DECARBONIZING COLUMBIA UNIVERSITY'S BUILT ENVIRONMENT

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HISTORIC PRESERVATION

COLUMBIA CLIMATE SCHOOL
Adapting the Existing Built Environment Network

Studio II | Spring 2024
Executive Summary

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Introduction

Columbia University is grappling with a rapidly evolving built environment policy landscape as it seeks to achieve net zero by 2050. Amid the urgency of the climate crisis, the university faces significant challenges to effective carbon reduction in its existing buildings and new construction. As the university plans its transition toward electrification and net-zero/renewable energy sources to meet the new regulatory goals set by New York City's Climate Mobilization Act (LL97) and New York State's Climate Leadership and Community Protection Act (CLCPA), the university's real estate portfolio and related systems will require significant retrofitting—even replacement—to reduce energy consumption and carbon emissions.

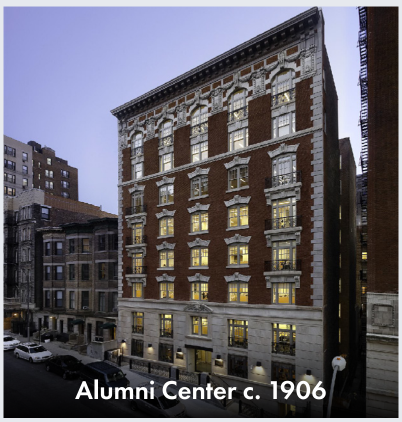
Government and university policies, to date, prioritize the reduction of operational carbon emissions. Although embodied carbon is often viewed in economic terms as a sunk cost, life cycle assessment (LCA) and circular economy research in the construction industry is shifting perspectives about demolition and recognizing the high upfront embodied carbon emissions of new construction. Similarly, the recurrent embodied carbon associated with energy upgrades, renovations, and maintenance is often unaccounted for in decision-making about how to reduce operational carbon and improve building performance.

This report emerges from and builds upon research compiled by graduate students in the Historic Preservation program at Columbia University, and led by professors Erica Avrami and Tim Michiels. The 2024 studio inquiry, "The Carbon Investment of Historic Buildings: Embodied and Operating Energy in the Preservation of the Columbia Campus," focused on the energy consumption and carbon emissions of the Columbia Morningside campus and its environs. Staff from Columbia Facilities and Operations and the Office of Sustainability generously shared their knowledge as part of the studio.

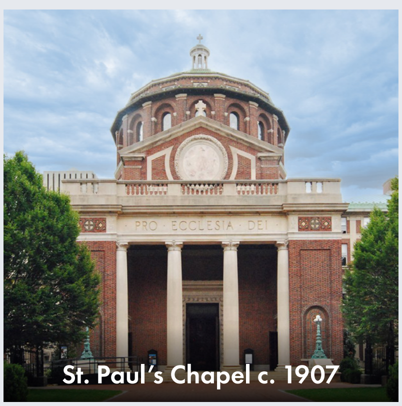
The studio used a selection of Columbia-owned buildings as case studies to explore approaches to quantifying and qualifying their embodied and operational carbon. The cases include both historic and non-historic buildings, and are intended to be representative of the construction typologies of Columbia's Morningside real estate portfolio. In all selected cases, analyses indicated that deep retrofits to an existing building would produce fewer carbon emissions over a 26-year timeframe than either new construction or doing nothing/preserving as is. The studio also analyzed the case study buildings in relation to city- and state-level legislation in order to understand how government policy and regulation impacts institutional decision-making.

Case study buildings included:

Buell Hall c. 1885



Alumni Center c. 1906



St. Paul's Chapel c. 1907

This report draws upon the representative cases and the regulatory landscape analysis to summarize findings and derive recommendations about the interplay of energy efficiency, operational carbon, and embodied carbon. It is intended to inform Columbia University's efforts to achieve net zero in ways that more fully account for the carbon impacts of the built environment.

Critical Pathways for Decarbonization

Discussed within this report are three primary policy pathways toward decarbonization of the built environment:

- Energy efficiency policies to reduce energy consumption
- Operational carbon policies to reduce greenhouse gas emissions
- Embodied carbon policies to avoid carbon impacts and promote more circularity in construction, demolition, and renovation

Energy Efficiency

According to the United States Department of Energy, "energy efficiency is the use of less energy to perform the same task or produce the same result. Energy-efficient homes and buildings use less energy to heat, cool, and run appliances and electronics" (Office of Energy Efficiency and Renewable Energy 2024). Accordingly, energy retrofits of existing buildings seek to improve performance, generally through insulation, windows and doors, mechanical systems, lighting, etc.

The primary policy tool used to promote energy efficiency is energy codes, which seek to reduce energy consumption and cost when a new building or renovation to an existing building is designed. At the state level, New York established its energy conservation code in 1979, the Energy Conservation Construction Code of New York State. NYC established its more stringent energy code in 2009, the New York City Energy Conservation Code.

Avery Hall c. 1912

Pupin Hall c. 1927

Schapiro Residence Hall c. 1987

To evaluate energy efficiency over time, NYC passed Local Law 95 in 2019, which generates an annual energy grade—A, B, C, D, or F—for a building, using the Environmental Protection Agency's online benchmarking tool, Energy Star Portfolio Manager. This building performance standard uses Energy Usage Intensity, or EUI, as a metric of efficiency. EUI is calculated by dividing a building's annual energy usage (kBTU) by its total square footage—typically, the lower the EUI, the more efficient a building.

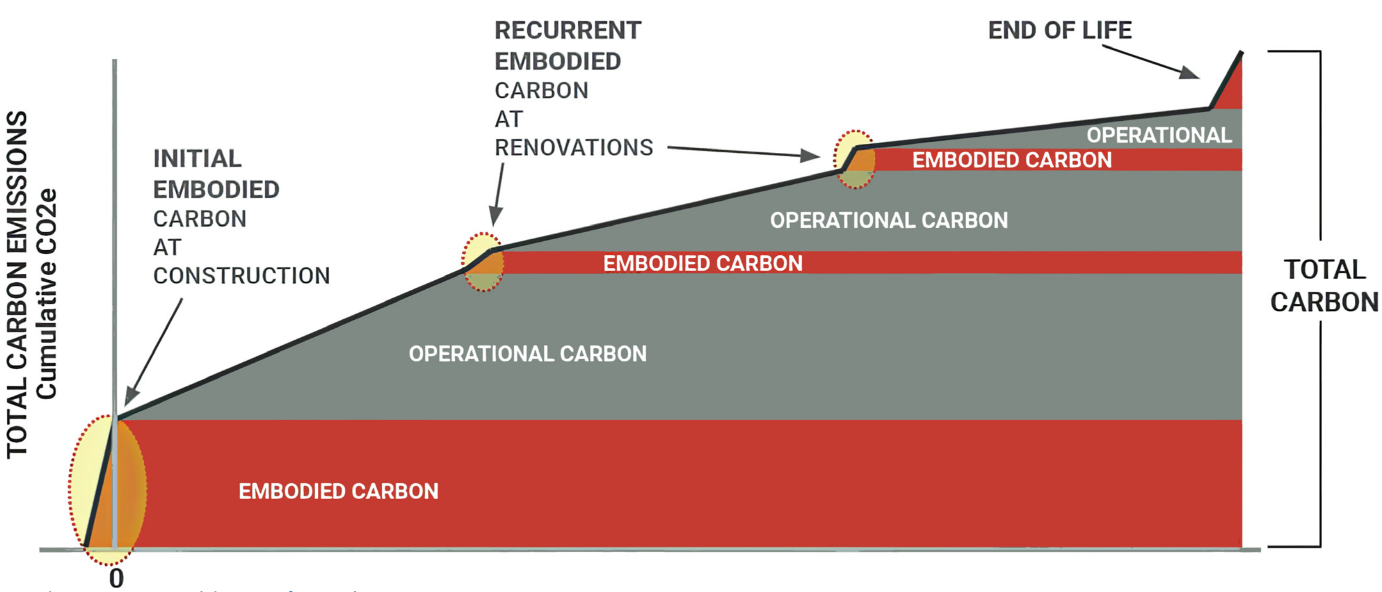
Operational Carbon

Emerging building performance standards seek to reduce operational emissions and energy use of existing buildings over time. Like EUI noted above, this requires benchmarking of actual energy consumption as well as reporting of energy sources, which is then used to calculate annual operational carbon emissions as Carbon Dioxide Equivalent (CO_2e). In New York City, annual emissions reporting categorizes operational carbon as "Total Location-Based GHG Emissions" in metric tons of CO_2e.

In contrast to energy codes, which have national models that can be adopted at the state level, building performance standards are mostly emerging from urban municipalities and are starting to develop at state levels. Also, in contrast to energy codes, buildings must continue to meet the standards post-occupancy. In New York City, Local Law 97 aims to drive deep cuts of emissions from buildings, which are responsible for more than two-thirds of city greenhouse gas emissions. The law places carbon caps on most buildings larger than 25,000 square feet and aims to reduce aggregate greenhouse gas emissions from covered buildings by 40 percent by 2030 and citywide emissions by 80 percent by 2050. It should be noted that when two or more buildings occupy a single tax lot and together total more than 50,000 square feet, as in the case of the Morningside campus, ALL buildings on the tax lot must comply with LL97 regardless of their individual size.

Embodied Carbon

Whereas, operational carbon is limited to the greenhouse gas emissions resulting from building operations, embodied carbon is the greenhouse gas emissions produced throughout multiple stages of a building's life cycle: extraction of raw materials, manufacturing of materials into building products, transportation of those materials to site, building construction, periodic maintenance (referred to as *recurrent embodied carbon*), and when applicable, demolition.



Carbon over a Building's Life Cycle.

Source: Goody Clancy and Architecture 2030

Improving energy efficiency, reducing operational carbon, and reducing embodied carbon are intrinsically tied to achieving net zero. However, as expanded upon below, embodied carbon is a nascent area of policy development due to a lack of available data on existing buildings, standardized inventories, and LCA accounting methods. Primarily, discussions of embodied carbon focus on building-level materials and structural systems. Though policies have not yet matured in New York State, City, or Columbia University, policy tools to reduce embodied carbon include regulations for deconstruction, building material recycling, embodied carbon limits in building codes (e.g., California), and incentives for building reuse (e.g., rehabilitation tax credits).

Columbia's Energy Landscape

Columbia Plan 2030 is Columbia's central and overarching institutional policy regarding energy efficiency, operating carbon, and, to a lesser extent, embodied carbon. Plan 2030 is a ten-year strategic institutional plan, from 2021 to 2030, developed by Sustainable Columbia in collaboration with experts and working groups from across the university. The primary goal of the strategic plan is to achieve net-zero emissions for Columbia's New York campuses by 2050, using 2019 emissions levels as the base year for calculating phased emissions reduction targets for 2025, 2030, 2035, and 2050 (Sustainable Columbia 2023). Through Plan 2030, the university has established an ambitious carbon reduction budget that is more stringent than the state and city-wide goals.

science-based targets

For more on SBTs, visit sustainable.columbia.edu/sbt

Science-based targets (SBTs) provide a clearly defined trajectory to reduce greenhouse gas (GHG) emissions in line with the Paris Agreement, which aims to limit global warming to 1.5°C above pre-industrial levels. More than a thousand public entities globally are adopting SBT to translate the latest climate science from global calculations to institution-specific targets. The targets outlined in Plan 2030, calculated from the base year of 2019, align all Columbia's campuses at the highest level to take immediate action on GHG reduction efforts.

2025 interim target =	15%
2030 interim target =	42%
2035 interim target =	63%
By 2050 or sooner =	100%

Plan 2030 Science-Based Targets.

Source: Sustainable Columbia, 2022–2023 Annual Progress Report.

As established by the International Greenhouse Gas Protocol, Columbia Plan 2030 follows a tripartite scoping approach to measure emissions. Scope 1 emissions are direct emissions from operations such as stationary combustion, fugitive gases, and the Columbia campus fleet. Scope two is indirect emissions from purchased utilities such as chilled water, electricity, and steam heating. Scope three emissions "are all indirect emissions not included in Scope 2, and that arise from upstream and downstream activities in Columbia's value chain," including "purchased goods and services, commuting, and waste from operations" (Sustainable Columbia 2023). Sustainable Columbia notes that early data indicates that Scope 3 accounts for approximately 70 percent of university emissions overall (Sustainable Columbia, 2024).

Columbia's Plan 2030 established science-based cumulative emissions targets for all three emissions scopes that cannot exceed reported emissions levels from 2019 (establishing the base level for all emissions reductions). The plan proposes a 15 percent reduction from 2019 levels by 2025, a 42 percent reduction by 2030, a 63 percent reduction by 2035, and a 100 percent reduction by 2050 or sooner to meet the ultimate goal of net zero emissions (Sustainable Columbia 2019a). Essentially, the reported university emissions from 2019—the base year—function as a set carbon budget cap, which shrinks with the reduction targets proposed by Plan 2030.

Although the performance of Plan 2030's proposed emission reductions are tracked against 2019 data, the plan also sets forth additional campus-specific emissions reduction goals. The Morningside Campus establishes a 66 percent emissions reduction from 2006 levels by 2030; Columbia University Irving Medical Center establishes a 66 percent reduction goal from 2012 levels by 2030; and the Lamont-Doherty Earth Observatory establishes a 72 percent reduction from 2016 levels by 2030 (Sustainable Columbia 2019b). These reduction targets are tracked institutionally and publicly reported by Sustainable Columbia.

Although Columbia outlines a more stringent reduction strategy with set emissions caps, it must still meet the requirements of New York's greenhouse gas law, which sets forth proportional emissions targets every five then ten years based on square footage and property type.

Local Law 97	Columbia Plan 2030
Emissions factors established by property type, proportional to square footage for individual buildings.	Set carbon budget for Columbia regulating Scope 1 and Scope 2 emissions.
Emissions factors established for 2024–29, 2030–34, 2035–39, 2040–2050.	Caps set for 2025, 2030, 2035, and 2050.

In addition, Columbia's plan does not explicitly address campus development projects and the operational and embodied carbon emissions they will generate. As noted by the New York City Department of Buildings, Columbia's Manhattanville project plan will "total approximately 6.8 million gross square feet above and below grade" (New York City Department of City Planning 2007). This significant expansion in square footage will necessitate an increase in operational energy requirements as well as substantial embodied carbon emissions associated with new construction.

To help achieve Columbia's ambitious emissions reduction targets, the university has also initiated a plan to electrify the campus's central steam and cooling loops and to phase building-level retrofits. This involves electrifying the campus at a rate that comports with the legislated electrification of the grid by 2040.

As noted, the stringent carbon budget established by Columbia Plan 2030 to achieve net zero by 2050 does not explicitly address embodied carbon in the built environment. The carbon costs associated with campus expansion, ranging from demolition of existing structures to the construction of new buildings, are currently not accounted for in the university's capped carbon budget. Simply put, substantial carbon impacts are overlooked when net zero policies solely focus on operational carbon and energy efficiency. While tracking emissions through scoping allows for a more clarified approach to emissions accounting for the university, scoping separates the treatment of operational and embodied carbon. In the built environment, operational and embodied carbon are inextricably linked. Integrating both operational and embodied carbon into decision-making about Columbia's built environment is critical to meeting net-zero emissions goals.

Operational and embodied carbon are critical to the university's efforts to achieve net zero by 2050.

Source: https://www.columbia.edu/content/columbia-and-new-york

Key Issues

The following key issues and their contingencies highlight both opportunities and challenges for decarbonizing Columbia University's building portfolio effectively.

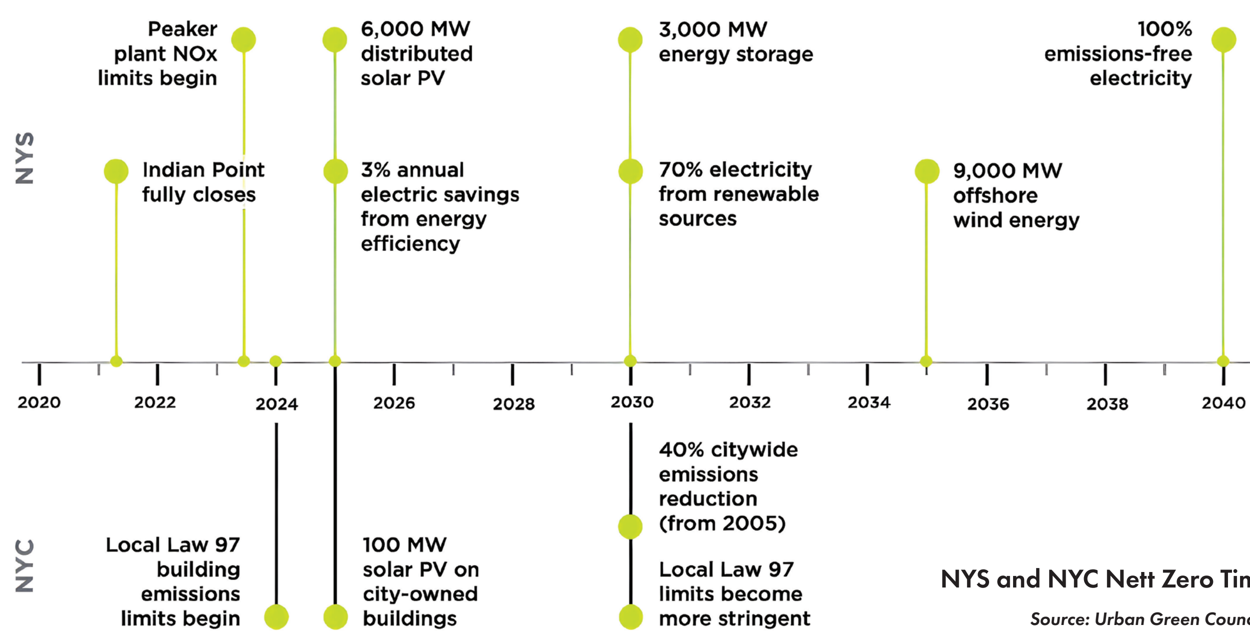
1. **Decarbonizing the Grid**
2. **Decarbonizing the Campus Steam Loop**
3. **Retrofitting Existing Buildings**
4. **Accounting for Embodied Carbon in Columbia's Building Portfolio**

Issue 1: Decarbonizing the Grid

Globally, building sector emissions account for 37 percent of operational carbon emissions (UN Environment Program, 2022). In New York City, that statistic is even greater, with the operational carbon emissions of existing buildings accounting for more than 70 percent of city emissions (Urban Green Council, NYC Greenhouse Gas Inventory, 2023). As established by New York State's Climate Leadership and Community Protection Act, the state must decarbonize its energy grid from natural gas to renewable sources by 2040. Predating state-wide grid electrification, New York City established a suite of laws primarily focused on the reduction of operational carbon (notably passing the nation's first greenhouse gas emissions law, or Local Law 97, in 2019).

To achieve mandatory reductions in operational carbon emissions, building owners in New York City have turned to the electrification of building systems. However, the success of these reductions is largely contingent upon decarbonization of the state electricity grid. Timing and effective coordination between grid- and property-level decarbonization is thus critical, as electrifying a property too soon can result in more carbon emissions if the grid is still generating fossil-fueled electricity. But failing to reduce operational carbon emissions incrementally, per the building-level targets established by LL97, can result in considerable monetary fines.

On Columbia University's Morningside campus, conventional energy efficiency upgrades are insufficient to meet both institutional carbon goals and long-term LL97 targets. While electrification is a viable solution, its implementation is timing-dependent. With the New York State grid still heavily reliant on non-renewable, fossil fuel-based energy sources, the transition to 70 percent renewables by 2030 and a 100 percent zero-emissions grid by 2040 is ongoing (New York State Energy Research and Development Authority n.d.).



NYS and NYC Nett Zero Timeline

Source: Urban Green Council, 2020

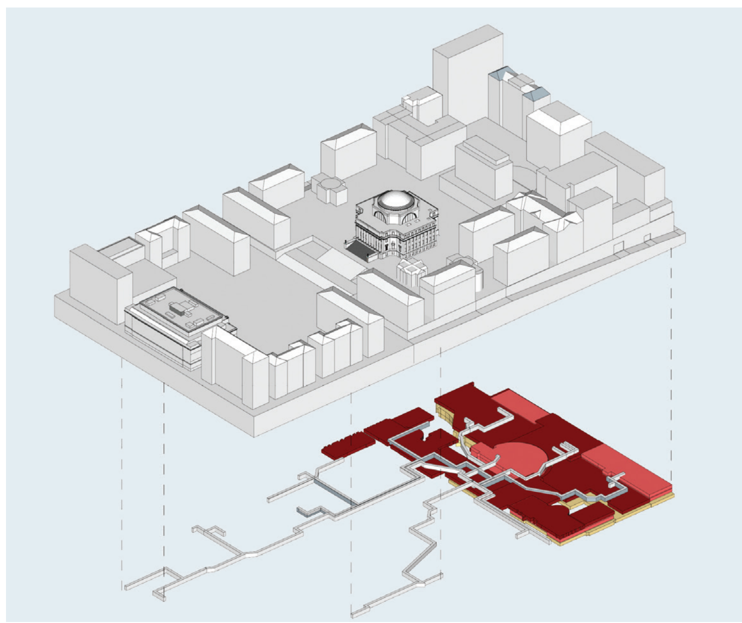
Electrification must account for when the grid infrastructure is prepared to handle increased demand and when renewable energy sources are readily available. If Columbia electrified too early (i.e., before the state grid decarbonizes), it would emit more carbon than if it phases electrification, because it would be drawing electricity from a grid that is still producing power with fossil fuels. Prioritizing electrification without considering grid limitations also risks straining an already overburdened system. Therefore, strategic planning and coordination with energy providers, Columbia policymakers, and Facilities and Operations staff are essential for a smooth transition to electrification to reduce both energy demands and operational emissions, and avoid regulatory fines.

Issue 2: Decarbonizing the Campus Loop

The Columbia Morningside campus relies largely on a thermal energy network, or steam (and cooling) loop. This energy infrastructure is more than a century old, and it was initially coal-powered. The university effectively transitioned the loop to oil and then to gas, though it is occasionally still powered by oil as a backup when requested by the city, due to demand overloads. In 2020, a majority of the steam loop's 30 percent emissions reductions were achieved through renewable energy credits, or RECs (Greenburg 2020).

University Policy and Electrification

As discussed in the "Columbia's Energy Landscape" section of this report, to help achieve Columbia's ambitious emissions reduction targets, the university initiated a plan to electrify the campus's central steam loop and undertake associated building-level retrofits, attempting to electrify the campus at a rate that will keep pace with the proposed electrification of the grid by 2040. Per a November 2023 decarbonization update, the university has proposed a partial building-level conversion of steam to central hot water heat pumps while continuing steam connections to terminal devices (e.g., radiators), ultimately running both in parallel until grid electrification is achieved. Partial building-level conversions will be completed campus-wide by 2040.



Campus Loop.

Source: Courtesy of Columbia Facilities and Operations & Nicolás Moraga

Laboratories and Energy Consumption

Across the portfolio of university buildings, the energy demands of those housing laboratories present a particular challenge. Essential for cutting-edge research, laboratories rely on energy-intensive equipment such as lasers, fume hoods, and sub-zero (down to minus 80 degrees) refrigeration systems. These energy needs may not be met effectively by relying on only the diffuse and intermittent nature of renewable energy sources like solar and wind (Karam 2023).

The sheer scale of fossil fuel-based energy consumption across the campus is staggering, from the thousands of high-energy-consuming sub-zero refrigerators to the heavy-duty air conditioning units required for stringent temperature control in laboratory buildings like Pupin Hall. Meeting these demands through all-electric pathways may need to be coupled with the development of more energy-efficient laboratory technologies, as well as possibilities such as adopting Energy Storage or Hybrid Systems.

An important point to underscore in terms of meeting regulatory requirements is how Columbia is reporting its laboratory buildings for required benchmarking. The university has categorized its Morningside laboratory buildings under the "college/university" Energy Star Portfolio Manager building classification, even though a "laboratory" classification is possible. Laboratory buildings, as outlined above, use more energy and often have higher operational emissions, and their benchmarking reflects this. Laboratory buildings thus have less stringent carbon targets than college/university buildings under Local Law 97. Due to this college/university classification, Columbia's Morningside laboratory buildings, like Pupin Hall, must meet a higher standard of carbon reduction, which is positive for the university's carbon budget but will undoubtedly involve complex retrofitting challenges. In addition, failure to meet that more stringent incremental LL97 targets will result in much steeper regulatory fines for a college/university-classified building versus a laboratory-classified building.

It should be noted that, after the completion of this studio's research, Columbia negotiated its LL97-related reporting requirements with the City of New York. Because most of the campus is part of a thermal energy network—the loop—rather than independently-powered structures, the emissions data for more than 65 buildings will be combined and calculated based on square footage and use. This will likely alter the amount of LL97 target-related fines the university may incur during its energy transition.

Building Typology and Energy Usage: Pupin Hall

In 2003, the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) published guidelines for low-energy laboratory design, revealing that laboratories typically consume 5–10 times more energy per square foot than office buildings. Specialty laboratories, such as clean rooms and those with large process loads, can even consume up to 100 times the energy of similarly sized institutional or commercial structures (Parsons and Branson 2003). As an astrophysics laboratory building, Pupin Hall houses over a hundred laboratories within its 149,085 square feet.

Based on 2024 observations, most Pupin classrooms and offices still rely on the heating and cooling systems from the university's main boiler and central steam loop. Because the majority of laboratories in the building require strict air regulation and temperature control as part of their operational requirements, Columbia installed additional stand-alone, purpose-built proprietary air conditioning units to meet these needs. Dozens of window air conditioning units, generally serving office spaces, are visible from Pupin's facade. In addition, laboratories typically demand 100 percent outside air, often requiring exchange rates between 6 and 10 air changes per hour (ACH) to meet the stringent exhaust requirements of fume hoods, aimed at preventing cross-contamination (Barrette and Fortier 2022). This combination of factors underscores the challenging and intricate interplay between operational requirements, comfort, and sustainability goals in the decarbonization of laboratory buildings like Pupin Hall.

Pupin Hall Main Heating and Cooling Control Room from The Central Plant

Source: Frederick, 2024

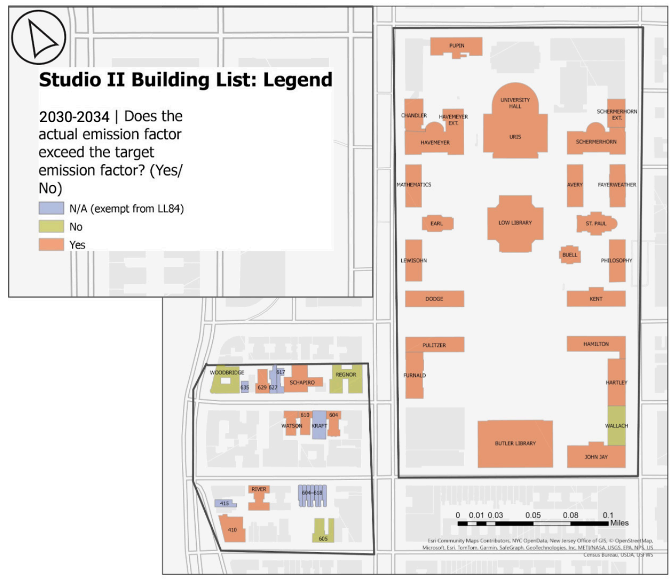
Issue 3: Retrofitting Existing Buildings

Like city- and state-level legislation to date, Columbia policies have prioritized the reduction of operational carbon. Plan 2030 sets an ambitious carbon budget (established from its reported emissions in 2019) that exceeds state- and city-mandated targets for reducing operational carbon, and aims to achieve net-zero emissions for the university's New York campuses by 2050 (Sustainable Columbia 2023). But even with a stringent institutional carbon budget, the university has some hurdles to achieving these reductions.

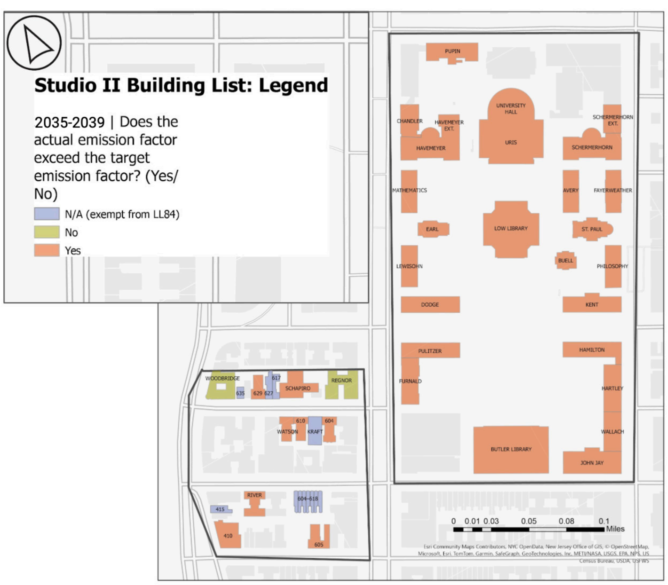
Building-Level Carbon Regulations vs. Campus-Level Carbon Budget

Looking closely at emissions reported to city government, the studio examined data from thirty-six buildings in Columbia's portfolio, covering historic buildings on the Morningside Heights campus and neighboring properties between West 113th and West 115th West of Broadway. Analysis indicated that 34 of the 36 buildings met the mandated emissions reduction targets for 2024–2029, but compliance with future, more stringent targets (for 2030–34, 2035–39, and 2040–2050) proved more challenging.

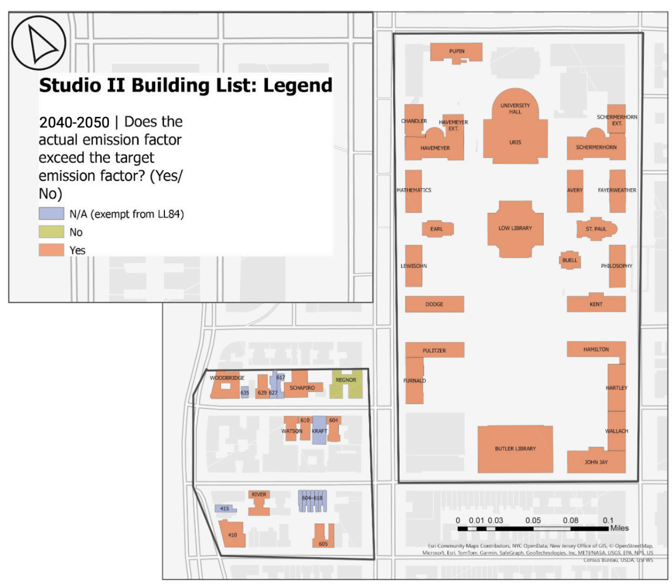
Emissions Targets, 2024–2029.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data



Emissions Targets, 2030–2034.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data



Emissions Targets, 2035–2039.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data



Emissions Targets, 2040–2050.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data

While Columbia should be lauded for its intentions of establishing a more rigorous carbon budget, that carbon budget is calculated at an aggregated **campus** level. Local law regulates operational carbon at a **building** level. In order to incentivize property owners to comply with carbon reduction targets, the law imposes financial penalties on individual buildings. It is therefore imperative that decision-making about building decarbonization on Columbia's campus include discrete, building-level analyses and phased retrofit strategies in order to avoid steep regulatory fines.

The studio team projected the minimum cumulative fines through 2050 for just the six studio case study buildings, presuming no retrofits and based on 2024 penalty rates (rates are expected to increase with each target period, but the percentage of the increase is not yet determined):

Pupin Hall **$34,825,161**

Avery Hall **$8,234,558**

Alumni Center...**$2,136,273**

Schapiro Hall **$1,358,761**

Buell Hall.. **$553,732**

St. Paul's Chapel **$388,530**

The above calculations are based on no retrofits before 2050, but Columbia indeed anticipates decarbonization of the loop and associated retrofits by 2050. This hypothetical analysis is intended to underscore the importance of *incremental* retrofits and their *phased* timing. It also demonstrates the significant costs that may be incurred if carbon reductions are aggregated at the campus level and not sufficiently analyzed and prioritized building-by-building.

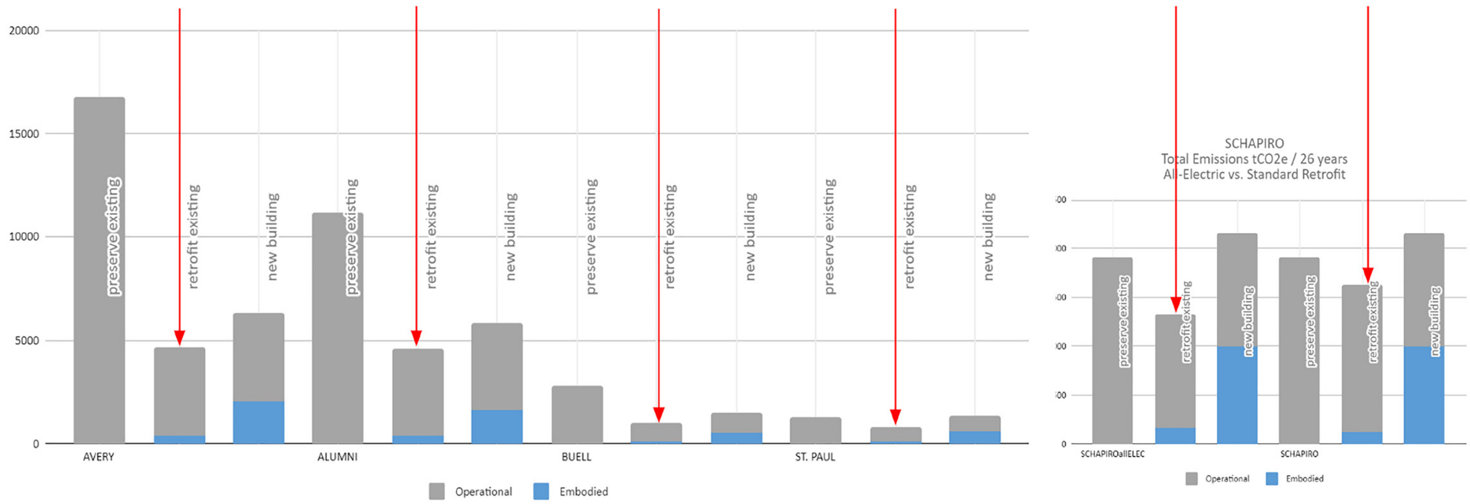
A notable and unintended consequence of these regulatory penalties is the incentive to demolish. Because upfront embodied carbon is not (yet) accounted for in Columbia's carbon budget or in NYC legislation, demolition of an existing building and replacement with a "net-zero" building (based only on operational carbon) may seem cost-preferable to retrofitting. However, this research demonstrated that demolition and new construction will likely be more egregious in terms of overall carbon emissions (see Key Issue 4).

Deep Retrofits Minimize Carbon Emissions

Deep retrofits involve extensive renovations in existing buildings to significantly reduce energy consumption and improve energy efficiency, in addition to reducing carbon emissions. They include upgrades to the building envelope to minimize thermal transfer between the interior and exterior as well as modifications to systems like HVAC and lighting. The conversion to electrified, renewable energy systems, i.e., decarbonizing Columbia's loop, is a critical step, but that foundational strategy must be augmented with building retrofits that reduce EUI regardless of the type of energy. Reducing the amount of energy consumed by buildings reduces operational carbon while the grid and loop are under conversion, and it is also important to managing the overall energy demands placed on the loop and the grid once converted. In the context of Columbia Morningside, this requires significant communication and coordination, as Operations is charged with the management and conversion of the loop, but Facilities manages building retrofits.

The studio used the CARE Tool (Carbon Avoided: Retrofit Estimator), to model the operational and embodied carbon expenditures of interventions to the selected case study buildings. This included exploration of the carbon implications of: a) preserve as is (do nothing), b) deeply retrofit, or c) demolish and build anew.

As shown in the figure below, if Columbia's buildings were to continue operating as is (option a), expenditure of operational carbon emissions would greatly exceed both emissions reductions targets mandated by the city and the carbon budget established by the Columbia 2030 Plan. CARE Tool analyses also indicate that demolishing a structure and constructing a low-emitting building (option c) also has significant carbon costs. While meaningfully reducing lifetime operational carbon emissions, new construction generates excessive embodied carbon emissions.



Building retrofitting pre-visualization in study cases: Avery Hall, Alumni Center, Buell, St. Paul and Schapiro.

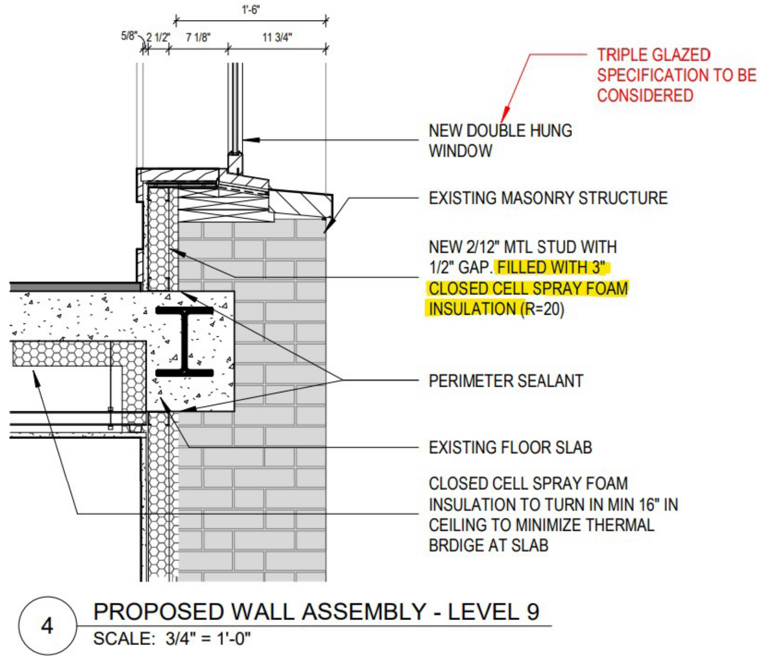
Source: Studio Team.

Deeply retrofitting existing buildings results in the lowest overall carbon emissions. The CARE Tool findings highlight the interdependence of embodied and operational carbon emissions, and the importance of considering both in decisions about decarbonizing the built environment.

Carbon Tradeoffs and Time

The decision to retrofit an existing building is not based on energy and carbon alone; it is a tradeoff that also considers cost, space, access, occupancy and use, and technical feasibility, as well as architectural significance on an historic campus like Columbia. However, if the university is to meet its carbon reduction goals and comply with NYC regulations, there is a need to more effectively integrate energy and carbon considerations into decision-making about Columbia's built environment, from new construction and renovations, to the replacement of furnishings and finishes.

The university is in the process of developing new Design & Construction Sustainability Guidelines, which are largely geared toward ensuring that Columbia-contracted teams comply with the university's environmental goals on a project-by-project basis. This is important to aligning the design and construction process with carbon considerations as it plans new construction, renovations, and cosmetic upgrades.



Typical bedroom in Hartley Hall (left) and a proposed addition of three inches of wall insulation on the interior (right). Adding insulation incurs competing priorities, as increased wall thickness can reduce interior square footage. In the case of Hartley, the additional insulation would have resulted in the loss of five beds across the building. In the context of NYC, housing more students on campus is always a critical concern, and one that can outweigh carbon reduction goals. The alternative to interior insulation is adding exterior insulation, but that would compromise the integrity of Columbia's designated historic buildings.

Sources: Columbia Housing (left), 1100 Architects (right)

However to effectively comply with existing and emerging regulations, this must extend beyond the planning and design phase to consider carbon—operating and embodied—across building life cycles.

Green building rating systems, like the Leadership in Energy and Environmental Design certification program (LEED), are slowly evolving to meet these challenges. The most widely recognized application of LEED is to new construction and major renovations, awarding silver, gold, or platinum status to projects based on *design* documents. While achieving LEED certification begins with commendable intentions for sustainable construction, the rating system is flawed. While seeking to become more data-driven, LEED's point system combines environmental concerns that involve very different metrics of evaluation, and thus does not effectively prioritize energy and carbon within a broader set of tradeoffs. Scholarly research about the LEED certification program now suggests that in many or even most cases, LEED buildings perform no better than non-LEED buildings over time (Clay, Severnini, and Sun 2023). Yet once a building receives certification, it is in place indefinitely, or at least until the next major renovation.

Actual energy consumption and carbon emissions over the operational phase of a building are only considered as part of LEED's Operations and Maintenance (O+M) program, which shows greater promise. It requires the submission of energy use data after a building is constructed and in use. As noted above, buildings that received certification at the time of design may not, in fact, be reducing carbon emissions as planned. LEED O+M in some respects functions like NYC's Climate Law by requiring annual reporting and benchmarking of actual energy consumption to determine performance.

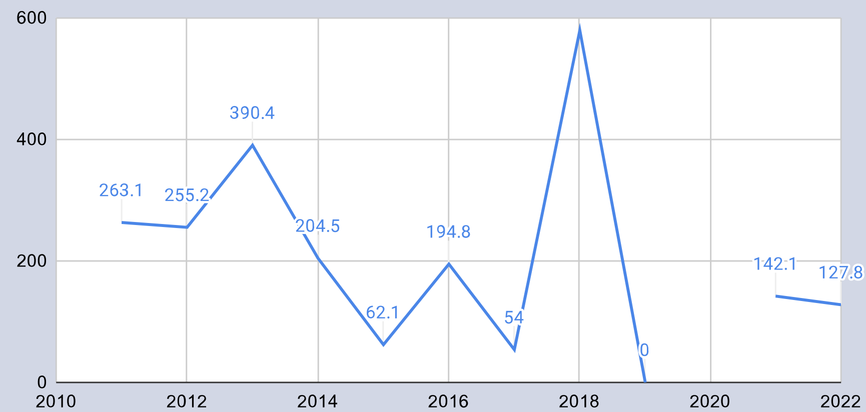
Alumni Center: Carbon and LEED Certification

The LEED rating system has grown to be the world's most widely used green building certification program covering over 110,000 buildings worldwide. Columbia's Alumni Center achieved LEED Gold certification for its renovation in 2010, earning a total of 39 points out of 69 in the LEED program version 2.2.

The renovation is a commendable reuse of an older building. It made significant changes to the building structure and mechanical, electrical, and plumbing (MEP) systems intended to reduce energy consumption. The addition of exterior wall and roof insulation, new double pane low-e glass windows, and a new cool roof (nearly a decade ahead of NYC's green and cool roof law), in theory, reduced Alumni Center's annual operating carbon emissions. However, the reported data suggests that the building's performance has not always been consistent with those intentions. Both EUI and carbon reporting provide insights:

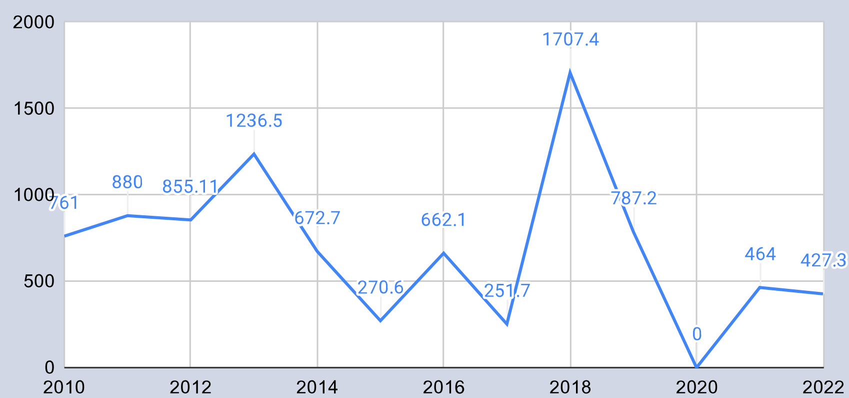
As illustrated in the graphs at right, the building has reported both startlingly high and impressively low EUIs (579 kBTU/ft^2 in 2018 and 52 kBTU/ft^2 in 2017) and inconsistent carbon emissions. The inconsistency is especially notable for data reported after 2015, when retro-commissioning efforts should have been initiated on the site.

In the case of Alumni Center, the varied LEED sustainability metrics and the mix-and-match implications of the point system do not necessarily result in quantifiable carbon reduction. For example, twelve of fifteen possible points were awarded for Indoor Environmental Quality, which focuses on fresh air ventilation and healthy indoor material selections, composing over 30 percent of the total points awarded. These features may certainly lead to positive health and environmental benefits; however, they do not necessarily reduce carbon emissions. This example illustrates the complicated tradeoffs involved in project decision-making that may not always prioritize carbon reduction, and the limitations of basing green certification on design documents alone.



Alumni Center's Annual EUI, 2010–2022.

Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data



Alumni Center's Annual Greenhouse Gas Emissions, 2010–2022.

Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data

Issue 4: Accounting for Embodied Carbon in Columbia's Building Portfolio

The integral relationship of operational and embodied carbon in the built environment cannot be overstated. However, embodied carbon receives less attention because it is viewed as a "sunk cost" given its upfront carbon investment, and it is proportionally less significant when compared to operational carbon over a building's life cycle. However, the upfront embodied carbon associated with new construction is particularly problematic in the context of the climate crisis and the need to reduce all emissions as soon as possible. In addition, as operational emissions decrease due to emerging building regulations, embodied carbon becomes a larger percentage of a building's emissions over its life cycle. The underestimation of embodied carbon creates a fundamental deficit in carbon accounting in the built environment, where regulation and monitoring of operational carbon without embodied carbon results in an incomplete calculation of emissions, which may incentivize the demolition and replacement of existing buildings.

Examples of how embodied carbon is reduced through policy include:

- implementation of whole building life cycle assessment (LCA) in new construction and renovation projects
- reuse of buildings and building materials, especially materials like wood that sequester biogenic carbon, which would be released in a landfill
- material passports to document material origins and reuse
- use of low-carbon and locally-sourced building materials, finishes, and furnishings
- deconstruction (rather than demolition) of buildings, to facilitate material reuse and recycling
- recycling of construction and demolition (C+D) waste and building furnishings

The absence of embodied carbon in policy and decision-making processes is driven, in part, by the lack of standardized measurement methods for embodied carbon, resulting in scarce and unreliable data. Current regulatory tools, such as those utilized for benchmarking, are ill-suited for addressing the unique challenges posed by embodied carbon assessment. Consequently, embodied carbon remains marginalized in discussions surrounding carbon budget calculations and other decision-making processes pertaining to the built environment.

Embodied Carbon Regulation Emerges

Although New York City and State are leaders in the regulation of operational carbon in the built environment, embodied carbon policies are nascent at both the municipal and state levels. Consequently, there is a limited regulatory framework for institutions like Columbia, and embodied carbon policy is thus underdeveloped at the university.

The city does not regulate C+D waste or require the recycling of building materials, nor does it mandate LCA of existing buildings in a retrofit or rehabilitation project (Urban Green Council 2016). However, in 2022, Mayor Eric Adams signed Executive Order 23, intended to promote life cycle assessment in NYC capital projects, including new construction and major renovations. Building on Executive Order 23, in March 2024, the New York City Economic Development Corporation (NYCEDC 2024) released an operational guide for capital construction projects titled "Circular Design and Construction Guidelines." While only applicable to capital projects of the EDC, the guidelines aim to reduce embodied carbon and waste through three phases: preconstruction; procurement, construction, and renovation; and decommissioning and deconstruction. Within each phase are suggested "circular strategies," such as circularity audits, planning and management of logistics to store reused material on site, and determining scopes for deconstruction in lieu of demolition (NYCEDC 2024).

Limited policy is in place to regulate embodied carbon at the New York State level. To date, two state-level policies—Executive Order 22 and the Low Embodied Carbon Concrete Leadership Act—begin to address the embodied carbon, though largely focus on new construction.

Recognizing the significance of embodied carbon, other states and municipalities are beginning to regulate it, such as the California Green Building Standards Code—Part 11, Title 24, California Code of Regulations—known as CALGreen. This regulation went into effect in July 2024, making California the first state to address embodied carbon through a mandatory code. Public and private non-residential buildings larger than 100,000 square feet and schools larger than 50,000 square feet will be required to comply with code requirements via three pathways of compliance, one of which is the reuse of an existing building or the deconstruction and reuse of its buildings materials. It is a tiered system, mandating a reuse minimum of 45 percent and going up to the optional reuse of 75 percent of the building enclosure and 30 percent of its non-structural interior elements.

Deconstruction ordinances—or laws requiring buildings slated for removal to be methodically dismantled and their materials stripped down and prepared for reuse—also function as an alternative policy tool to address embodied carbon. Cities like Portland, Oregon, an earlier deconstruction ordinance adoptee, illustrate how upfront embodied carbon impacts of new construction may be offset—or significantly reduced—through deconstruction and reuse, particularly materials like timber whose biogenic carbon would be released if left to deteriorate in a landfill. In New York, the NYCEDC's "Circular Design and Construction Guidelines" exemplify how capital construction can embrace circularity, utilizing life cycle assessment and deconstruction.

A critical dimension of the success of regulated deconstruction is the development of a market for material reuse. As the largest private landowner in New York City, and an institution committed to a major expansion, Columbia has a unique opportunity to forge creative partnerships for future construction and renovation projects that pioneer deconstruction and test market possibilities, as well as experiment with alternative embodied carbon policies.

Embodied Carbon Policy at Columbia

As with New York City, Columbia has yet to develop a clear policy regulating embodied carbon in capital construction projects or in its existing building portfolio. That said, the university's categorization of its emissions into different scopes hints at its path forward.

To reduce emissions, the university followed the greenhouse gas protocol established by the World Resources Institute. It includes three scopes to measure emissions, allowing it to track its current efforts and future next steps with its commitment areas and scopes in tandem. Scope 1 emissions occur from the stationary and mobile combustion of fuel. Scope 2 is from purchased electricity, and Scope 3 is from business travel, commuting, and waste from operations. For all scopes of emissions in Columbia's Plan 2030, cumulative emissions targets cannot exceed the base data of reported emissions in 2019. Annual reductions based on goal years are an overall 15 percent reduction by 2025, 42 percent reduction by 2030, 63 percent reduction by 2035, and 100 percent reduction by 2050, meeting the ultimate net zero emission goal.

Columbia's forthcoming guidelines for sustainable design and construction expand the classification of Scope 3 emissions to include construction materials. Within these new scoping guidelines, both new and existing buildings will have to adhere to responsible design and construction standards (Columbia Green Buildings Program 2025).

While the university's expanded definition of Scope 3 emissions begins to monitor embodied carbon for new construction, two issues arise. Firstly, will embodied carbon be accounted for in Columbia's carbon budget, and if so, how will it account for carbon expended prior to the issuance of the new Guidelines? And secondly, as discussed in Issue 3, while LEED-silver designation for all newly constructed buildings in Columbia's portfolio might help to ensure that some efficiency and sustainability measures are planned in the design phase, it will not ensure that emissions reductions are met after the building is in use. Alternatively or in tandem, the university may choose to prioritize LEED version 4.1 Operations and Maintenance (O+M) certification, which evaluates existing buildings and bases LEED points on high energy efficiency with ongoing tracking to ensure sustained performance over time.

Accounting for Embodied Carbon at the University

While Columbia's policy position does not explicitly incentivize demolition, its persistent focus on new, "green" buildings leaves older buildings vulnerable. For example, Manhattanville plans incur the demolition of a number of existing buildings. The design of replacement buildings, to date, claim "net zero" based on operational carbon alone; there is limited to no accounting of the upfront embodied carbon required to construct those replacement buildings. In addition, there is limited attention paid to the embodied carbon associated with demolition, especially the biogenic carbon of many low-rise buildings with structural timber floors, which will release sequestered carbon if not reused. This is a gaping omission. Columbia has set out stringent caps on carbon emissions as it aims for a net zero campus by 2050. Without embodied carbon accounting for its buildings, Columbia's carbon emission reporting does not accurately reflect the university's real impacts on climate change.

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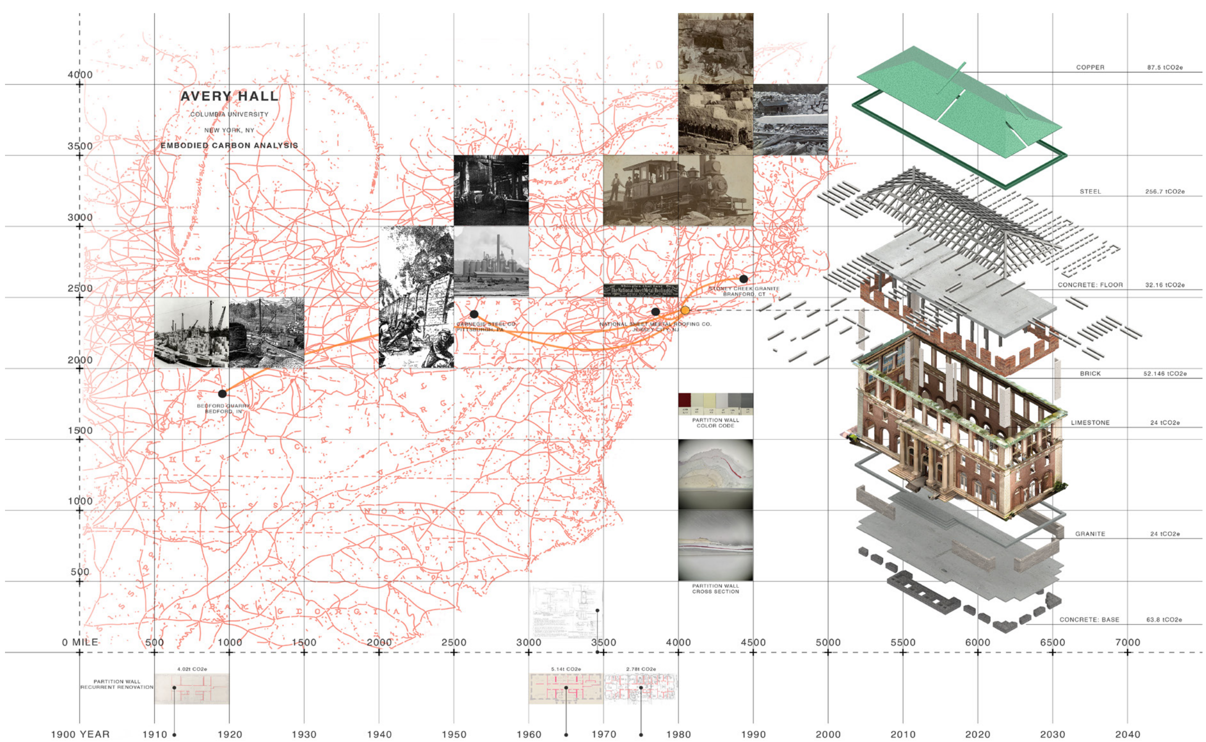
Some critical interventions are already underway at the university, like the Guidelines noted above. Lookbooks, developed by Columbia Facilities and Operations, "support the construction and renovation of new and existing buildings," on Columbia's campuses and are being updated by Columbia's Design and Compliance Group. Covering a range of interior finishes and furniture, these lookbooks attempt to provide guidance to design professionals and facilities managers on the environmental impacts and benefits of products regularly replaced at the university. The latest iterations of the lookbooks use a leaf grading system (more leaves, more sustainable) to rank products based on environmental product declarations and BIFMA standards for disclosure of materials relating to health product declarations, often considered comparable to LEED designations for buildings. The inclusion of these standards illustrates Columbia's move towards considering the complete life cycle of a product. A next step, currently under development, is adding data about embodied carbon to guide procurement that considers product-related emissions and circularity, i.e., the reuse and recycling of product components at end of life.



Embodied Carbon Analysis of Avery Hall.

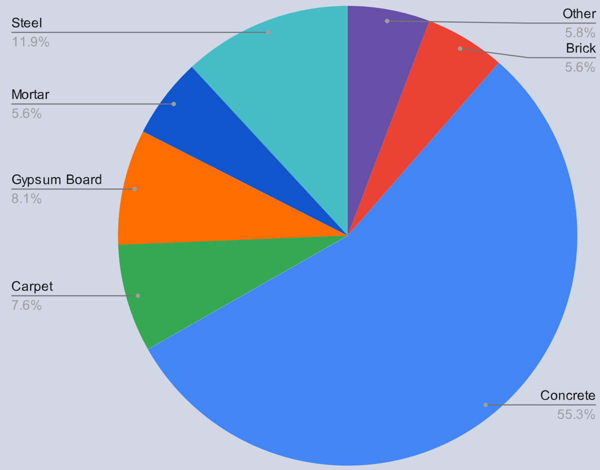
Source: Zhaosen (Aaron) Luo

Embodied Carbon and Interior Finishes in Schapiro Hall

As a 17-story building encompassing over 100,000 square feet of habitable space, Schapiro Hall's embodied carbon per square foot value is calculated to be approximately 18 kg CO_2e/ft^2.

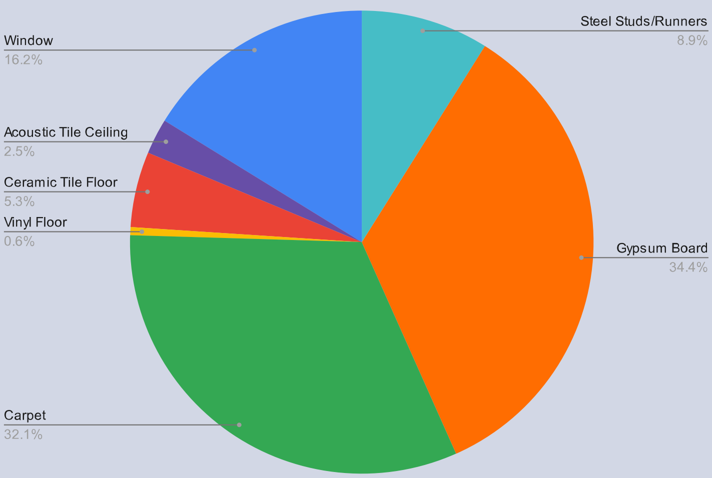
Studio research found unexpected interior components that contributed to Schapiro's high embodied carbon, with the two largest being gypsum board and carpet. These two components both individually exceed the value of Schapiro's brick cladding and almost equal the value of its interior bearing walls.

Several of Schapiro Hall's components are especially liable to be replaced over time, including finished flooring, ceilings, windows, and partitions. These components, even without regular replacement or maintenance, already represent nearly 550 tCO_2e, almost a quarter of Schapiro's total embodied carbon. Their replacement involves a complicated decision-making process that takes into account durability, cost, accessibility, maintenance and cleaning, acoustics, and more. In this category, carpet is one of the largest concerns, amounting to twice the embodied carbon of Schapiro's windows. Carpet currently represents 6 percent of Schapiro's total embodied carbon. If the carpet were replaced even once (assuming an average carbon-intensive replacement carpet at 20kg CO_2e/m^2), the cumulative carpet-related embodied carbon would exceed that of the building's structural steel.



Embodied carbon of Schapiro Hall (tCO_2e) by material type.

Data source: Ice DB V3.0, EC3, CUIN Glass, and IStructE.



Embodied carbon of Schapiro Hall's non-structural components (tCO_2e) by material type.

Data source: Ice DB V3.0, EC3, CUIN Glass, and IStructE.

Insufficient Data and Carbon Inventories

A hurdle in the development of embodied carbon policy is insufficient data. The lack of standardized baseline data, especially New York City-specific data, makes it difficult to set policies about embodied carbon. Data collection on embodied carbon is the first and biggest challenge for policymakers.

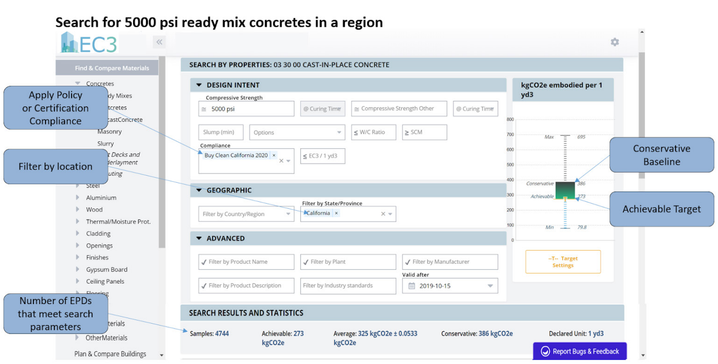
The process of assessing a building's embodied carbon is contingent upon access to carbon inventories that accurately quantify a range of building components and produces. While different carbon databases may lead to divergent results, the results of this studio work were obtained by consistent use of the ICE database. Therefore, relative results between buildings are accurate, even though the actual absolute carbon emission values might vary if using a different database. In the absence of a national consensus, Columbia should adopt one metric for institutional consistency.

Three different carbon values for the same building! (Green Book Db, Epic Db and Ice Db)

Source: Petrass 2022

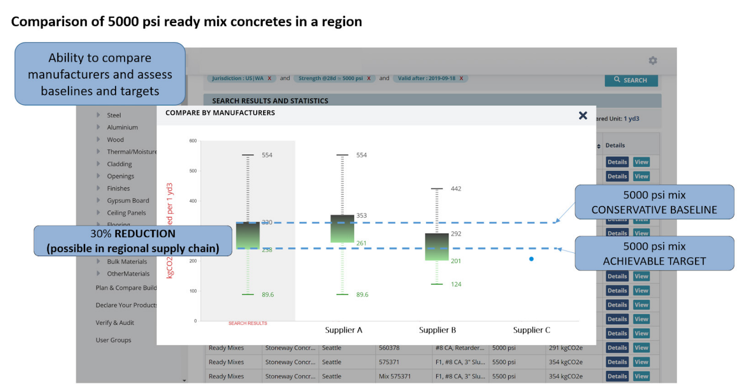
Consideration of Historical Data

Available carbon inventories predominantly rely on contemporary data, reflecting emissions associated with modern materials. They essentially allow for the calculation of the *replacement value* of embodied carbon, meaning how much embodied carbon would be emitted if the building were constructed with similar materials today. The *actual* embodied carbon of a building's existing materials may be quite different, based on when and where materials were originally sourced, how they were transported, and more. Consequently, buildings older than a decade present substantial hurdles in carbon inventory assessments, given the scarcity of historical data and the complexities involved in retroactive calculations.



EC3 material search

Source: Building Transparency, 2022



EC3 material comparison

Source: Building Transparency, 2022

Buell Hall and Biogenic Carbon

1900 view of Buell Hall

Source: Columbia University Archives

Buell Hall is the oldest building on Columbia's Morningside campus, dating to 1885. The studio team sought to explore the *actual* embodied carbon of its historic timber components, including windows, joists, studs, and its now-demolished veranda. Widder and Meinreinken's embodied carbon calculations for a wood-framed 1875 window at Olana, served as a precedent. While the exact source of Buell's timber is undetermined, southern yellow pine grown in North Carolina was presumed, given New York City's increased reliance on southern timber towards the latter part of the nineteenth century.

In analyzing the timber used in Buell Hall, it was assumed that there was negligible carbon output for hauling and curing the timber due to horse hauling or floating of logs for initial transportation, as well as natural curing processes for the wood. The milling of the lumber may have contributed to carbon emissions if the sawmill was steam-powered; however, given the possibility of the mill being hydro-powered, the emissions of the milling process were undeterminable, yet likely small.

The primary historic embodied carbon emissions stem from the unsustainable forestry practices of the nineteenth century, which would have released emissions from root systems and tree branches and from transporting the timber from Western North Carolina to New York. Relying on research conducted by Widder and Meinrenken into the CO_2e of the American white oak used at Olana (that determined how many kg of CO_2e was released per kg of white oak produced). This was then adjusted, assuming that the amount of sequestered carbon is directly related to the density of the material. Because American yellow pine is much lighter than white oak (Sexton n.d.), the embodied carbon associated with unsustainable forestry of yellow pine harvested was estimated at 1.89 kg CO_2e/kg

Subsequently emissions from transporting the timber to New York City were estimated. Asheville was selected as the hypothetical starting point of transport, as the nearest major city in western North Carolina. The journey between Asheville to the New York City area was approximately 700 miles, and freight trains at that time would have burnt about 97.5 lbs of coal per mile (Llanso n.d). It was then approximated that about 12,000 planks of 20-foot-long 3 × 8s would have been transported in a single shipment, giving each plank an embodied carbon value of 5.3 kg CO2e. Assuming the weight of each plank is about 45kg, 1kg of timber would have resulted in 0.12 kg of equivalent CO_2 emissions (0.12 kg CO_2e).

Combining the emissions of rail transport with the embodied carbon of unsustainable forestry practices, the historic embodied carbon per kilogram of lumber in Buell was approximately 2.0 kg CO_2e, just over four times that of the contemporary replacement value of timber, without accounting for the carbon sequestered by the timber within Buell.

Carbon databases play a pivotal role in evaluating a building's embodied carbon within the framework of Life Cycle Assessment (LCA). Notably, tools like the Embodied Carbon in Construction Calculator (EC3) serve as repositories of data concerning the embodied carbon of contemporary materials, facilitating comparative analyses among suppliers. However, a significant limitation arises when assessing the *actual* embodied carbon of existing buildings, attributable to the influence of historical factors, rather than the *replacement value* of embodied carbon. For instance, the determination of the actual embodied carbon of the historic timber in Buell Hall necessitates meticulous consideration of variables such as tree species and harvesting and transportation methods. Consequently, accurately assessing the *actual* embodied carbon of older, and especially historic, buildings—to fully understand their carbon investment and implications—mandates the incorporation of historical data into carbon databases.

Standardizing Embodied Carbon Estimates

Though a number of institutions have promoted LCA tools, such as the International Living Future Institute (ILFI) and tools such as EC3, the lack of standardized, industry-wide LCAs tailored specifically for assessing embodied carbon in buildings poses significant impediments to accurate evaluations. In response to these challenges, the launch of the Embodied Carbon Harmonization and Optimization (ECHO) Project in 2023 signals a collective effort to address these issues. This collaborative initiative aims to ensure uniformity in embodied carbon reporting across the United States, encompassing both whole building and project scales. However, it focuses largely on new construction, and the realization of its full potential remains contingent upon overcoming existing barriers to collaboration and standardization within the industry (Carbon Leadership Forum 2023). As noted above, in the absence of a national consensus, Columbia should adopt one metric for institutional consistency.

Acknowledgements

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https://www.arch.columbia.edu/student-work/13596-the-carbon-investment-of-historic-buildings-embodied-and-operating-energy-in-the-preservation-of-the-columbia-campus

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