of this construction is approximately 3729 million metric tons of CO₂ per year (Architecture 2030). This means that **embodied carbon will be responsible for half of total new construction emissions between now and 2050**. These emissions are also called upfront carbon since they occur before a building or infrastructure begins to be used and no amount of grid decarbonization, future innovation, or energy efficiency measures can take them back. For practicing architects, engineers, policymakers, and anyone who cares about strategic emissions reductions, this should give us pause.

Fortunately, there exists clear methods and tools for architects and engineers to assess and reduce the carbon impacts of their projects. **Life Cycle Assessment (LCA)** is a method for evaluating the environmental impacts of a building or product over its full life cycle, from initial material extraction through manufacturing, distribution, construction, use, recycling, and final disposal. The practice of LCA has been around for almost three decades

and is widespread across industries and sectors. It is the international standard for evaluating the carbon footprint of everything from biofuels to blue jeans, cellphones to the entire meat industry. In the last decade, it has increasingly been embraced by architects and engineers. New tools and data sets have become available, and LCA is beginning to be integrated into professional practice as the primary means of providing designers with actionable carbon data at a resolution in which it can influence design decisions.

While LCA tools and data are increasingly available to architects, it can be challenging to make sense of and effectively communicate these data. This course brings together in-depth training on LCA modeling, with insight into how to integrate such analysis into design decisions. In the course, students will receive hands-on experience building comparative LCA models using a range of currently available software tools, while also deepening abilities to research material life cycles, industrial processes, supply chain dynamics and political and economic dimensions of environmental impact data. Finally, the course will discuss and debate current innovations in materials manufacturing and policy changes that are set to mainstream the consideration of embodied carbon and transform construction practices.

Course Objectives

The overall goal of the course is to increase carbon literacy and to empower students with a working understanding of climate change, life cycle assessment, and the many strategies by which designers can immediately reduce the carbon footprint of their projects. The course objectives are for students to:

- Gain a broad understanding of the underlying science of climate change and the role that architecture, engineering, and construction play in global carbon budgets.
- Develop research skills to explore building materials in depth.
- Develop the analytical skills of life cycle assessment (LCA) and the ability to apply environmental impact data to a design project.
- Develop an understanding of current policy work addressing climate change in the design and construction sector.

Class Format

This course is a seminar, structured around the direct application of LCA topics, methods, and principles. Class time will be split between lectures, discussions, and modeling demonstrations. Students will learn LCA concepts, modeling techniques, international standards, and best practices through hands-on work in individual and group projects. The class will be taught in person, with a combination of live instruction and select material (software tutorials, guest lectures) pre-recorded for students to listen to on their own time.

Throughout the semester, the class will include software demos and tutorials in which we will learn a range of LCA programs and peek under the hood, learning how they were made and discussing their benefits/limitations. Students should bring their own laptops to class or may share computers if this is not feasible. Some software demos may be pre-recorded by the instructor and shared via canvas.

Although the instructor will give lectures each week, students are responsible for all required readings and should come to class prepared to ask questions or comment on the material assigned. Vigorous participation in class discussions is encouraged.

Assignments

Building Materials Life Cycle: (Individual project) Each student will explore the full life cycle of a specific building material or assembly of their choice. Students will research their material from material extraction through the end of life, understand its economic, political and environmental context, and explore LCA impacts through topic research, modeling, and diagramming.

Communicating Life Cycle Impacts: (Individual project) Communicating LCA results and concepts can be challenging. In this assignment, we will explore LCA concepts that can be difficult to explain or image. Students will critique existing graphics and representations and develop new graphics or animations.

Comparative Life Cycle Assessment: (Group or individual project, per student choice) During the second half of the semester, students will collaborate on a comparative life cycle assessment of a material, assembly, or full building. Groups will work together to build custom models from peer-reviewed, published data sources or based on their previous studio projects, if of sufficient resolution. Students can choose from a variety of LCA modeling tools introduced in the course. Each group will produce a structured LCA report demonstrating a research question, modeling methodology, data sources used, and key findings. In-class time will be dedicated to working collaboratively on models.

Grades will be determined by the instructor as follows:

- 20% Weekly discussions
- 20% Assignment 1: Communicating LCA Results
- 20% Assignment 2: Modeling Building Materials
- 40% Assignment 3: Comparative LCA

Schedule Overview

Week 1	1/17	Carbon and the Built Environment: Intro to LCA
Week 2	1/24	LCA Methods: The Challenge of Comparison
Week 3	1/31	Materials Deep Dive: Concrete
Week 4	2/7	<i>Travel Week - no class</i>
Week 5	2/14	Materials Deep Dive: Metals
Week 6	2/21	Materials Deep Dive: Plastics and Insulation
Week 7	2/28	Materials Deep Dive: Wood & Fiber
Week 8	3/7	<i>Spring Break - no class</i>
Week 9	3/14	Material LCA Pin-Up
Week 10	3/21	Whole Building LCA - Tools and Techniques
Week 11	3/28	Embodied Carbon Policy and Targets
Week 12	4/4	Expanding Scope: Building Reuse & MEP
Week 13	4/11	Expanding Scope: Carbon Sequestration and Forestry
Week 14	4/18	Special Topic TBD
Week 15	4/25	Whole Building LCA Pin-Up

Software & Data

Students will be introduced to a range of LCA modeling tools and practices including Embodied Carbon in Construction Calculator (EC3), SimaPro, Tally, OneClick LCA, EPIC, BEAM, and Athena Impact Estimator for Buildings. Classwork and final projects will be conducted using software matched to their topic of interest. Students will learn to access and use a range of life cycle assessment data sources available for building.

Questions & Extra Help

Instructors will be available to answer questions and discuss assignments by appointment, or by email. In the spirit of collaborative teamwork, students are encouraged to also seek help from their teammates and peers. If students would like to meet, they are expected to contact the instructor via email (scarli@design.upenn.edu).
Office Hours: online or in-person by appointment.

Suggested Bibliography

All assigned readings are listed on Canvas, per week. Additionally, the following resources may be useful in completing assignments and digging deeper into life cycle assessment concepts and material research:

- Carbon Leadership Forum. *Life Cycle Assessment of Buildings: A Practice Guide*. and *Life Cycle Assessment of Buildings: Technical Guidance for Whole Building LCA*. Seattle: University of Washington, 2018.
- Holger König, Niklaus Kohler, Johannes Kriesig & Thomas Lutzkendorf. *A life cycle approach to buildings: Principles – Calculations – Design tools*. Munich: Redaktion, DETAIL, 2010.
- King, Bruce ed. *The New Carbon Architecture: Building to Cool the Climate*. Gabriola Island, BC: New Society Publishers, 2017.
- Royal Institution of Chartered Surveyors, "Whole life carbon assessment for the built environment RICS professional statement, UK," London, 2017.
- Simonen, Kate. *Life Cycle Assessment. Pocket Architecture Technical Series*. New York: Routledge, 2014.
- Simon Sturgis. *Targeting Zero: Embodied and Whole Life Carbon Explained*. London: RIBA Publishing, 2017.
- Tillman, A. M., and H. Baumann. *Hitch Hikers Guide to LCA: An orientation in life cycle assessment methodology and application*. Lund, Sweden: Studentlitteratur AB, 2004.
- World Green Building Council. *Bringing Embodied Carbon Upfront: Coordinated action for the building and construction sector to tackle embodied carbon*. London: WorldGBC (2019).

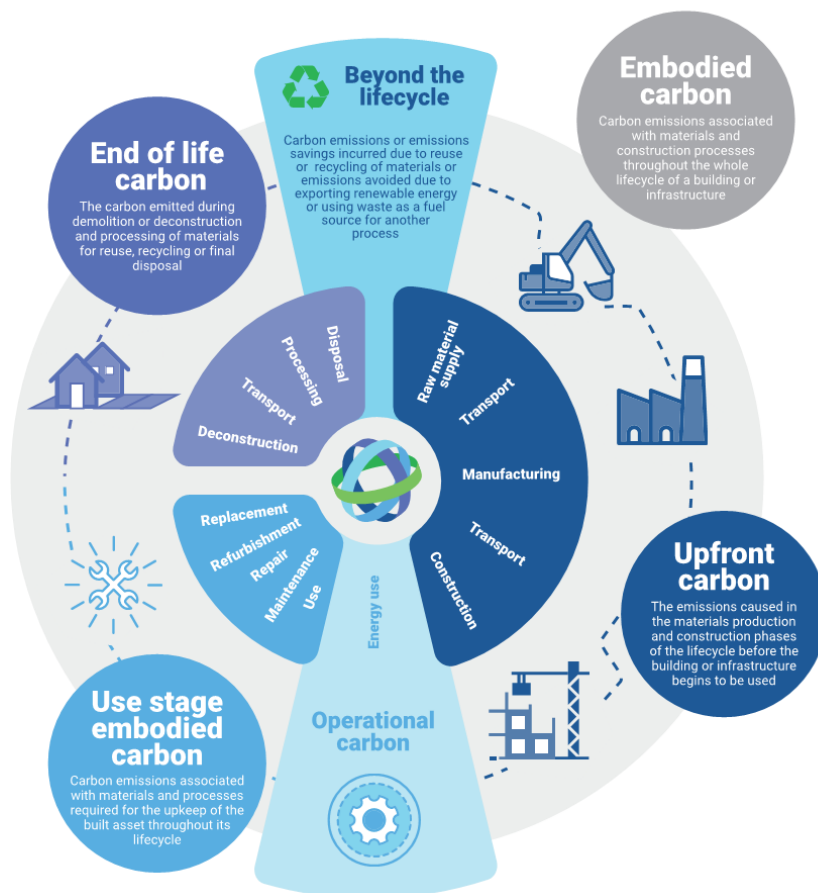


Figure 1. Building life cycle showing scope of definitions and need for whole life cycle consideration (Source: World Green Building Council, *Bringing Embodied Carbon Upfront* 2019)