THE CARBON INVESTMENT OF HISTORIC BUILDINGS

EMBODIED AND OPERATING ENERGY IN THE PRESERVATION OF THE COLUMBIA CAMPUS

Historic Preservation Studio II - Spring 2024
Columbia University Graduate School of Architecture, Planning, and Preservation

COLUMBIA

GSAPP

HISTORIC
PRESERVATION

Columbia Climate School
Adapting the Existing Built Environment Network

CONTENTS

ACKNOWLEDGMENTS

This report was produced by Columbia University's Graduate School of Architecture, Planning, and Preservation (GSAPP). It compiles the findings from a semester-long Historic Preservation (HP) studio conducted in the spring of 2024 at GSAPP. This experimental studio focused on the concepts of embodied and operational carbon in the context of historic buildings, using Columbia University's campus as a case study.

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Students and faculty benefited from the insights and perspectives provided by representatives from various Columbia University entities, as well as external collaborators, professors, scholars, and professionals. The team would like to express their gratitude and acknowledge their contributions:

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Students and faculty especially wish to thank:

Lori Ferris, who taught a workshop for the studio team and provided insights to students on the use of the Carbon Avoided Retrofit Estimator Tool (CARE Tool);

Christoph Meinrenken, who taught a session on life cycle assessment (LCA)

Lynnette Widder, whose research with Christoph Meinrenken on historic embodied carbon served as an inspiration for the studio ("Three Windows: Accounting for Embodied Resources and Cultural Value," in Rahman Azari, ed., The Routledge Handbook on Embodied Energy in the Built Environment. Routledge, 2023)

Eleanor Phetteplace, who so generously shared her thesis research, "Guidance for Calculating Embodied Carbon Emissions from Structural Interventions for Existing and Historic Buildings."

The studio team extends its gratitude to Columbia colleagues who lent time and support to the studio, including the faculty at-large of GSAPP, especially Profs. Jorge Otero-Pailos, Andrew Dolkart, Françoise Bollack, Norman Weiss, David Benjamin, and especially Prof. Bilge Kose, whose assistance with the ArcGIS mapping was indispensable.

The studio team wished to thank Nicolás Moraga and Judy Wang for the graphic design of the report.

Historic Preservation Studio II (2024) in Columbia University Campus. Photo by Andrew Dolkart.

Low Library, Columbia University Campus, 2024. Photo by Frederick.

INTRODUCTION

As part of the Spring 2024 Historic Preservation Studio II, students enrolled in Columbia University's Graduate School of Architecture, Planning, and Preservation (GSAPP) studied historic buildings and their relation to embodied carbon, operating carbon, energy efficiency, and preservation.

In the current climate crisis, preservation discourse has largely focused on how climate change threatens heritage. This studio asserts that the preservation enterprise has an affirmative obligation to examine how historic buildings may both contribute to and potentially mitigate climate change. The research and report focus on carbon emissions associated with the built environment because they constitute an urgent issue with global impact. The emitting of carbon and other greenhouse gases directly contributes to more frequent and intense climatic conditions, including sea level rise, storms and precipitation, inland flooding, wildfires, desertification, and more.

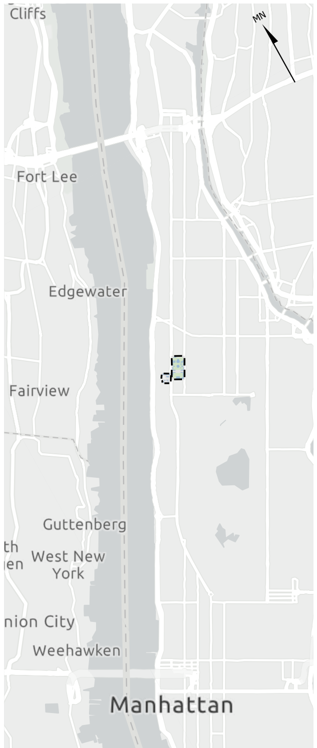
As such, the studio examined the relationship of energy and carbon emissions, over the lifecycle and history of construction, maintenance, preservation, retrofitting, and adapting historic buildings. This report documents that research and explores potential trade-offs and pathways for future action toward energy efficiency and net-zero carbon emissions. It aims to frame and inform preservation research and action focused on issues of energy consumption and carbon dioxide emissions in relation to the climate crisis.

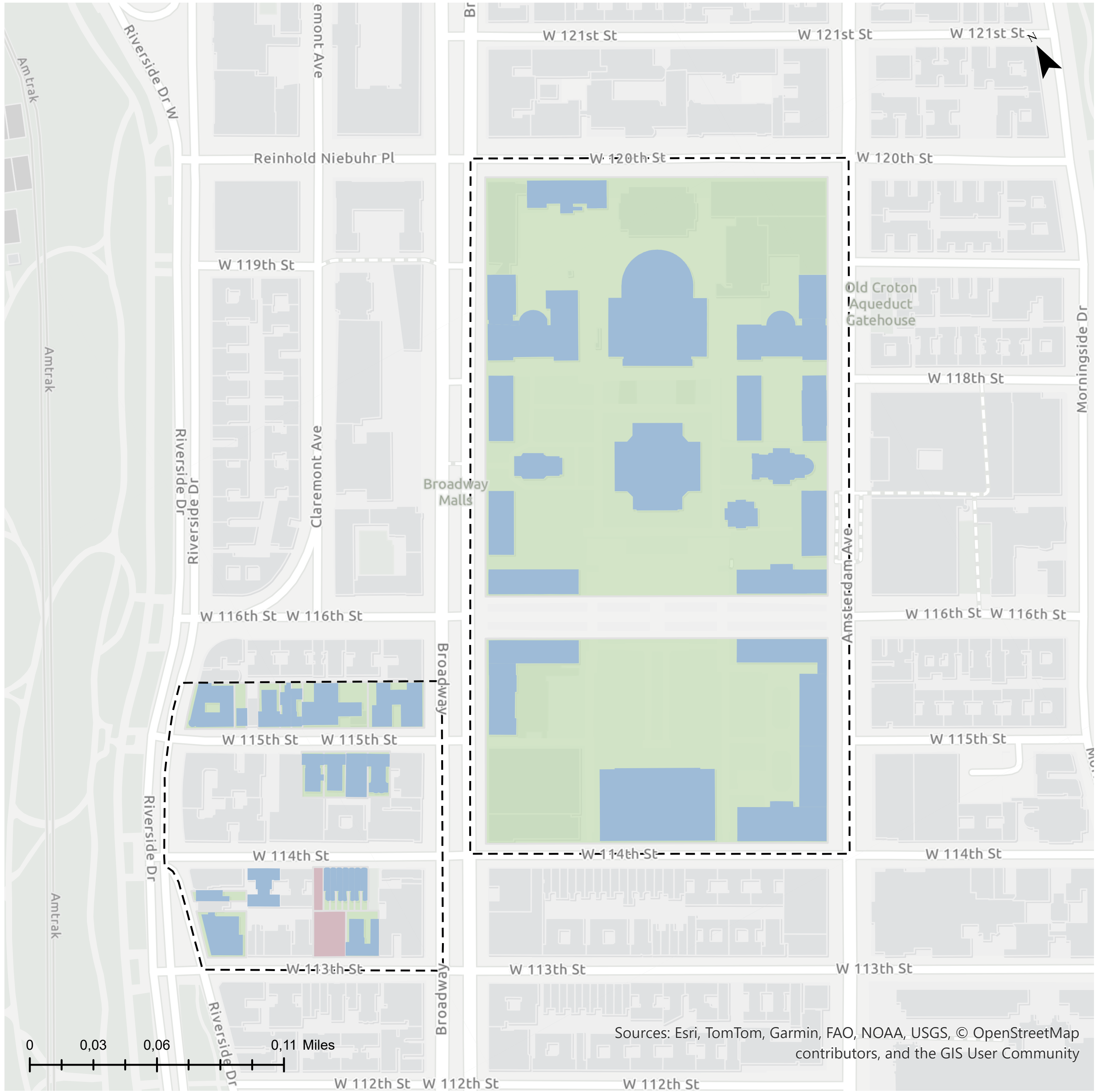
THE STUDY AREA

The Columbia University Morningside Campus and its environs served as the study area and a didactic experimental case for interrogating carbon and the historic built environment. The Columbia Campus and what the studio team refers to as the "West District" are characterized by numerous historic properties owned and operated by the university, including New York City landmarks and historic districts, as well as National Register-listed and -eligible buildings and districts.

New York City is home to the first greenhouse gas law in the country, and Columbia University has set even more ambitious decarbonization targets at the institutional level. The University is one of the largest private property owners in the city; it occupies over 15.5 million square feet of built area and that number is increasing with new construction in Manhattanville. As the university implements a campus transition toward electrification and the use of renewable energy sources, the buildings in the Studio's study area will undergo significant retrofitting to reduce energy consumption and carbon emissions. Replacement of buildings may also be considered. The historic campus thus serves as a timely and relevant locale to study the relationship of carbon and existing buildings, and to explore how preservation research and action can address energy consumption and carbon emissions.

Columbia University Campus, 2024. Photo by Frederick.





STUDIO AREA MAP

Legend

Columbia Owned Buildings in Studio Area.

Columbia Owned Lots (Parking or Empty) in Studio Area.

Columbia Owned Lots (with Buildings) in Studio Area

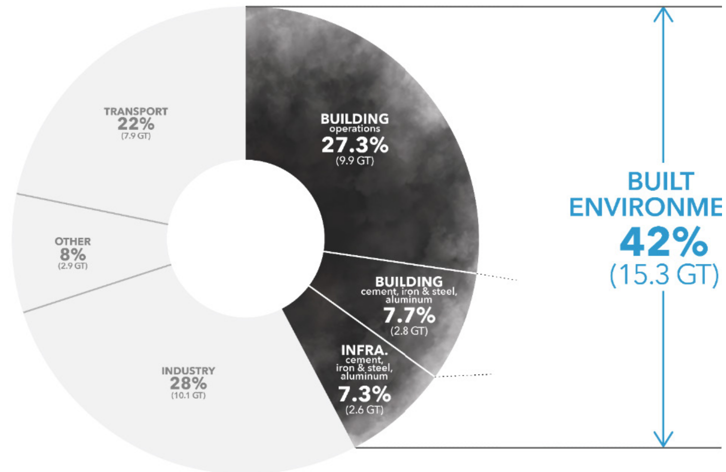
Studio Area Boundary

Columbia University Campus, 2024. Photo by Frederick.

CARBON AND BUILDINGS

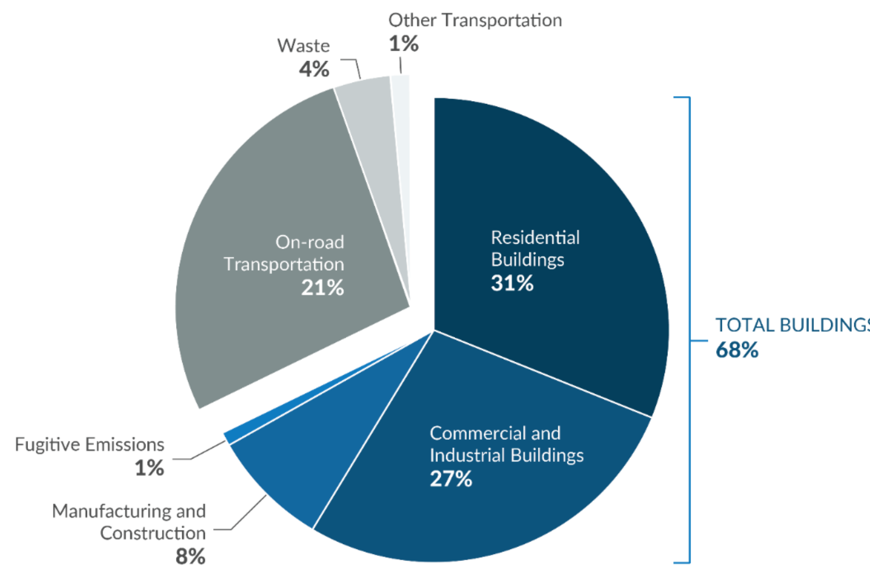
The wider context of climate change and how the building sector relates to this global problem frame the context of this study. Climate change is exacerbating extreme weather events all over the world and intensifying rising sea levels, wildfires, heavy precipitation and flooding, and desertification and droughts. At the root of the problem are greenhouse gases, most notably carbon dioxide emissions—or carbon emissions—which are created by the burning of fossil fuels. From 1950 to 1990, carbon emissions nearly quadrupled. And since then, global carbon emissions have continued to surge. As a result, the current concentration of carbon dioxide in Earth's atmosphere is higher than any in the last 2 million years.

Globally, forty-two percent of all global carbon emissions are attributed to the built environment. In New York City, the numbers are even more staggering. Currently, the building sector in New York City is responsible for sixty-eight percent of all of the city's carbon emissions. To avoid catastrophic climate disasters, we must reduce carbon emissions to zero as fast as possible.



Total annual global CO_2 Emissions, globablly. Source: Architecture 2030.

Pedestrians pass One World Trade Center in NYC as the air is filled with smoke from wildfires in Canada. June 2023. Source: latimes.com. Author: Julie Jacobson / Associated Press).



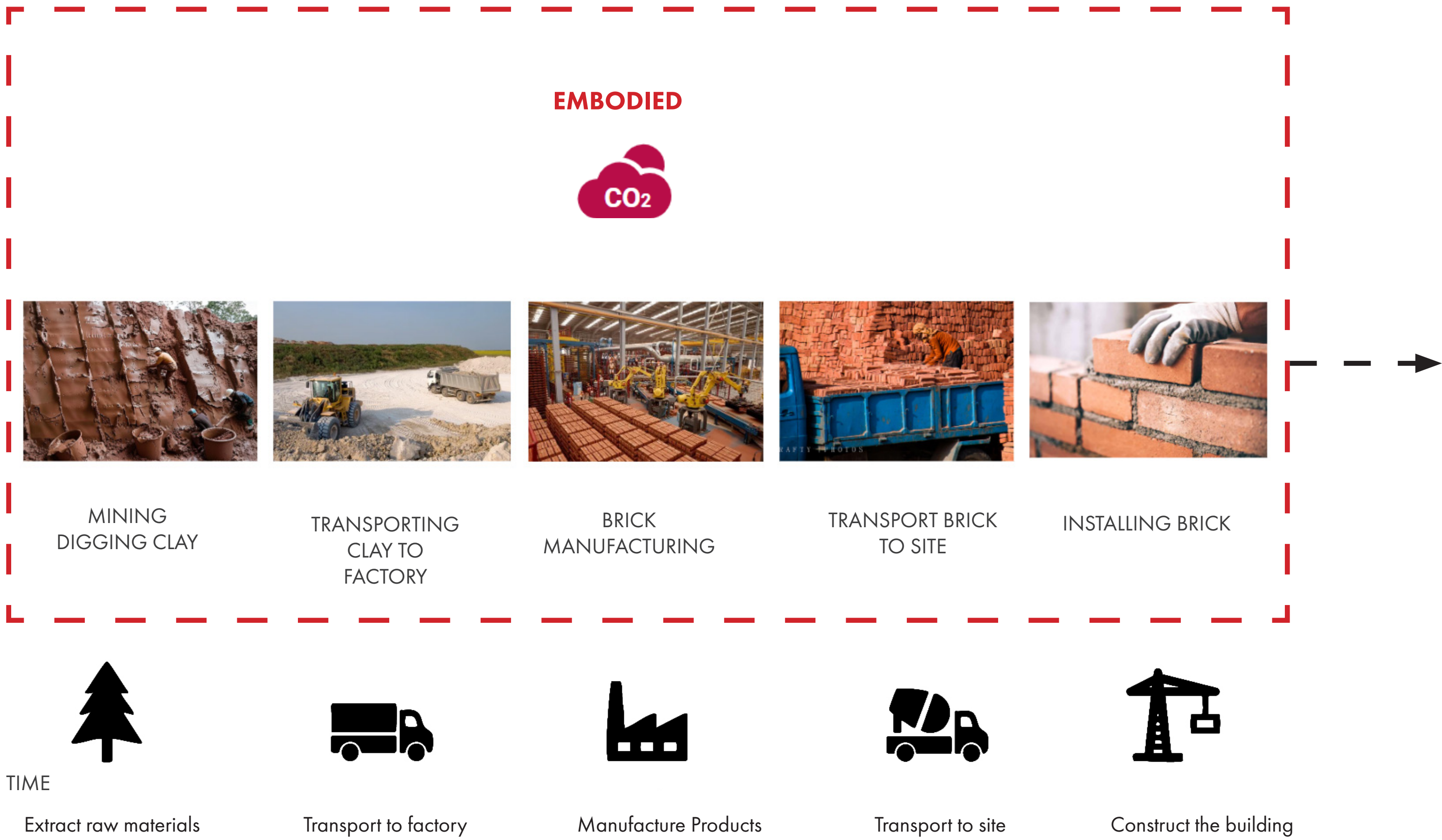
Buildings account for 68% of all carbon emissions in NYC, according to NYC Mayor's Office of Sustainabilty.

BRICK: ILLUSTRATING EMBODIED CARBON

Carbon emissions begin with product manufacturing. For brick, this is the mining and digging of clay, transportation of the raw materials to the factory and then manufacturing. Each of these steps emits carbon and is added to the embodied carbon total. As the bricks are transported to a site and a building is constructed, more embodied carbon is emitted. With every building component replacement and repair over time, embodied carbon emissions recur and accrue.

If a building is decommissioned, the carbon emitted during demolition, transport of waste brick, and the process of recycling or landfill disposal is also added to the total embodied emissions.

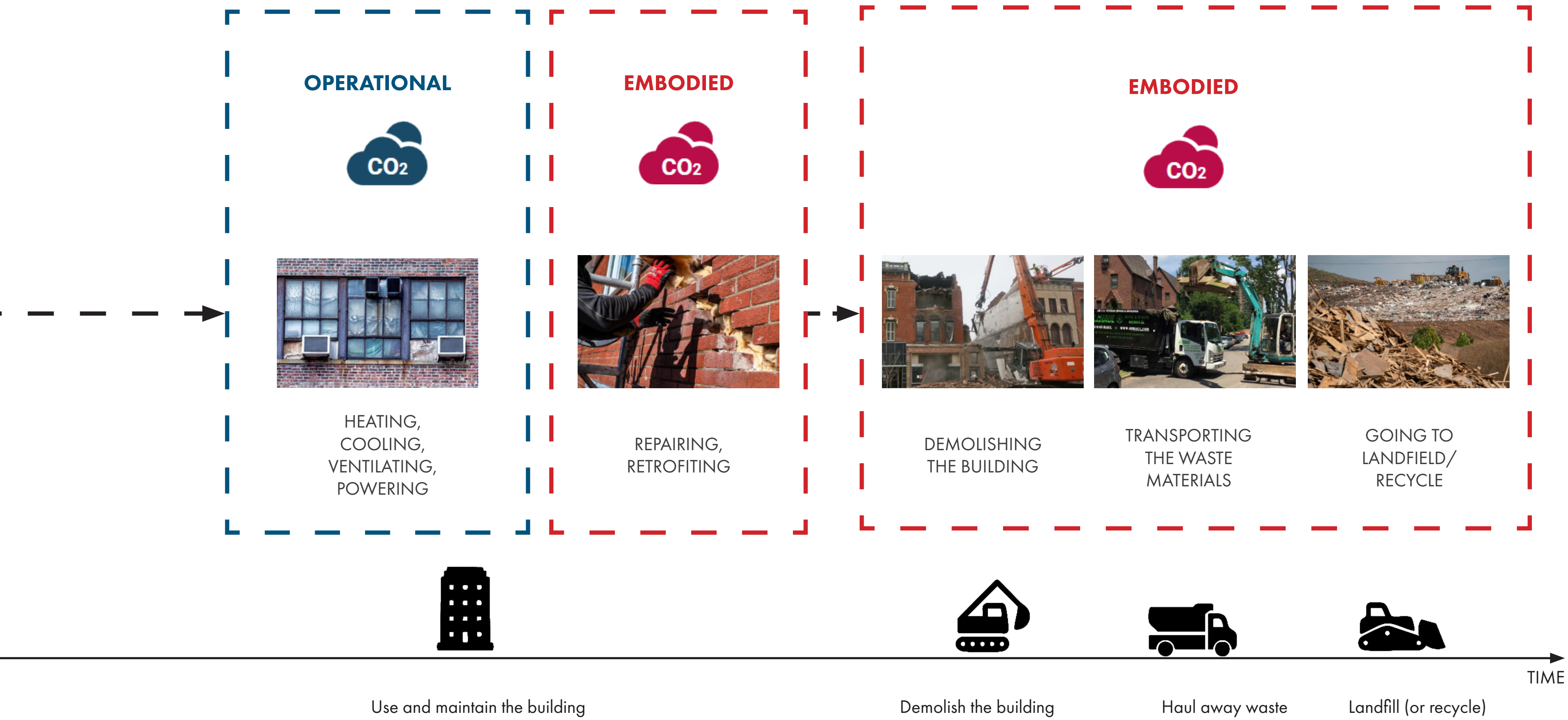
Avery Hall, Columbia University.



By the end of life, the brick has accrued the largest amount of embodied carbon making a very strong case for material reuse and recycling, which will be addressed elsewhere in this report.

A significant amount of embodied carbon expended at and before construction. This is referred to as initial embodied carbon (shown in red in the accompanying graph). Once a building is in use, operational carbon (shown in gray) accrues. With significant renovations and replacements, additional embodied carbon accrues. These building interventions are typically smaller emitters of carbon and known as recurrent embodied carbon.

At present, policy in New York City and at Columbia University is focused almost exclusively on reducing operational carbon. But we need to reduce both operational and embodied carbon to reach Net Zero and avoid catastrophe.



CARBON IN A BUILDING'S LIFE CYCLE

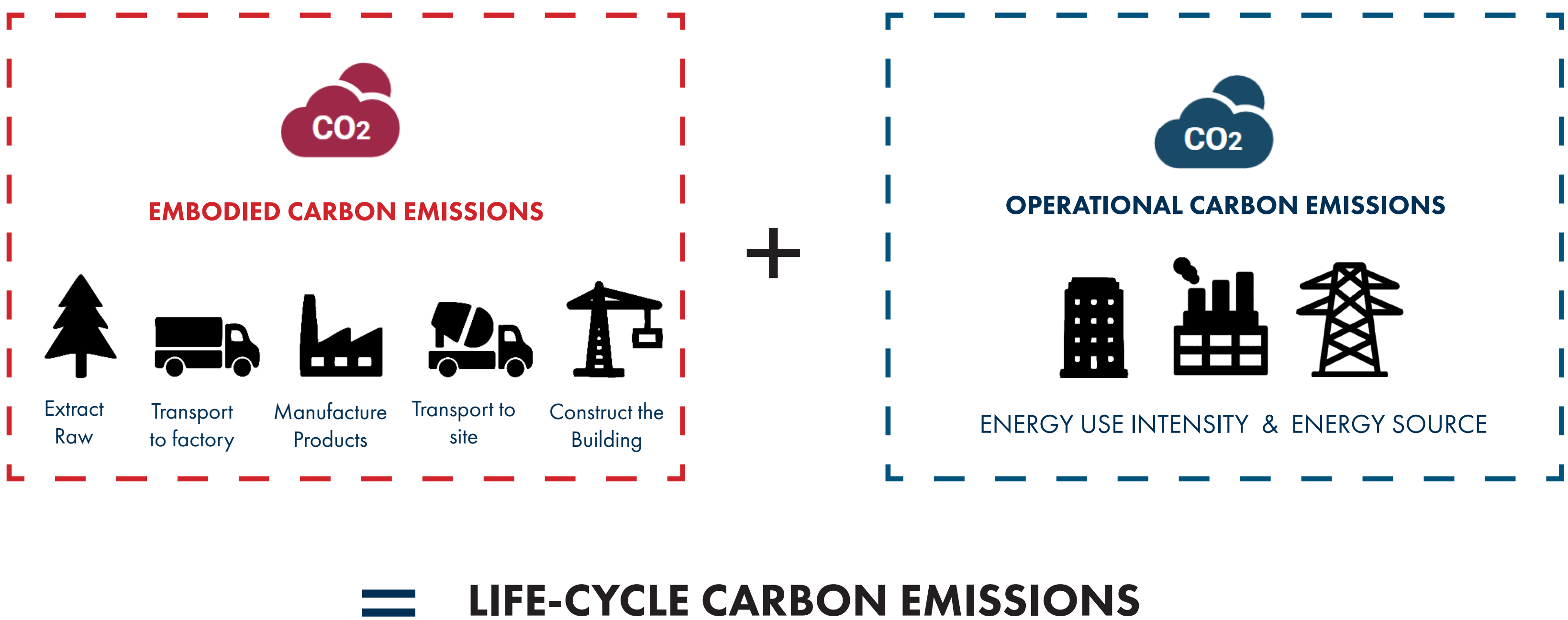
Carbon is emitted across a building's life cycle, from material extraction to construction to use and maintenance to end-of-life demolition. There are two types of carbon emissions: embodied carbon and operational carbon.

Embodied carbon is produced during the extraction of raw materials, the manufacturing of materials into building products, the transportation of those materials to the site, the construction of the building, the periodic maintenance, repair, and replacement of building elements, and when applicable, the eventual demolition at the end of a building's life.

Operational carbon is emitted only while the building is in use, and refers to the emissions associated with the heating, cooling, ventilating, lighting, and powering of buildings. Measuring operational carbon is generally a more manageable calculation, made easier because most buildings in the US are already equipped with management systems and meters to calculate energy usage, which can be converted to carbon emission.

While studies vary on the breakdown between operational vs. embodied carbon over the life cycle of a building, while energy continues to be generated largely from the burning of fossil fuels, operational carbon accounts for the majority of a building's carbon emissions. This fairly direct relationship between energy use and operational carbon will decouple with transitions to renewable energy.

Embodied carbon calculations are more complex. To better understand the layers of embodied carbon, the team selected one common building material from this study, brick, to didactically outline how embodied carbon accrues over the life cycle of a building.

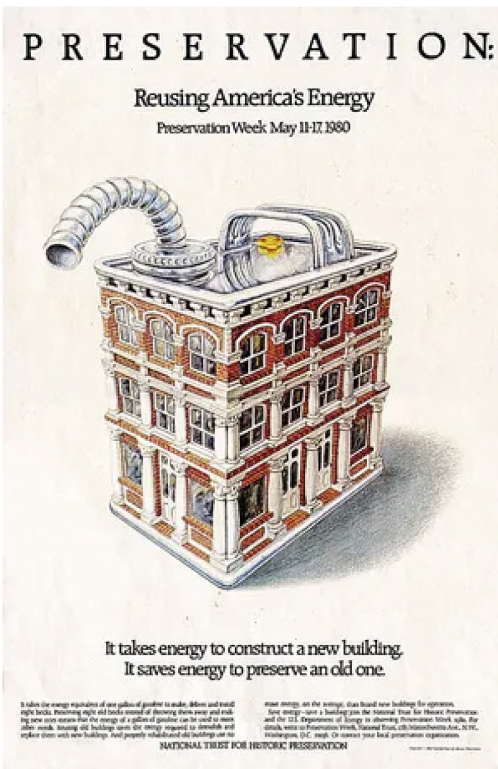


A building's carbon footprint over its lifespan is the sum of its embodied plus operational emissions.
Source: Globalabc.org. Adapted from Madwood et al. 2021.

DECARBONIZING EXISTING BUILDINGS

This process of reducing both operational and embodied carbon emissions in buildings is called decarbonization. There are three primary pathways to reduce the carbon emitted by buildings: increasing energy efficiency, reducing operational carbon, and reducing embodied carbon.

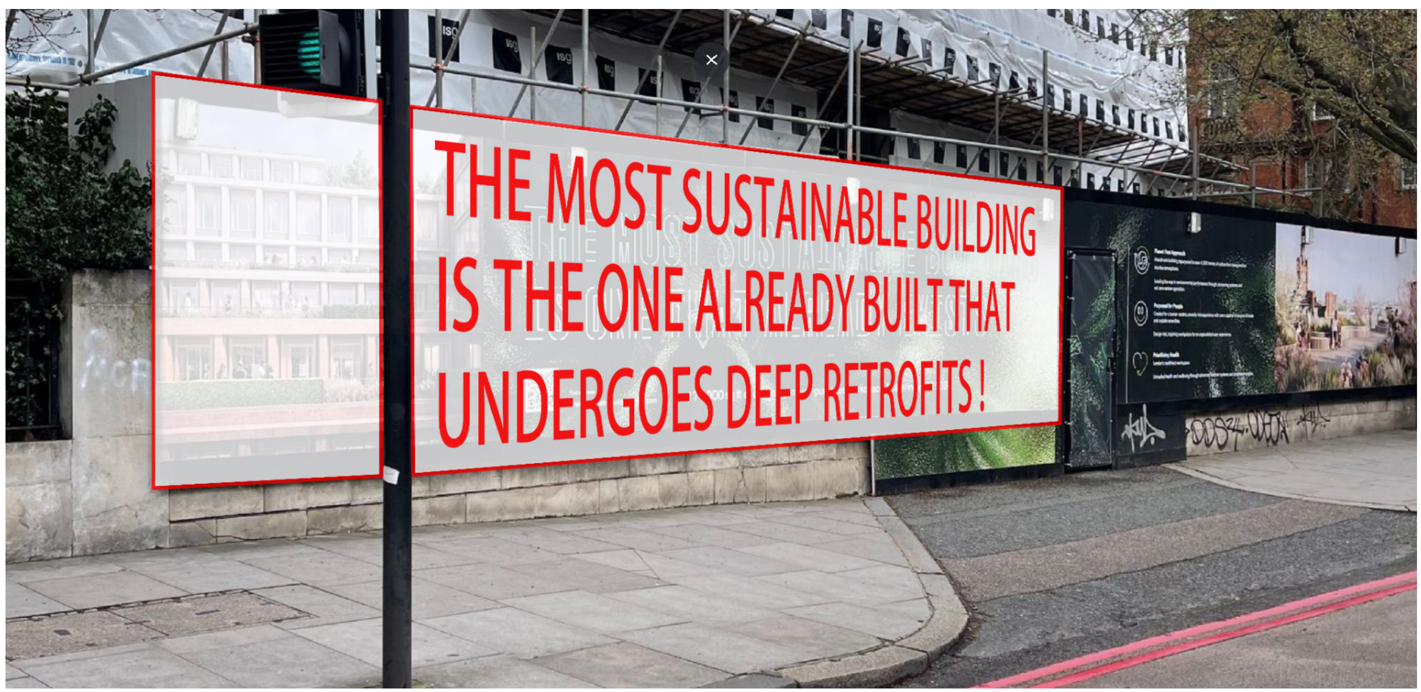
For some preservationists, the term embodied energy may be more familiar than embodied carbon. This National Trust poster from 1980 is an example of how preservationists have been promoting building reuse and energy savings for many decades. Within the context of the energy crisis of the 1970s and 80s, strong messages were being used to recognize existing buildings as repositories of energy.



Preservation Week Poster, May 1980. Source: National Trust for Historic Preservation

> "Preservation saves energy by taking advantage of the nonrecoverable energy embodied in an existing building, and extending the use of it."
>
> Advisory Council on Historic Preservation, 1979.

Today, a similar message is being used to advocate for building reuse, recognizing the carbon savings when we preserve a building rather than demolish and build new. The accompanying photo taken last month in London, shows an adaptive reuse project declaring, "The Most Sustainable Building is the One that Already Exists" to market its new condos. However, this studio challenges that longstanding assumption by asserting that the most sustainable building is NOT the one that already exists but rather the one that exists and also undergoes deep energy retrofits to reduce operational carbon and avoid recurrent embodied carbon



Condominium advertisement in London noting “the most sustainable Building is one that already exists” This research advocates for a shift in this premise: “The most sustainable building is the one already built that undergo deep retrofits”. Image and photomontage by A.M. Foster, London 2024.

Columbia University Campus, 2024. Photo by Frederick.

STUDIO METHODOLOGY

SCOPE AND LIMITS OF THE STUDY

This study is situated in a limited area of the Columbia campus and its environments in Morningside Heights. The precise boundaries of the study area were defined by faculty to keep the study manageable within the limited timeframe, and to include a range of building typologies.

With some exceptions, the studio focused on historic buildings that are locally designated or National Register-listed or -eligible. Therefore, data was not collected for every building within the study area. The studio's "building set" included 47 buildings, two vacant lots, and two demolished buildings. These properties encompass a wide array of construction typologies, building uses, policy adherence, and other conditions relevant to the study of energy and carbon. This represents a small yet representative sample of Columbia University's building portfolio.

Columbia University has a very rich architectural history. A wide array of literature is available on this subject, much of which was utilized by the studio during the historical context assessment. This report is not meant to provide a comprehensive or detailed description of the historical development of the campus. The historical context assessment provides only background information that is directly pertinent to the research on carbon and energy.

RESEARCH PROCESS

This report is a culmination of collaborative work completed over the course of a semester. Students were divided into small groups for each phase of research: policy assessment, historical context assessment, and building case studies. Students worked across groups to synthesize information into a set of key findings and recommendations.

Sources utilized during the research process include legal policies and regulations; books on Columbia's history; historical newspapers and photographs; energy and carbon reportings; archival documents and drawings; interviews; and physical observation of buildings.

Legal policies and regulation. Several policy frameworks exist at the institutional, local, and state level. These include Columbia University's Plan 2030, New York City's Local Law 84 and 97, and the New York State Energy Conservation Code, among many others. These policies were critically and comparatively analyzed for their potential implications on the historic built environment.

Books and historical literature. Several texts were consulted for historical context assessment. Three sources were particularly helpful: Andrew Dolkart's Morningside Heights: A History of Its Architecture & Development (1998), Robert McCaughey's Stand, Columbia: A History of Columbia University (2003), and the semester report previously completed by Columbia's Spring 2019 Historic Preservation Studio, The Columbia Community: Promoting Inclusion Through Preservation (2019).

Historical newspapers, photographs, archival documents and drawings were consulted relating to individual buildings and the area at large. Several of these sources were available online, while others were accessed through the Avery Architectural Library's Drawings and Archives department, the Columbia University Archives at the Rare Book & Manuscript Library, and the New York City Historical Society archives.

Energy and carbon data were accessed primarily through NYC Open Data, based on the mandatory reporting requirements of Local Law 84. Some energy usage data was generously provided by Columbia Facilities & Operations, such as retro-commissioning reports and building meter data.

Physical observation of buildings was completed throughout the semester for both exterior and interior conditions. Columbia Facilities & Operations arranged guided building tours for each of the case study buildings. The studio team was interested in identifying character-defining features, alterations, mechanical systems, and occupant use and accessibility.

Much of this information was further imported into spreadsheets, ArcGIS maps, and computer-aided design software such as AutoCAD and Rhinoceros 3D for further analysis.

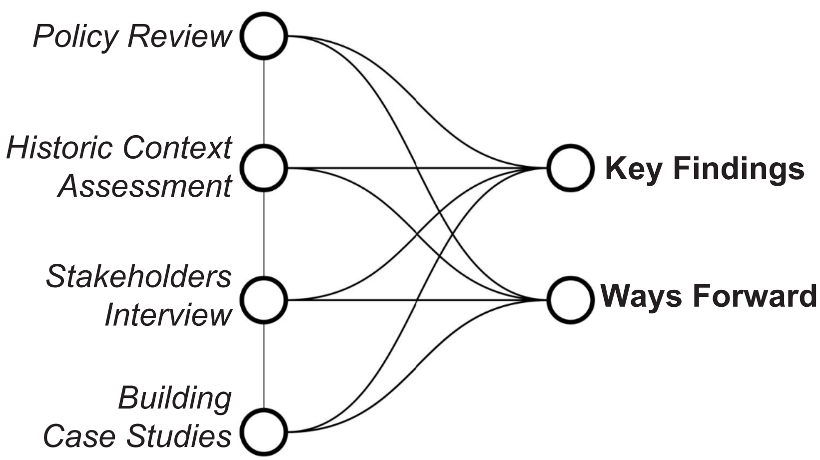


Diagram of workflow of studio´s methodology. Source: Studio II.

Students visiting Saint Paul Chapel Dome's for a On-field Survey. Photo by Tim Michiels, 2024.

STAKEHOLDER INTERVIEWS

Completing stakeholder research was crucial to developing an understanding of how New York City at large is currently addressing building-related carbon emissions, as well as the current discourses and gaps in knowledge that will affect future decisions. Students identified relevant stakeholders at Columbia, including policymakers, communicators, facilities managers, and advocacy groups. Beyond Columbia, these included government policymakers and regulators; policy researchers and educators; and technical researchers and educators.

The guiding questions of the interviews also fell within themes. The questions addressed topics of operational and embodied carbon, energy, fuel systems, and building retrofits. These questions were tailored to learn more about these topics from both a broad and granular level of detail. As a non-exhaustive list, the studio gained useful information about calculation methods for carbon, issues of data access, developing expertise and pedagogy around energy and carbon, and other challenges and opportunities in the realm of decarbonization.

In total, the studio collected information from 23 individuals, representing 16 different organizations. This unique research phase does not constitute an individual chapter of this report. Instead, findings from all 16 interviews are integrated throughout the report.

RESEARCH CONCLUSIONS

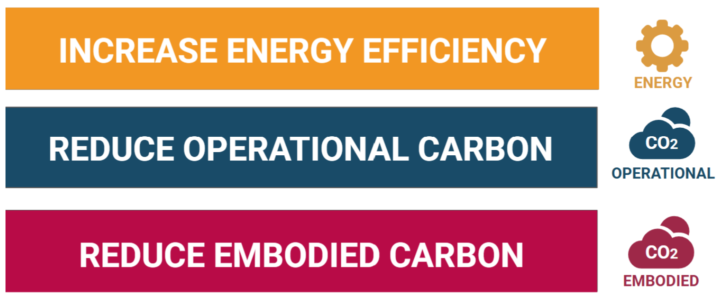
The "Key Findings" and "Ways Forward" sections of this report comprise the studio's primary takeaways from a semester's worth of research. In these sections, the studio team identify challenges, opportunities, and recommendations for both Columbia University and preservation professionals in furthering the decarbonization of existing buildings. These conclusions were also informed by a four-hour final studio review, which included a student presentation to and dialogue with an audience of Columbia Facilities & Operations staff, preservationists, and carbon and energy experts based in New York City.

Wien Reading Room at Butler Library, Columbia Campus. 2024. Photo by Frederick.

POLICY REVIEW

POLICY REVIEW

Amid the landscape of rapidly changing energy policy relating to decarbonizing the existing built environment, expanding discussions of compliance have led to urgent reconsiderations of how buildings are managed and the need to retrofitted them. The buildings selected as case studies for this report must comply with various levels of government and institutional policies that aim to reduce greenhouse gas emissions and increase the energy efficiency of buildings. Thus, this policy review examines climate policies that pertain to the built environment at the state, local, and institutional levels, which collectively influence Columbia University's actions in preserving, renovating, and retrofitting its building portfolio toward decarbonization. Please note that an expanded policy review section is included in Appendix A.



Policy Pathways to Decarbonization. Source: Frederick, 2024.

At governmental and institutional levels, there are three main policy pathways toward decarbonization:

- Energy efficiency policies to reduce energy consumption
- Operating carbon policies to reduce greenhouse gas emissions
- Embodied carbon policies to avoid carbon impacts and promote more circularity in construction, demolition, and renovation (Avrami, Most, Gasha, and Ghoshal 2023).

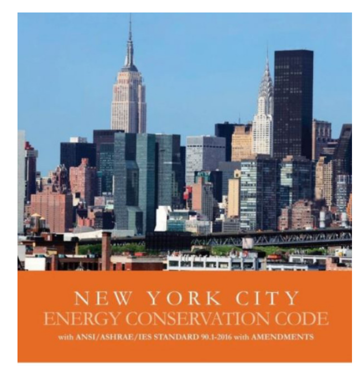
This section briefly evaluates these three areas, analyzing how energy and carbon reduction goals are addressed, which areas may be underrepresented by current policy, and implications on the built environment.

ENERGY EFFICIENCY AND HISTORIC BUILDINGS

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. However, the energy regulations outlined in these codes often feature significant exemptions for historic buildings.

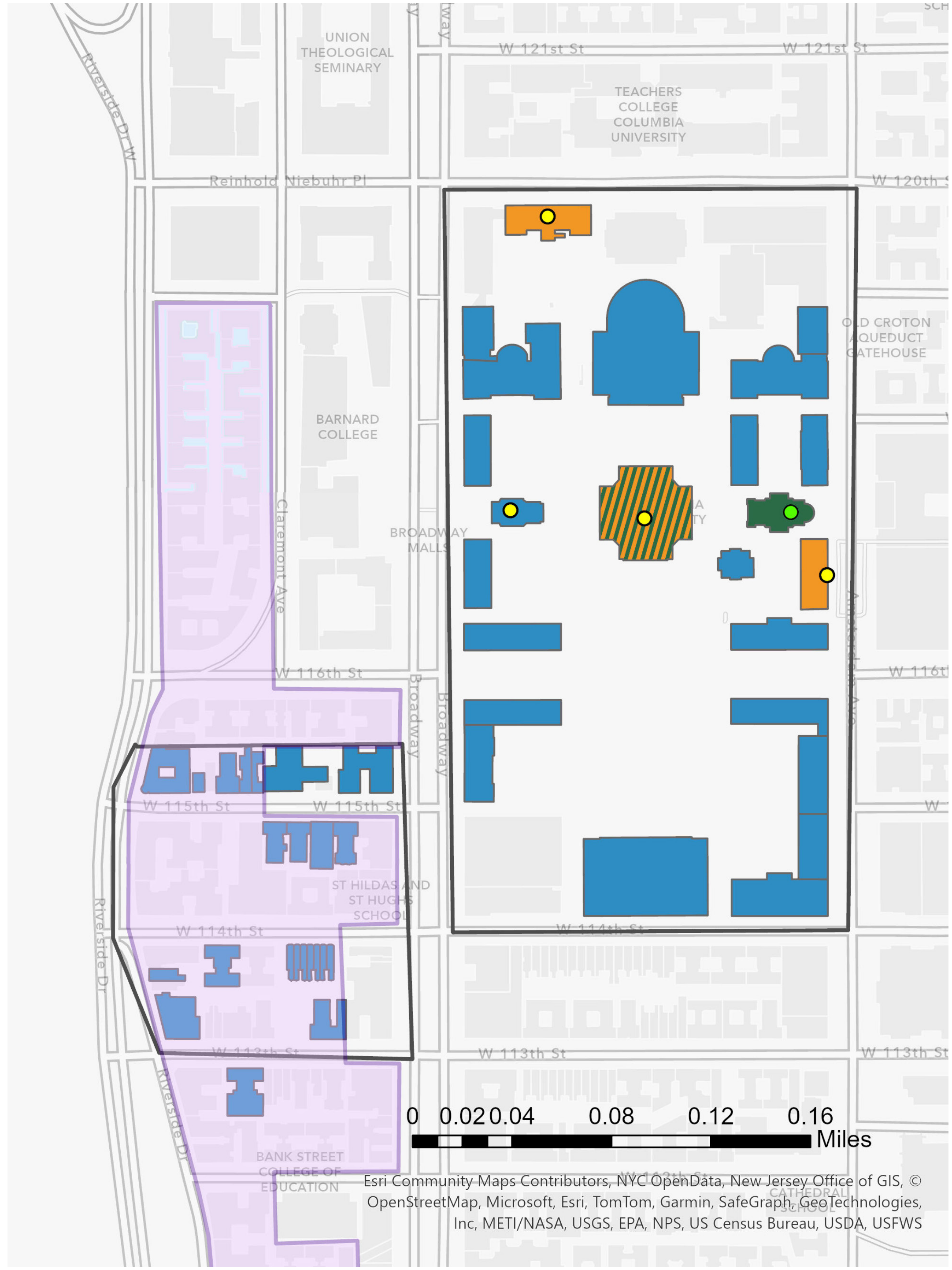
Historic buildings, namely National Register-listed and -eligible buildings, are exempt from energy codes in New York State and City. These exemptions date back to the 1970s when preservationists argued that complying with energy codes would adversely affect the architectural and material integrity of historic buildings and, using very limited data, claimed that older buildings were inherently more energy efficient (Avrami, Most, Gasha, and Ghoshal 2023).



Energy Codes to promote efficency (State and Local Laws). Left, NY State Energy Code (NYS DOS, 2019) and NYC Energy Conservation Code (Intelligreen Partners)

Map Legend. Studio II Building Designation Selection
National Register Status.

- Eligible for the National Register
- Listed on the National Register
- National Register Eligible and NYC LPC Historic District
- Studio Area Boundary
- NYC LPC Designated Building and National Historic Landmark
- NYC LPC Designated Building
- National Historic Landmark
- Columbia Owned Buildings in Studio Area



HOW DO NEW YORK STATE AND CITY DEFINE HISTORIC BUILDINGS?

The Energy Conservation Construction Code of New York State provides historic buildings exemptions from certain provisions that consider construction, repair, alteration, restoration and movement of structures, and change of occupancy (Kaminsky 2021). So, how does the state define historic buildings? The term 'historic building' is defined in state code as an existing building or structure that:

- Is listed in the New York State Register of Historic Places, either individually or as a contributing building to a historic district.

- Is listed in the National Register of Historic Places, either individually or as a contributing building to a historic district.

- Determined to be eligible for listing in either the New York State Register of Historic Places, either individually or as a contributing building to a historic district, by the New York State Commissioner of Parks, Recreation and Historic Preservation.

- Determined to be eligible for listing in either the New York State Register of Historic Places, either individually or as a contributing building to a historic district, by the U.S. Secretary of the Interior.

In New York City, historic buildings that are exempt from the New York City Energy Conservation Code (New York City 2009b) are similarly defined as buildings that are:

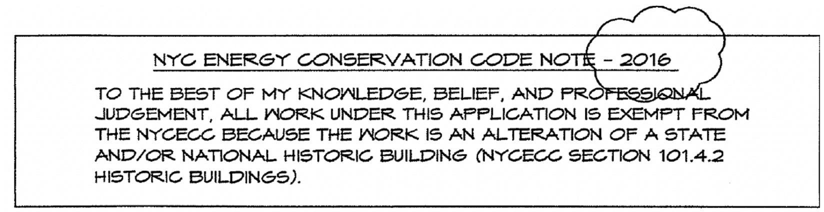
- Listed in the National or State Register of Historic Buildings.

- Designated as historical property under state law.

- Designated as a contributing source for a Historic District on the National Register of Historic Places, and/or,

- A contributing source that is supported by State Historic Preservation or Keeper of the National Register of Historic Places.

Importantly, buildings only designated by the Landmarks Preservation Commission are not exempt from New York City energy code.


NYC ENERGY CONSERVATION CODE NOTE - 2016

TO THE BEST OF MY KNOWLEDGE, BELIEF, AND PROFESSIONAL JUDGEMENT, ALL WORK UNDER THIS APPLICATION IS EXEMPT FROM THE NYCECC BECAUSE THE WORK IS AN ALTERATION OF A STATE AND/OR NATIONAL HISTORIC BUILDING (NYCECC SECTION 101.4.2 HISTORIC BUILDINGS).

Excerpt from the renovation report for Saint Paul's Chapel at Columbia, illustrating how the exemption for historic buildings in the New York City energy code is used by architects when advising clients on retrofits. Source: WBMA, 2019.

Despite the high number of National Register buildings in Columbia's portfolio, the university voluntarily complies with the stringent energy code established in New York City. However, in some instances, like the recent repairs to St. Paul's Chapel design consultants claim the exemption for historic buildings to avoid more substantive retrofits.

OPERATIONAL CARBON

Transitioning from energy efficiency to operational carbon, building performance standards seek to reduce actual operational emissions and energy use of existing buildings over time, thus setting standards for carbon or energy.

Amid the backdrop of New York State's Climate Leadership and Community Protection Act of 2019, which establishes that the state must decarbonize the grid by 2040, New York City became a national leader by implementing the nation's first greenhouse gas emissions law, or Local Law 97, in the same year. The law establishes building performance standards through emissions reduction targets based on square footage that stipulates an approximate 40 percent reduction of operational emissions by 2030 and 80 percent by 2050 (New York City 2019). It also stipulates that buildings will be fined if they do not meet emissions reduction targets beginning in 2025. Historic buildings are not exempt from LL97 compliance.

LOCAL LAW 97: SUSTAINABLE BUILDINGS AND GREENHOUSE GAS EMISSIONS

Local Law 97 aims to drive deep emissions cuts from buildings, responsible for more than two-thirds of NYC's greenhouse gas emissions. The law places carbon caps on most buildings larger than 25,000 square feet — covering nearly 50,000 properties across NYC. The law aims to reduce aggregate greenhouse gas emissions from covered buildings by 40 percent by 2030 and citywide emissions by 80 percent by 2050 (New York City 2019).

There are three main categories of buildings that are covered by Local Law 97:

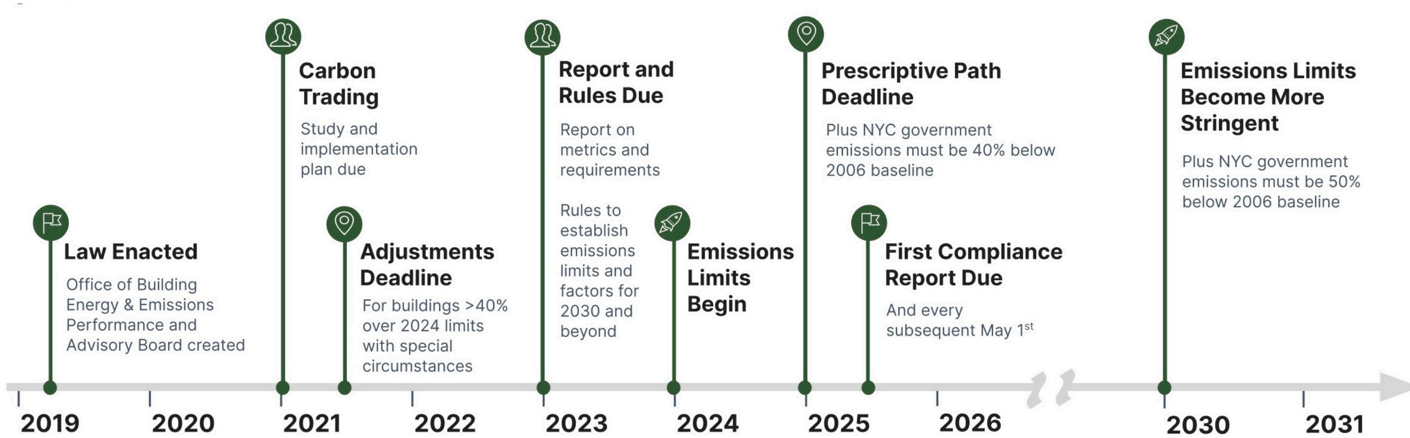
- A building that exceeds 25,000 gross square feet.

- Two or more buildings on the same tax lot exceed 50,000 square feet.

- Two or more condominium buildings governed by the same board of managers and that together exceed 50,000 square feet.

Alongside Local Law 97, the city also has a benchmarking law, Local Law 84/133, which requires building owners to annually measure and report their energy consumption and operational emissions, and Local Law 87, which requires owners to audit their energy usage and complete energy saving retrofits every ten years (New York City 2009a, 2009c). The case studies found later in this report utilize benchmarking data Columbia reported to the city for a range of analyses, alongside retro-commissioning reports completed for each building. Benchmarking, retro-commissioning, and audit regulations combine Energy Efficiency and Operating Carbon reporting.

Columbia Plan 2030 is Columbia's central and overarching institutional policy regarding energy efficiency, operating carbon, and (to a much lesser extent) embodied carbon. Plan 2030 is a ten-year strategic institutional plan running from 2021-2030 developed by Sustainable Columbia and other university entities. Its primary goal is to reach net-zero emissions for Columbia's New York campuses by 2050, using 2019 as the base year for calculating future emissions targets (Sustainable Columbia 2023). At an institutional level, Columbia has set an ambitious carbon reduction budget that is more stringent than the state and city-wide goals.



Local Law 97 Implementation Timeline. Source: The Urban Green Council.

LOCAL LAWS 84/133 AND 87: BENCHMARKING AND RETRO-COMMISSIONING

Passed concurrently in 2009, Local Laws 84/133 and 87 represent the minimum efforts owners must take to reduce the energy usage of their building portfolio, as mandated by the city. Local Law 84/133 requires building owners to measure their energy and water consumption annually through the Environmental Protection Agency's online benchmarking tool, Energy Star Portfolio Manager® (New York City 2009a). Local Law 87 requires owners to carry out retro-commissioning of base building systems. Critically, audits cover energy usage and suggested areas for improvement from an operating perspective (New York City 2009c). Though Local Laws 84/133 and 87 were initially implemented to improve energy efficiency through data collection and energy planning, these efforts ultimately impact operating carbon emissions. Local Law 84/133 data collection includes emissions reporting and therefore informs, through retro-commissioning, operating carbon over a building's life cycle.

Buildings required to comply with Local Law 84/133 and 87 are qualified as a "covered building" (New York City 2009a). The LL84/133 covered building criteria, included below, vary slightly from those of LL97:

- A building that exceeds 25,000 gross square feet
- Two or more buildings on the same tax lot that together exceed 100,000 gross square feet
- Two or more buildings held in the condominium form of ownership that are governed by the same board of managers and that together exceed 100,000 gross square feet, or
- A City building.

Property owners must enter and submit their usage data to the City by May 1st of every year. As stipulated by Local 87, energy audits must be conducted every ten years (New York City 2009c). Significantly, historic buildings are not exempt from complying with benchmarking and energy audits.

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.

COLUMBIA'S EMISSIONS REDUCTION STRATEGY

To reduce emissions, the university followed the greenhouse gas protocol established by the World Resources Institute, which 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 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 (Sustainable Columbia 2019a).

Although the performance of Plan 2030 is generally tracked against the base year of 2019, the campus-specific overall goals for greenhouse gas reduction are not divided among Columbia's three New York campuses. The Morningside+ Campus has a specific target of a 66 percent reduction from the 2006 base year by 2030; Columbia University Irving Medical Center also has a 66 percent reduction goal from the 2012 base year by 2030; and the Lamont-Doherty Earth Observatory has a 72 percent reduction from the 2016 base year by 2030 (Sustainable Columbia 2019b). The targets of percent reduction are meant to be tracked and publicly available in each annual report relative to their corresponding base year.

It is important to note that the emissions reduction targets of Columbia's Plan 2030 are based on percentage reductions of total emissions that do not account for expansions of the floor area of campus buildings. This stipulation effectively makes Columbia's reduction budget more stringent than LL97 requirements. In doing so, however, Columbia's campus area continues to expand. The NYC Department of Buildings notes that Columbia's Manhattanville project plan, though outside of this studio's study area, "would total approximately 6.8 million gross square feet above and below grade" in addition to the large campus that already exists and is trying to reach net-zero by 2050 (New York City Department of City Planning 2007).

Columbia University has set specific goals with detailed strategies in six key commitment areas. The content in these areas was developed by sustainability planning working groups with faculty, student, and administrator participation. Source: Sustainable Columbia.

To help achieve Columbia's ambitious emissions reduction targets, the university has also initiated a plan to begin to electrify the campus's central steam loop through 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 divides (e.g., radiators), ultimately running both in parallel until grid electrification necessitates a complete conversion to centralized HHW heat pumps. Partial building-level conversions will be completed campus-wide by 2040.

EMBODIED CARBON

Reducing operating carbon, improving energy efficiency, and regulating embodied carbon are intrinsically tied to achieving net zero. Primarily, discussions of embodied carbon focus on building level materials and structural systems. Though policies have not yet matured in New York State, at the city level, or at Columbia University, policy tools applied in other locales include deconstruction ordinances, recycling of construction and demolition waste, embodied carbon regulation through building codes (e.g. California), and incentives for building reuse (e.g. rehabilitation tax credits). Thus, the studio explored embodied and operational carbon – and their interdependence – in the selected case studies.

EMERGING GUIDELINES ON EMBODIED CARBON

Current local policies regarding carbon in the existing built environment only regulate the operating stage of a building's life cycle. In 2022, Mayor Eric Adams signed Executive Order 23, intended to promote life cycle assessment in new and extensive renovations of city-owned buildings. However, the city does not regulate the recycling of building materials in the construction process or require accounting for the life cycle of existing buildings in a retrofit or rehabilitation project (Urban Green Council 2016).

Building on Executive Order 23, in March of 2024, the New York City Economic Development Corporation (EDC) released an operational guide for capital construction projects titled Circular Design and Construction Guidelines. While only applicable to capital construction projects of the EDC, the guidelines aim to reduce embodied carbon and waste through three phases: one, preconstruction; two, procurement, construction, and renovation; and three, 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 consultants and contractors must "prepare a circular design and construction plan" and identify innovative procurement strategies for low-emissive materials (NYCEDC 2024). Though currently limited to NYCEDC, the circular design guidelines lay the groundwork for other entities with significant property holdings to develop guidelines for their capital construction. Very little policy is in place to regulate embodied carbon at the New York State level. To date, two state-level policies have begun to address the embodied carbon in new building materials. They do not address the embodied carbon of existing buildings.

Executive Order 22, signed by Governor Kathy Hochul in September 2022, partially requires calculating and reporting embodied carbon for four high-carbon materials specified for state-owned construction projects with contracts over $1 million. Beginning in August 2024, concrete, asphalt, steel, and glass specified for a state-owned construction project over a certain material quantity threshold must be reported. Executive Order 22 does not address or regulate embodied carbon calculations relating to existing building rehabilitation or end-of-life demolition. Since the studio, several additional New York State bills aimed at reducing embodied carbon in construction have been introduced.

The Low Embodied Carbon Concrete Leadership Act established guidelines for procuring building and transportation construction materials for New York State agency contracts. The guidelines are designed to become increasingly stringent, where in 2025, they will require additional scrutiny to track and measure the Global Warming Potential of the material. This is a small first step to incentivize and regulate embodied carbon of new building materials and only applies to state-owned projects.

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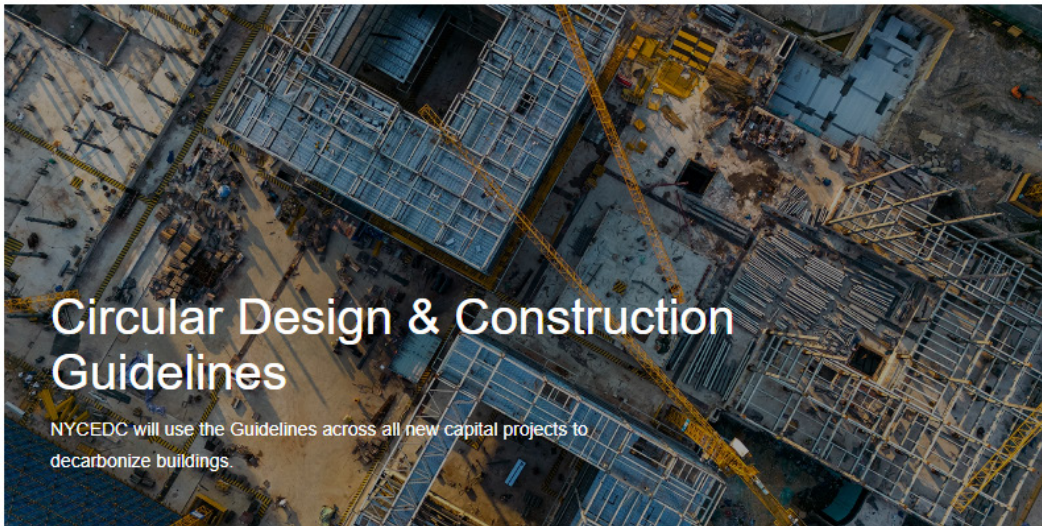


The Guidelines will:

- Reduce embodied carbon and waste within NYCEDC capital projects
- Develop knowledge and capacity across industry stakeholders
- Drive demand for cleaner and more circular design and construction across NYC

The Guidelines contain the following resources:

01 Circularity goals for project teams to work towards during design and construction

02 Required deliverables to document project teams' approach to circularity and track progress throughout a project's lifecycle

03 A series of strategies to guide project teams towards compliance

Circular Design and Construction Guidelines Webpage.

Columbia Campus. 2024. Photo by Frederick.

CASE STUDIES INTRODUCTION

CASE STUDIES

To better understand the study area and associated carbon concerns, both operating and embodied, of historic buildings, six Columbia University owned buildings were selected for further research from the initial 47-building study set, including Pupin Hall, St. Paul's Chapel, Avery Hall, Buell Hall, Alumni Center, and Schapiro Hall.

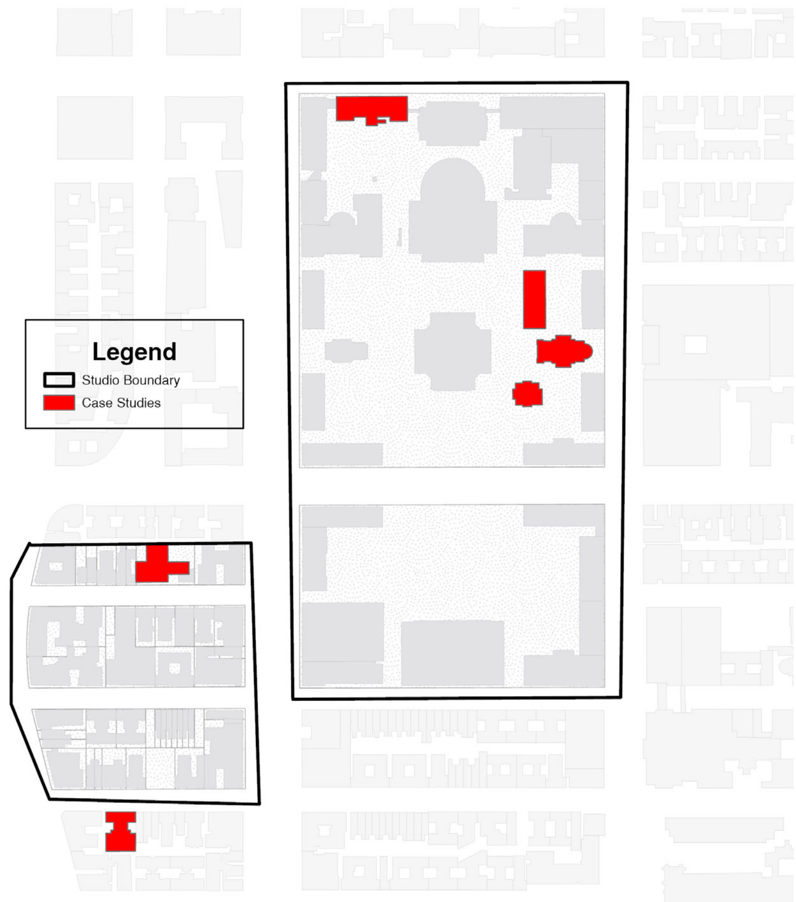
These buildings broadly represent different phases of Columbia's development from 1885 to 1987 (additional information about the historical development of buildings in the studio area can be found in Appendix D). Most of the buildings are heated by Columbia's own, on-campus thermal energy network, referred to as the steam loop, and all of the buildings have predominantly brick facades, although their structural systems vary.

OVERVIEW OF MATERIALS & TYPOLOGIES

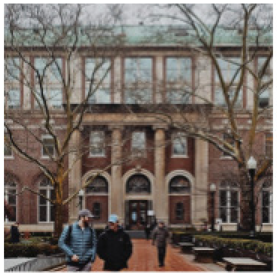
The six case study buildings are constructed primarily of the following materials:

• Brick and Mortar • Steel • Reinforced concrete • Timber.

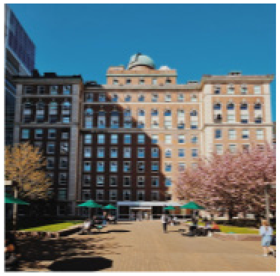
Additional character-defining materials include granite, limestone and copper. All six can be sorted into two structural typologies: load-bearing masonry and steel frame structures.



Map of Studio II Study Area with Case Studies in Red.
Author: Studio II Mapping Group



Avery Hall (1912)



Pupin Hall (1927)

Schapiro (1987)

Alumni Center (1906)

San Paul Chapel (1907)

Buell Hall (1885)

Selected Case Studies. Source/Photographer(s): Frederick 2024, Columbia Housing n.d., Alexander Severin n.d., Walter B. Melvin Architects n.d., Columbia GSAPP n.d.

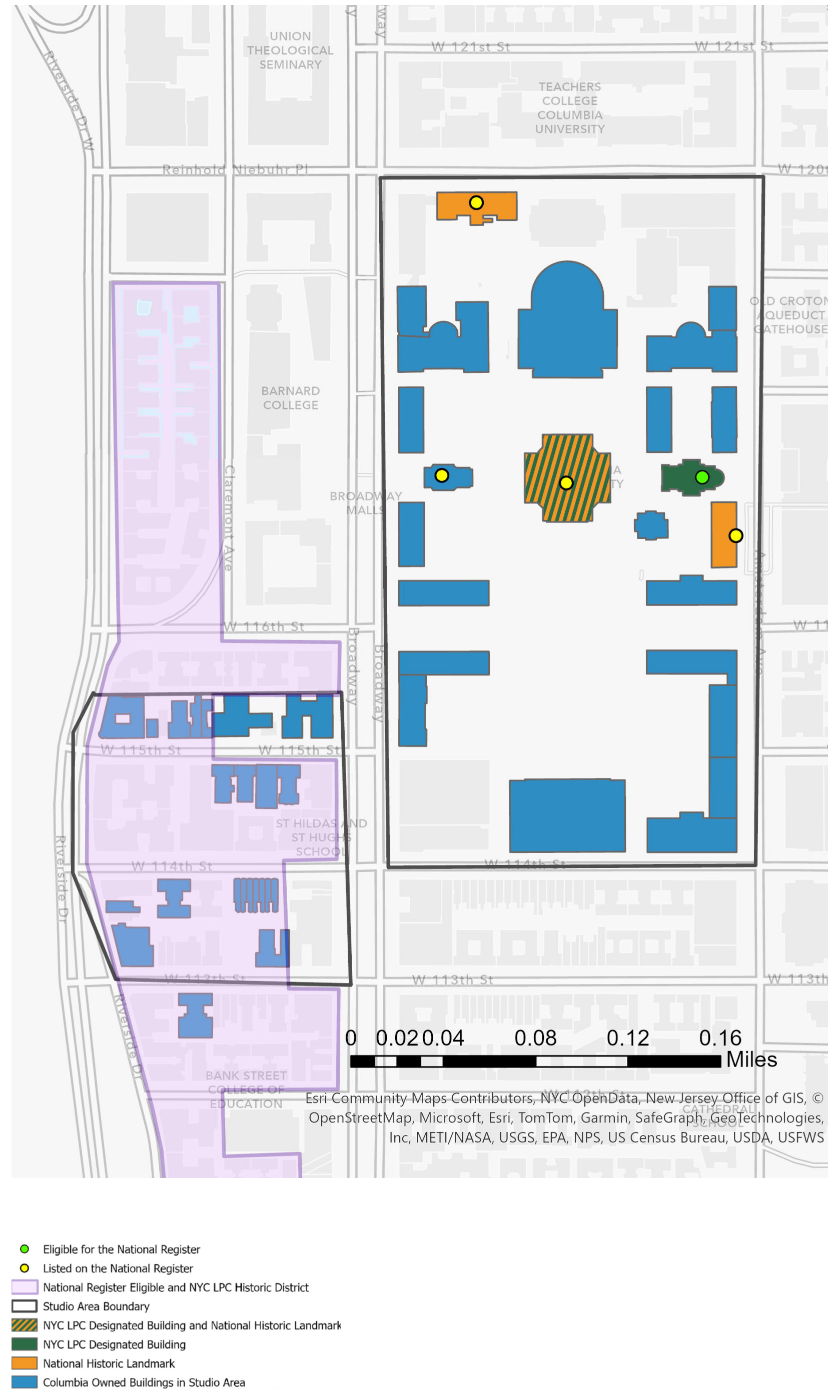
The Columbia campus and property portfolio includes a multitude of buildings that are National Register- listed or -eligible and within the National Register-eligible Broadway-Riverside Drive Historic District. Columbia also has two buildings that have received landmark designation from the New York City Landmarks Preservation Commission (NYC LPC), St. Paul's Chapel and Low Library (the rotunda of which is also an interior landmark), and a number of Columbia-owned buildings are located in the NYC Morningside Heights Historic District.

Historic recognition amongst the case study buildings include:

- Pupin Hall: National Historic Landmark and National Register-listed
- St. Paul's Chapel: NYC Landmark and National Register-eligible
- Avery Hall: National Register-eligible
- Buell Hall: National Register-eligible
- Alumni Center: within the National Register-eligible Broadway-Riverside Drive Historic District and the NYC LPC Morningside Heights Historic District
- Schapiro Hall: no historic recognition but sits on the lots of two demolished buildings that would likely have received the same historic recognition as Alumni Center if they had not have been demolished.

Two of the case study buildings are sited outside of Columbia's main Morningside campus: Schapiro Hall and Alumni Center. These two buildings were selected because they offered a unique set of questions that could be investigated through embodied carbon calculations.

Schapiro Hall, located on West 115th Street between Broadway and Riverside drive is a Columbia residential hall completed in 1987. As noted, Schapiro stands on the site of two new law tenement buildings completed in 1903 which were demolished in 1977. Alumni Center, located on 113th Street also between Broadway and Riverside, is a new law tenement completed in 1908 that underwent a LEED-Gold renovation in 2009. Alumni Center's LEED certification made it a good case study to investigate the insights that embodied carbon calculations might provide considering the contrast between the demolition of previous buildings and a LEED-certified renovation.



Studio II Buildings Historic Designations. Source: Studio II Mapping Group.

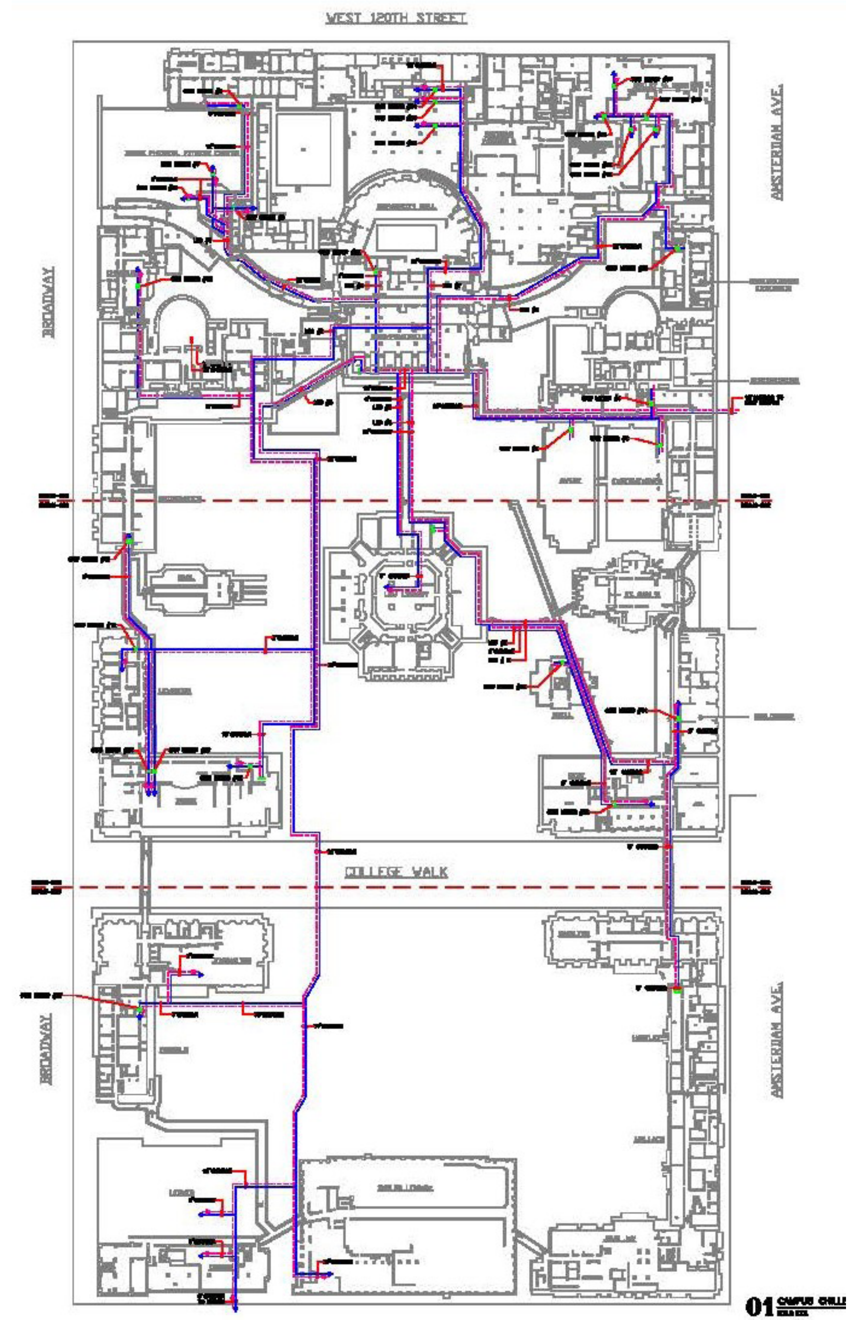
ENERGY DELIVERY AND THE STEAM LOOP

As a major research institution, Columbia requires cost-effective and reliable 24-hour air conditioning for a large number of buildings on its Morningside campus, as well as consistent heating during the cold seasons. Throughout the history of campus development, different energy sources have been used. At first, coal produced the university's electricity and steam; then diesel and finally natural gas and electricity as main power sources today.

Columbia operates its own power plant through a steam supply and distribution system. The main powerhouse is located within the superstructure, a complex of underground interconnected spaces under north campus area, that distributes chilled water and steam to all the campus buildings. Electricity is provided by Con Edison.

All of the case studies within the Morningside campus rely on this steam loop, as well as Schapiro Hall, which is located just outside the Morningside main campus. In the case of Alumni Center, the natural gas, oil, and electrical systems are independent of Columbia's own power plant.

Steam loop Control Room at the basement of Pupin Hall.
Photo by Frederick.



Columbia Chilled Water and Steam Distribution Plan.
Source: Columbia Facilities and Operations.

QUANTIFYING EMBODIED CARBON

A significant challenge in considering the embodied carbon of historic buildings is that calculations typically assess the embodied carbon required to replace the building using similar, but contemporary, materials. Very little research attempts to calculate the actual embodied carbon of the historic materials themselves. The research of Lynnette Widder and Christoph Meinrenken is a notable exception, as it reveals the quantifiable differences of embodied carbon CO_2e values and time periods. Widder and Meinrenken calculated the embodied carbon of three historic windows of similar size, specifically in regards to glazing area, at three different time periods. Their research demonstrates that embodied carbon values can vary significantly based on the time period in which the building materials are produced and constructed. For example, one of the three windows studied was located at Frederick Church's historic Olana house in Hudson, New York, built in 1872. In the 1870s, the window at Olana was built by hand from unsustainably harvested old-growth timber, the glass was fired using a coal-powered furnace, and it was transported to the site on a boat along the Hudson Canal pulled by animal-drawn carts. An example of this type of transportation method is shown in the image above. Widder and Meinrenken confirm that the total embodied carbon for this window production in 1870 is very different from a similarly sized window produced in 1950, 2001 and what would be calculated today.

> "For example, had we applied the standard emissions factors for oak or for water transport to the Olana windows, our results would have been different because of assumptions about tree and forest management, and about the energy source for water transportation. The Olana oak was harvested from a native forest, not from a farm or plantation, so that the entirety of each tree's carbon sequestration potential had to be included in the calculations. Water transport was, in the 1870s, largely driven by animal or tidal power, with only a small portion of it steam-powered; this is utterly different today." (Widder and Meinrenken 2023).

This studio aspired to calculate actual embodied carbon of the case study building materials based on time of construction, inspired by this embodied carbon work of Widder and Meinrenken. However, there were limitations in data availability and time. Indeed, some case study groups attempted to determine the actual embodied carbon of select materials based on potential historic values and this has been noted where applicable. There is a key qualitative dimension to the study of historic embodied carbon by providing a more precise calculation and therefore a better understanding of the real embodied value of the fabric of historic buildings.

Transportation of Goods Along the D&H Canal in Rosendale, NY (1903)
Source: Larry Arvidson, CC BY-SA 3.0, via Wikimedia Commons.

Carbon dioxide (CO_2) is Earth's most important greenhouse gas: a gas that absorbs and radiates heat. Unlike oxygen or nitrogen (which make up most of our atmosphere), greenhouse gases absorb heat radiating from the Earth's surface and re-release it in all directions—including back toward Earth's surface. Without carbon dioxide, Earth's natural greenhouse effect would be too weak to keep the average global surface temperature above freezing. By adding more carbon dioxide to the atmosphere, people are supercharging the natural greenhouse effect, causing global temperature to rise. According to observations by the NOAA Global Monitoring Lab, in 2021 carbon dioxide alone was responsible for about two-thirds of the total heating influence of all human-produced greenhouse gases.

Source: Rebecca Lindsey. Climate.gov. Understanding Climate.

The studio-wide embodied carbon totals presented in this report were calculated using CO_2 equivalent values for building materials published in current databases, based on the amount of carbon that would be emitted to produce and transport each material today, rather than at the time of building construction. Each case study pulled from a variety of sources to determine quantities of materials in embodied carbon calculations including drawings, construction documents, retro-commissioning reports, Department of Buildings I-cards, and others. With these sources, material inventories and CAD software aided in calculating quantities of materials. Following this, faculty formulated carbon factors based upon existing databases such as the "Inventory of Carbon and Energy" (ICE) database, which were then applied to material inventories and total embodied carbon (Jones 2024).

STANDARDIZED EMBODIED CARBON UNITS

All six case study buildings use the following units when reporting Embodied and Operational Carbon as well as Energy Use Intensity.

Embodied and Operational Carbon Units:
tCO_2e = Metric Tons of Carbon Dioxide Equivalent, a measurement of all greenhouse gas emissions, but converted and expressed in terms of an equivalent amount of carbon dioxide

Energy Use Intensity (EUI) Units:
kBtu/sqft = thousands of British thermal units per square foot

THE CARE TOOL

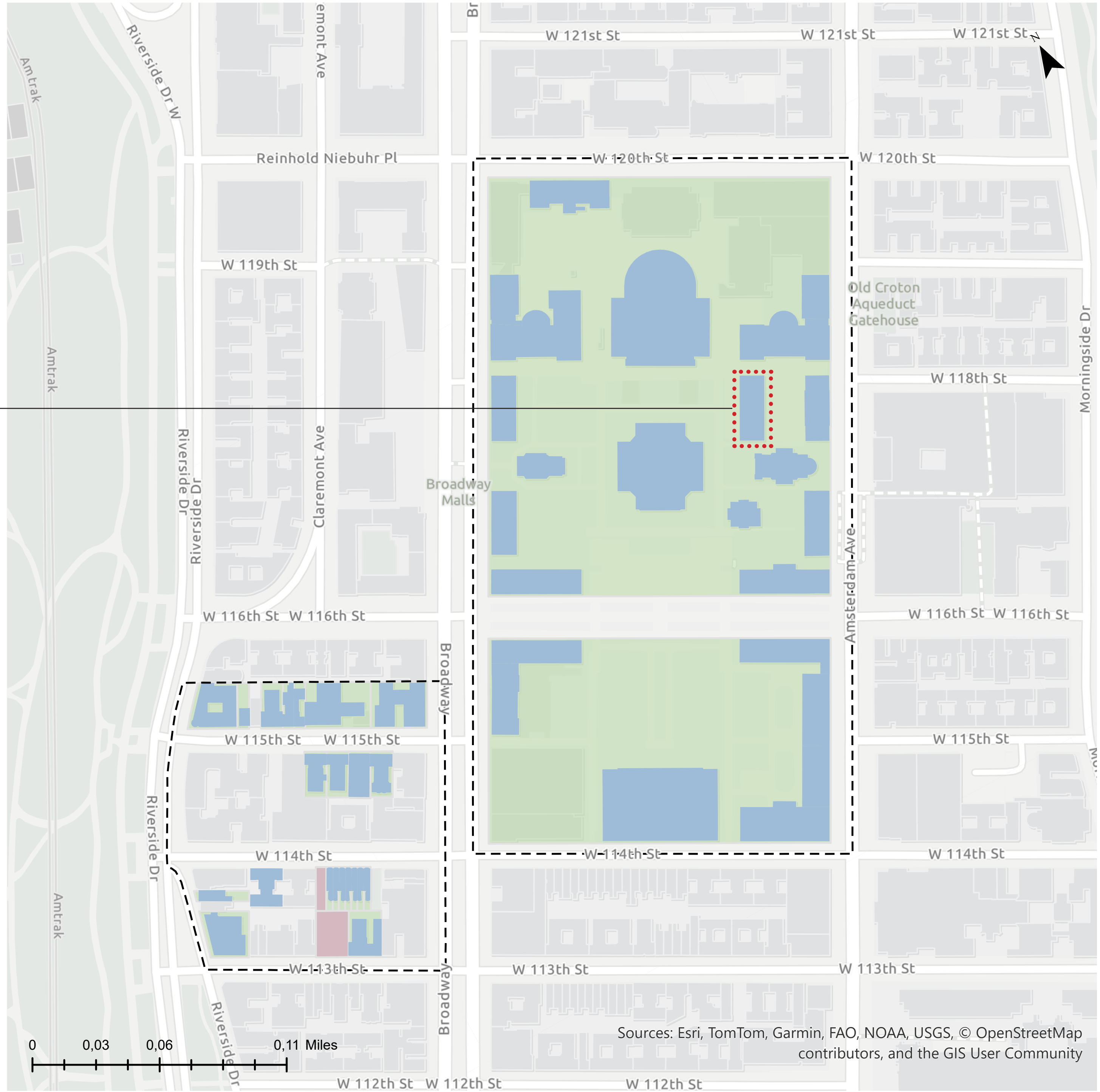
The primary tool used to compare tradeoffs between operational and embodied carbon in this studio was the CARE (Carbon Avoided: Retrofit Estimator) Tool. The CARE Tool is a decision-making tool that encourages designers, building developers, and others to evaluate and compare the carbon emissions of doing nothing or preserving as is, retrofitting, or replacing with new construction. The CARE tool synthesizes and standardizes operational and embodied factors to produce different scenarios and impacts. At the present, CARE relies on energy use intensity as an building performance indicator, whereas in NYC, local laws regulate actual greenhouse gas emissions. While future iterations of the CARE tool may allow the user to input emissions, the use of EUI presented challenges for the studio. This limitation within the CARE tool was overcome by developing and applying estimates of total emissions for the studio's buildings over 26 years, respective of property type and the emissions factors dictated by Local Law 97. Therefore, the CARE tool examples listed later on in this section all take into account the total operational carbon budget each building must comply with to reach Columbia and NYC's target of being net-zero by 2050 (Appendix B).

CASE I : AVERY HALL

Students:
Lili Garcia , Zhaosen (Aaron) Luo, Huanyu (Will) kuang.

Avery Hall, 2024.
Photo by Frederick.

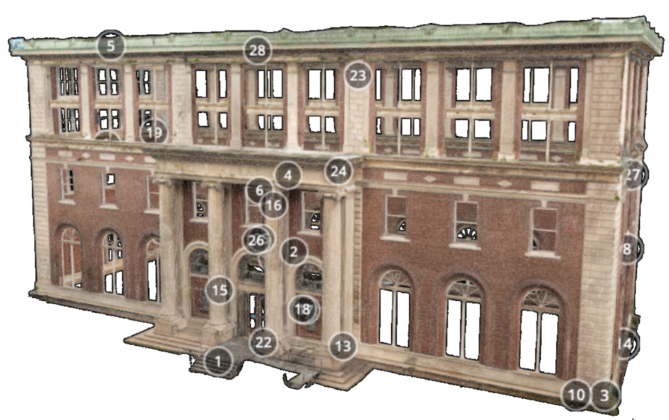
CASE I: AVERY HALL



ANALYZING AVERY HALL

Avery Hall is the heart of GSAPP and home to the "largest architectural library in North America" (International Confederation of Architectural Museums 2022). It is the building students and faculty of GSAPP are most familiar with on the Morningside Heights campus. The following case study examines Avery from the embodied carbon perspective and critically analyzes the material history of Avery and its role when it comes to carbon emissions. For this case study, there were extensive archival resources available, including drawings and documents from the New-York Historical Society as well as a digital 3D model from a past summer GSAPP workshop.

These resources led the research to take a material-oriented approach. Before discussing the first phase of research, please note that the following analysis does not focus on the 1974 extension of Avery. It was decided that for the scope of this case study, the research would only focus on the part of the building that was completed in 1912 since it is the features from this time that define the character of Avery.



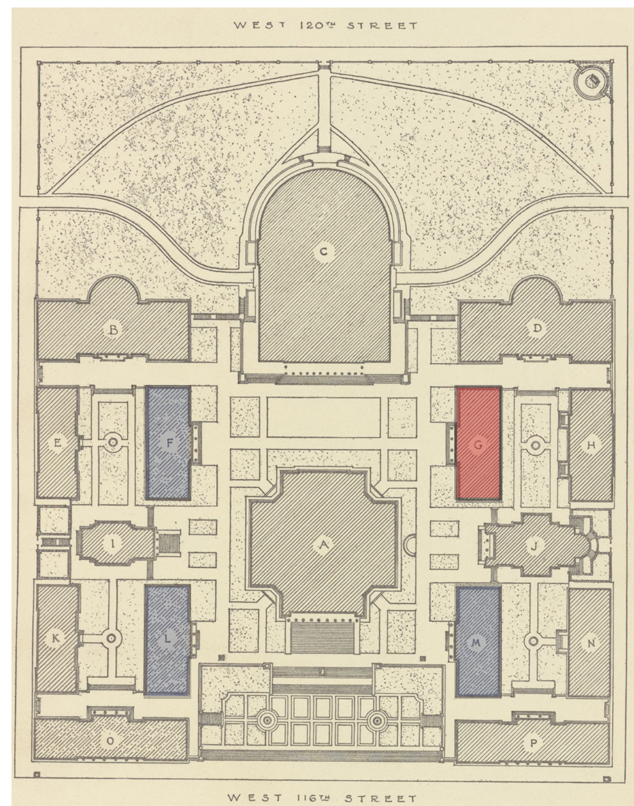
3D Model of Avery Hall on SketchFab (June 2022).
Source: Preservation Technology Lab.

CHARACTER-DEFINING FEATURES

The first phase of research involved identifying the character-defining features of Avery. By understanding the historical significance of the building, it was then possible to think about how it relates to embodied carbon. To determine what features define the character of Avery, a physical survey and historical assessment were conducted. The character-defining features are sorted and discussed into the next three paragraphs of this report.

1) Location On Campus Is Unique

Focusing first on the overall physical aspect of the building, Avery's location on the campus is a character-defining feature.



McKim, Mead & White's Master Plan (1915). The red block indicates Avery Hall, while the blue blocks were part of the original plan but were never erected.
Source: New York Public Library .

It is the only inner pavilion built from McKim, Mead & White's master plan which makes it unlike any other building on campus. However, paradoxically, it is Avery's ability to conform with the other academic buildings of the Columbia campus that is at the core of its identity.

2) Exterior: Conformity with campus

According to a page found in the University Archives, Avery's ability to take "its place among the surrounding buildings with an almost human ease" (Price 1913) is an essential part of its identity. What allows Avery to conform is how it is rectangular in plan, has a masonry facade with limestone quoins, pilasters, and a belt course between the second and third stories. The building has arched windows on the 1st story with one over one windows on the stories above, an Ionic portico, and a low-pitched hipped copper roof with an ornamental stone cornice. These are all character-defining features of the exterior.

3) Interior: Foremost an architectural library

In terms of the interior, the original intention of the building greatly influenced what was identified as character-defining. Avery is foremost an architectural library. The donors, Samuel and Mary Avery, thought the building "'shall be primarily devoted to the Avery Library and exclusively so devoted whenever the growth of the Library demands'" and "envisioned a time when the studios and offices of the school would be displaced by the expanding library" (Dolkart 1998, 182). The donors wanted the building to solely be a library. They did not want the building to be classrooms, studios, and offices with a library. They accepted that the upper floors would be utilized in this way temporarily but the donors' original intention was that the library would one day occupy the entire building. Therefore, this research posits that the interior character-defining features are all related to the 300-level library, not the upper floors. The coffered ceiling, alcove plan, and square capitals are all an essential part of Avery's identity in this space.

McKim, Mead & White's Master Plan (1915).
Source: New York Public Library

300-Level Library (n.d.).
Source/Photographer: Olef Wolberger.

All these features of Avery explain above—the location of Avery, its exterior features, and interior library—are ones that can be visibly seen. However, the structural typology, in particular, the steel frame, is a character-defining feature, too. While these features are one way to understand the identity and architectural significance of Avery, what are the environmental costs of these features? In addition, how can the history of these materials help people understand their embodied carbon?

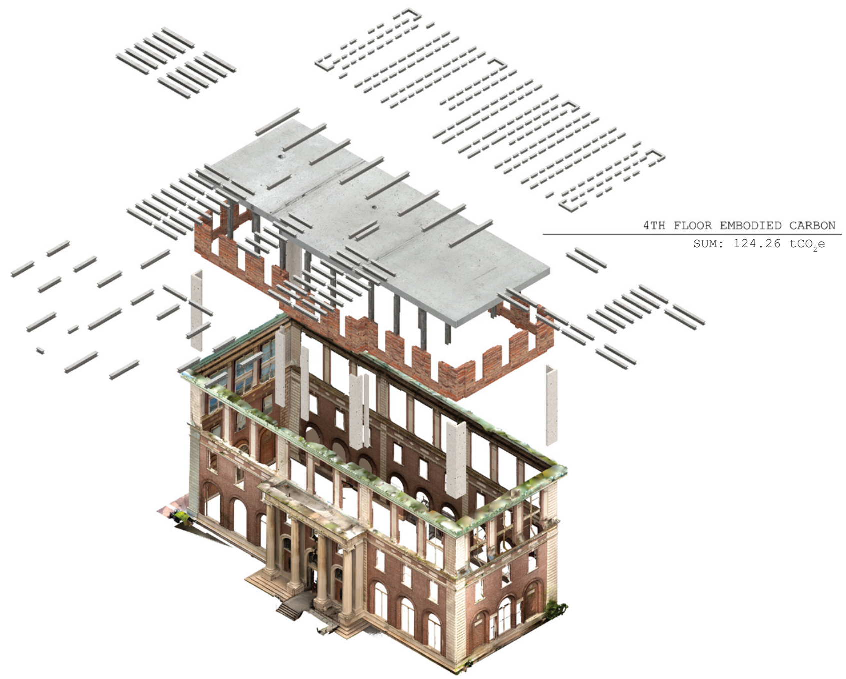
EMBODIED CARBON

With these questions in mind, the embodied carbon calculations were primarily informed by archival drawings, such as the framing plans. The steel beams were then organized by type and steel beam prototype information from 1910 steel manual books were used to inform the calculations. The purpose of this research and calculation was to get the most precise quantitative replacement embodied carbon data for Avery's material inventory. Since qualitative historical data related to embodied carbon was also available, such as quarry site and transportation methods, it was possible to make assumptions about the historical embodied carbon of Avery's materials, and get an overall image of this building's embodied carbon investment.

To show how these numbers from the calculations translate to tangible things, a visual journey is provided that reconstructs Avery by breaking down the embodied carbon in the different building elements and describes some of the history of the material sourcing.

Avery floor framing plan (1910). Source: New-York Historical Society. Highlighting represents the different sizes of steel beams.

4TH FLOOR IS REPRESENTATIVE



Breakdown of the 4th floor: overview (2024). Source/Graphic: Aaron Luo

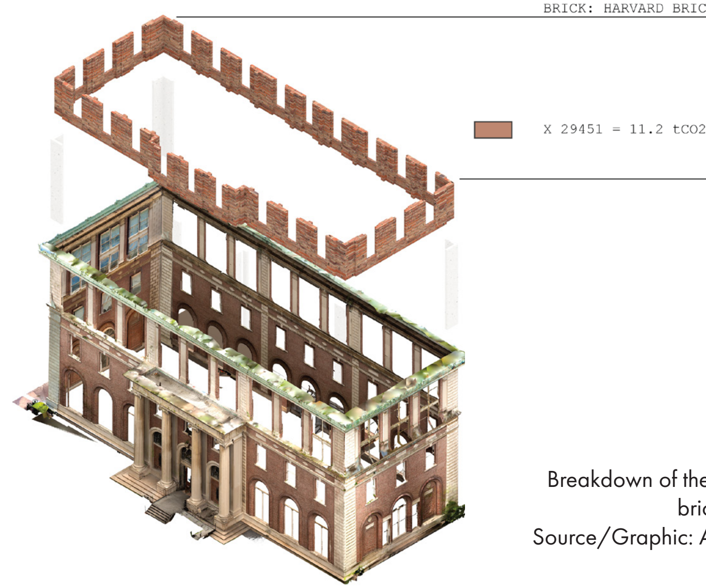
The image above is the 4th floor of Avery. To understand the amount of embodied carbon in this building, it is broken down and discussed by material. First is limestone; the limestone quoins and pilasters are character-defining features of the exterior and have an associated embodied carbon emissions (replacement) value of 12 tCO_2e. That means if Avery were rebuilt today, the process for creating and building these limestone features would release 12 tons of carbon dioxide into the atmosphere. Now, why would so much carbon dioxide be emitted? To understand this, it is helpful to think about the historical production and transportation of these limestone features.

The company and quarry that Avery's limestone came from are known (M. Reid & Company 1911) as was identified from archival correspondence. The Bedford Quarry Company is located in Bedford, Indiana, far from the site of Columbia University. The limestone therefore has a story to tell.

THE STORY OF LIMESTONE AND GRANITE

Before it was the quoins or pilasters on Avery, the limestone was rock in the earth. It was quarried by means of steam channelers, cut into blocks of desired size, and loaded on cars or otherwise handled by powerful steam derricks (Perazzo 2013, 277). Once on a train, the limestone was transported roughly 792 miles to New York City. This process incurred carbon dioxide emissions. Even though the calculations are based on replacement values, thinking about the historical context demonstrates how these materials are carbon-intensive and a significant carbon investment has already gone into creating them.

While the story of granite is similar to that of limestone, it came from a different location, Branford, Connecticut, and there was more detailed information related to its transportation. In particular, an image of the train, which typically transported Stoney Creek granite to New York City, was found.



Breakdown of the 4th floor: brick (2024). Source/Graphic: Aaron Luo.

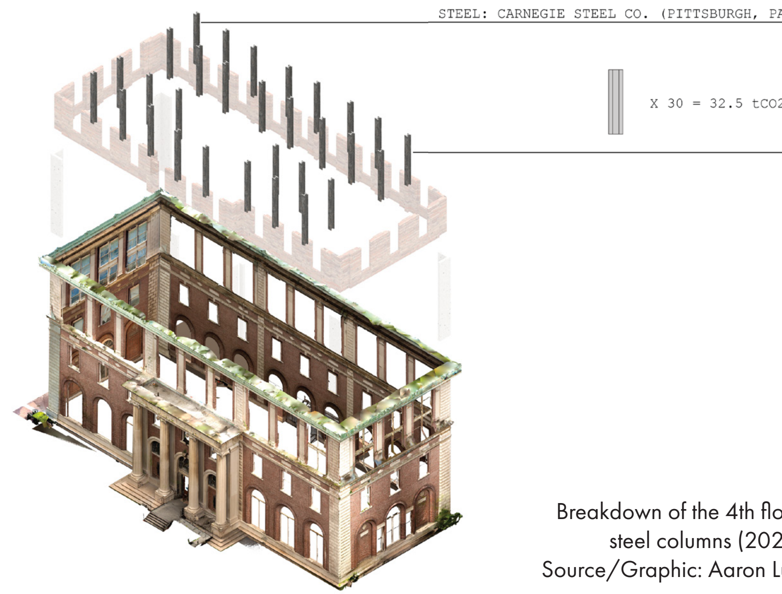
BREAKDOWN OF THE 4TH FLOOR: BRICK

The next material is brick. Based on the calculations, the brick of Avery contains 11.2 tCO_2e. To learn about the production and transportation of brick, please review the St. Paul's Chapel case study.

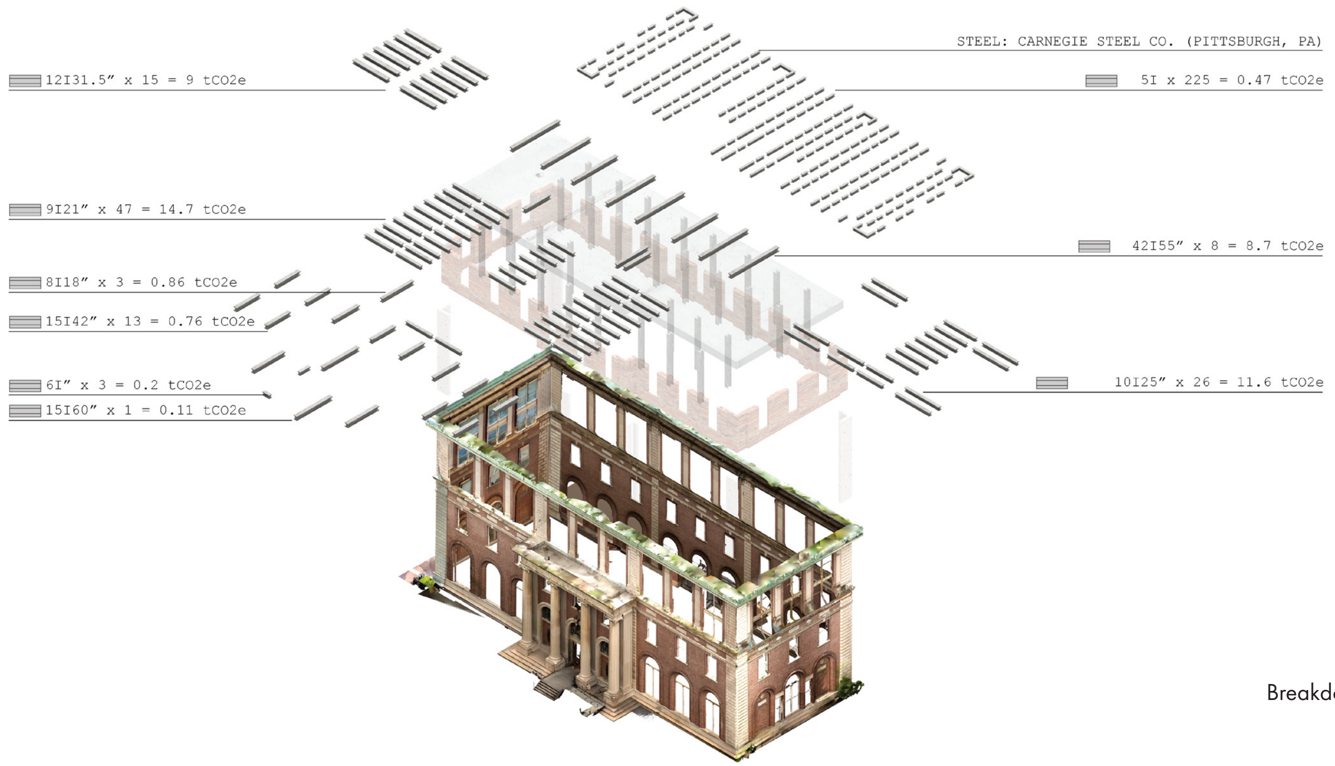
BREAKDOWN OF THE 4TH FLOOR: STEEL

After brick are the steel columns, which is the material in Avery that has some of the most embodied carbon, with a staggering 32.5 tCO_2e. Archival material revealed the beams are from the Carnegie Steel Company in Pittsburgh (Hildreth & Co 1911). Let's take a closer look at the process and journey of the steel to understand what makes it such a carbon-intensive material.

Different types of steel beams have different dimensions and weights. For more accurate calculations, a detailed framing plan of the 4th floor was used to count and calculate the embodied carbon for each type of steel beam.



Breakdown of the 4th floor: steel columns (2024). Source/Graphic: Aaron Luo.



Breakdown of the 4th floor: limestone (2024).
Source/Graphic: Aaron Luo.

Lucy furnace at Carnegie Steel Company (1900-1915). Source: Library of Congress.

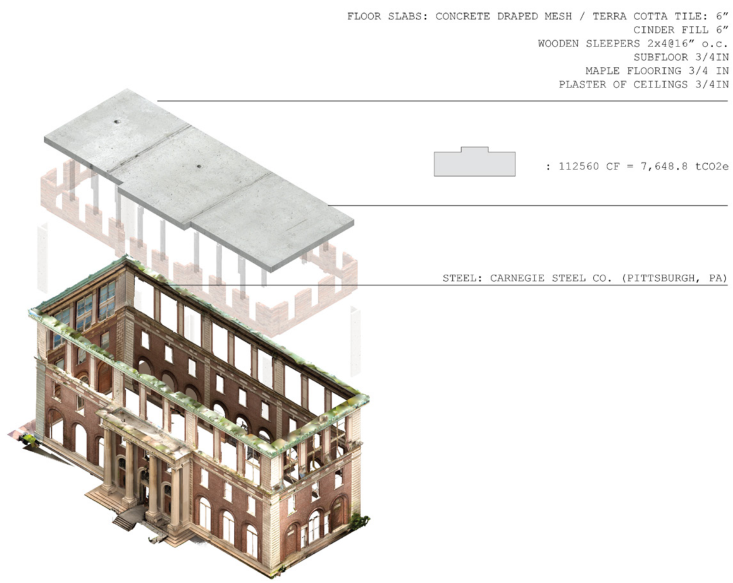
THE STORY OF STEEL

The image at left is a historic photograph of a furnace at the Carnegie Steel Company's plant in Pittsburgh, PA. Inside, a flurry of coal-reliant activities take place that transform extracted iron ore to eventually a steel beam. The plumes in this photo are an almost direct visualization of the waste gasses that helped contribute to the climate crisis that the world faces today. It is these kinds of images of furnaces and plants that people visualize when they think of industrialization. Steel production was, and remains, a manufacturing process that is the essence of being carbon-intensive.

Carbon did not only get emitted at the plant, but also in the process of transporting the steel beams roughly 375 miles from Pittsburgh to New York City by train. Once again, researching the historical context helps with understanding the embodied carbon of these materials.

BREAKDOWN OF THE 4TH FLOOR: FLOOR SLABS

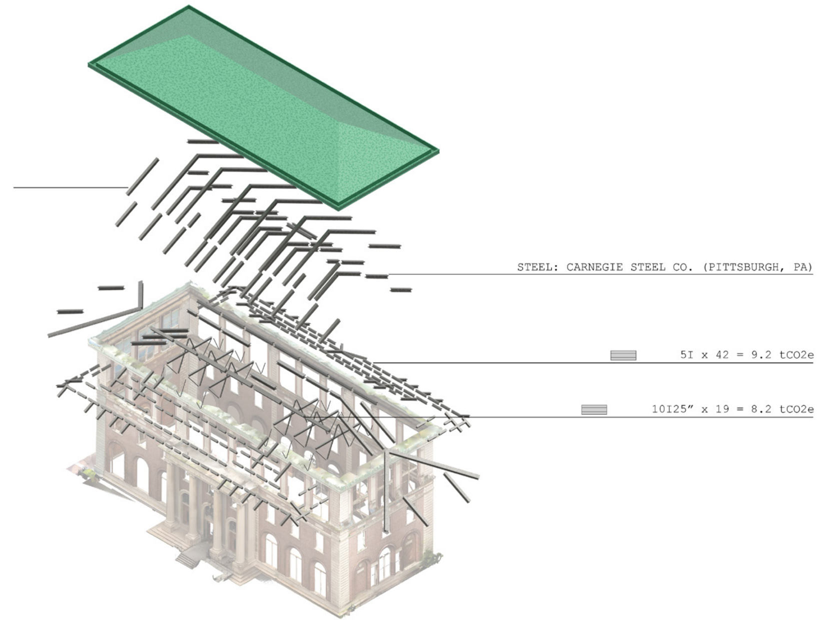
For the floor slabs, through investigation and review of similar contemporary systems, the floors were divided into multi-layers: a concrete draped mesh slab structural layer covered in cinder fill, wooden sleepers, subfloor, maple flooring, and with a plaster ceiling suspended from it. The total embodied carbon for the 4th floor slab is 34.6 tCO_2e



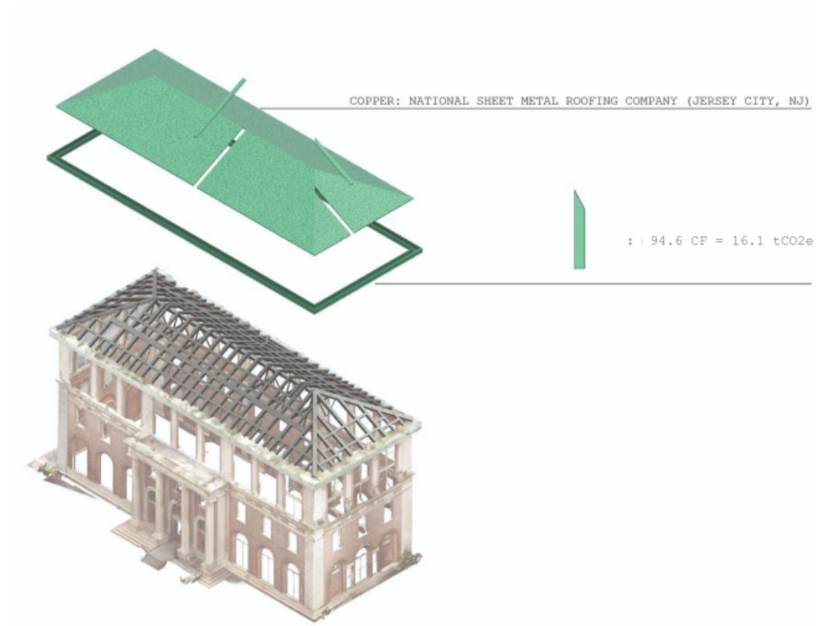
Breakdown of the 4th floor: concrete floor slab (2024). Source/Graphic: Aaron Luo.

THE ROOF MATTERS

The roof is also a character-defining feature of Avery with its use of copper. Across the buildings of the Morningside campus, the majority have a copper roof nearly identical to Avery, therefore, this roof calculation is likely representative. Copper roofing is typically 22-gauge (or 0.55 mm thick), but copper has a significantly high replacement embodied carbon factor of 3.75kg CO_2 per kg of copper because the mining, milling and smelting and refining is a very energy intensive process. In this case, the total embodied carbon of the roof is 16.1 tCO_2e. For the calculation of the roof steel frames, the same methodology was used as the 4th floor..



Breakdown of the roof: steel (2024). Source/Graphic: Aaron Luo.

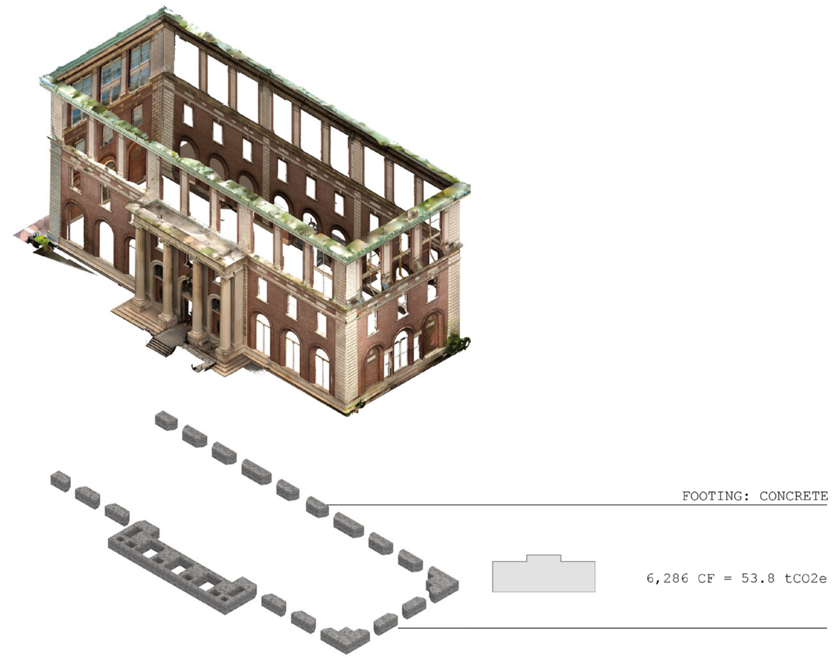


Breakdown of the roof: copper (2024). Source/Graphic: Aaron Luo.

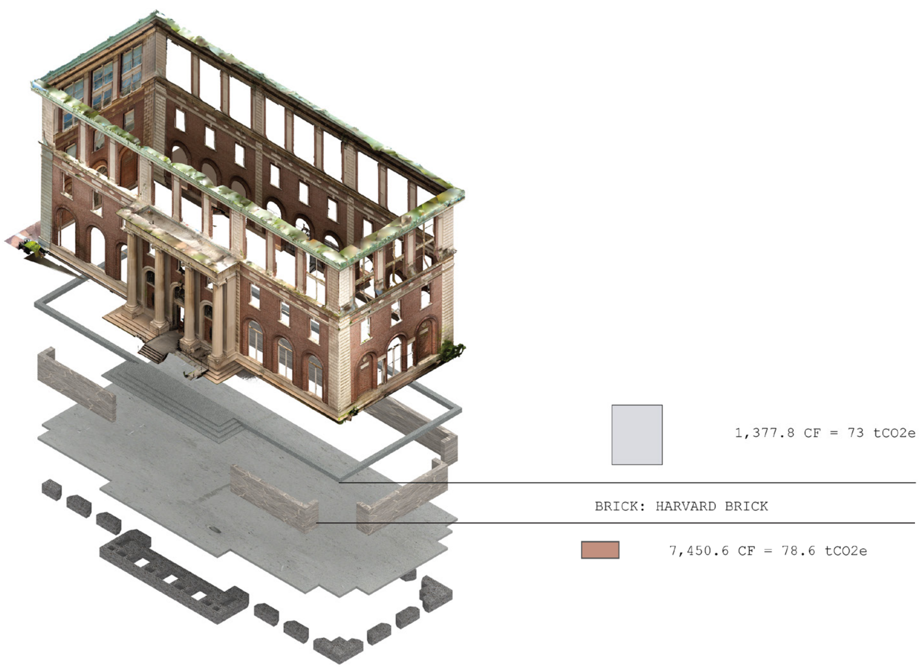
FOUNDATION

The replacement embodied carbon of the foundation of Avery Hall was also calculated, including several elements such as footings (image at top right), foundation walls (bottom left) and slab (bottom right) While the foundations of buildings are often given little attention since they are rarely visible, they constitute a significant upfront embodied carbon investment.

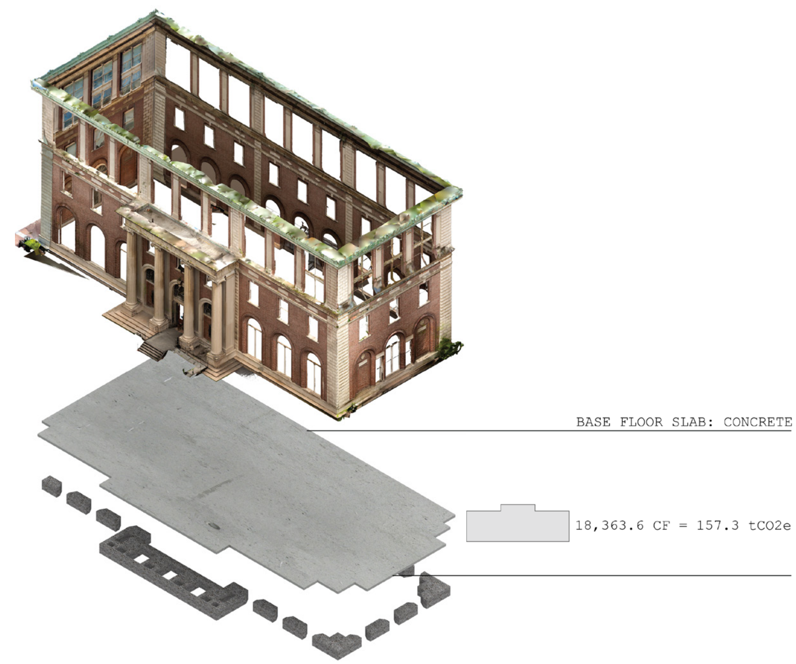
The total embodied carbon of the whole foundation is 116 tons CO_2e. This is a large proportion of the building's total embodied carbon.



Breakdown of the foundation: footings (2024). Graphic: Aaron Luo.



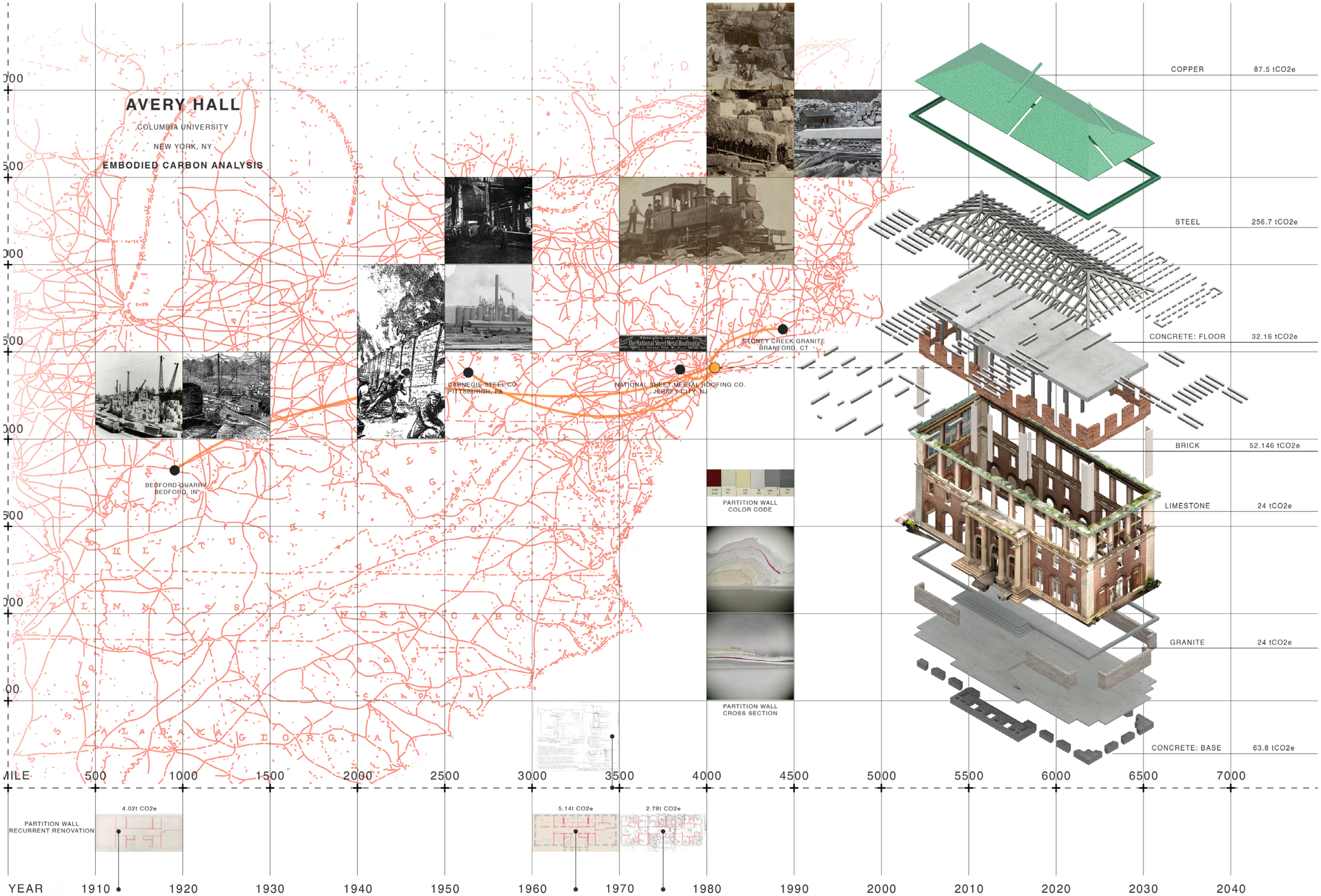
Breakdown of the foundation: Walls and granite (2024). Graphic: Aaron Luo



Breakdown of the foundation (2024). Graphic: Aaron Luo.

MAP

Throughout this journey, there are two factors that are significant to the study of historic embodied carbon emissions: time and distance. The map below shows that both the transportation of materials and the recurrent construction incurred embodied carbon.



Material sources map (2024). Source/Graphic: Aaron Luo

PARTITION WALL

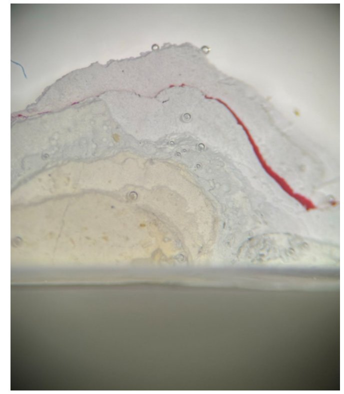
Historical archive drawings and architectural finish samples from Avery's 4th floor were used to determine the historical renovation of the interior partition walls. Collecting samples from walls under the staircase, which were original walls, revealed the oldest finishes to the most recent one. More than ten layers were identified under the microscope. Partition walls that were built later would likely have fewer layers.

400 -LEVEL RENOVATION

The major structural components, such as steel columns and beams have a lifespan of over 100 years (or much longer if kept dry), but certain architectural components may require more regular maintenance or even reconstruction. The layout of the partition walls for example changes over time as the use of interior spaces changes, and each change incurred embodied carbon emissions. The 1912 original design used plaster-covered terra cotta blocks for partitions, while later construction used light-gauge steel studs with a drywall plaster cover. Over 60 years, the replacement carbon value of the plaster-covered steel-stud partition assembly on the fourth floor was calculated as 11.9 tCO_2e, and that is still less than the 14.6 tCO_2e of granite, which has the least embodied carbon of the other building elements. Although the amount of carbon appears small compared to structural components, the carbon cost of replacing partitions is relevant if such reconstruction takes place regularly.

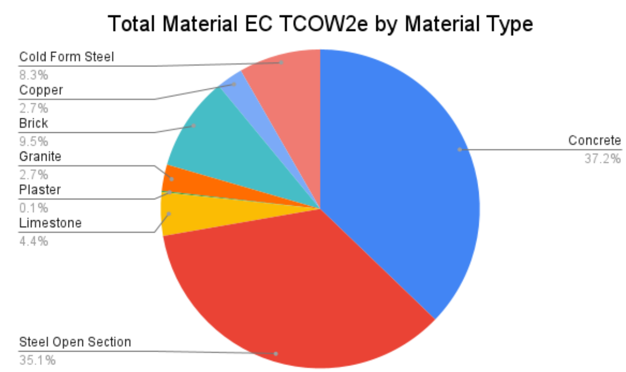
EMBODIED CARBON CALCULATION

The embodied carbon calculation pie chart shows each material's percentage in the overall building. The structural steel framing accounted for the majority of carbon emissions, nearly 48 percent. Surprisingly, the copper roofing is the third highest embodied carbon material in Avery. Analysis reveals material density and embodied carbon factors play significant roles in embodied carbon calculation. For instance, copper has a carbon factor of 3.75 $kgCO_2e$, which is about 20 times higher than the carbon emission factor of 0.195 $kgCO_2e$ for bricks (Jones 2024). In this case, even though the amount of copper material used to form the roofing is small in proportion to the overall structure, its embodied carbon should not be neglected.

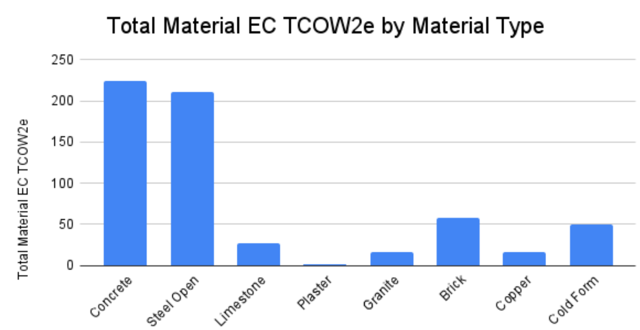


Paint layers of Avery 4th floor. Source/Photographer: Aaron Luo

Avery 4th floor. Sourcer: https://www.arch.columbia.edu/admissions/virtual-visit



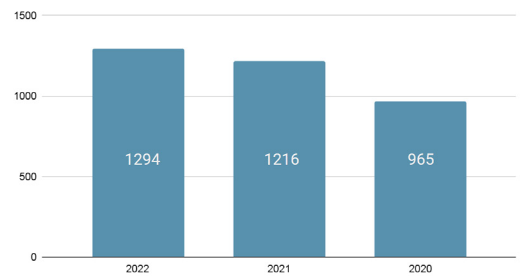
Avery embodied carbon pie chart (2024). Source/Graphic: William Kuang



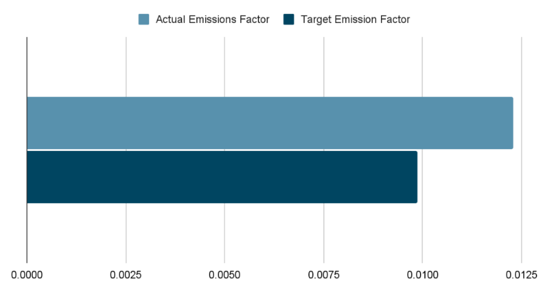
Embodied carbon emission of different material (2024). Source/Graphic: William Kuang

OPERATING CARBON

According to the 2022 LL84 report, Avery consumed much more energy compared to other similar academic buildings like Fayerweather and Pulitzer, responding to an average of 1200 metric tons of greenhouse gas emissions annually. This may be due to metering issues that combine Avery and Avery extension in the same report. Currently, Avery was reported as an academic building instead of a library which gives it more leeway, but still Avery in general is underperforming and struggling to meet the targets set by the Columbia 2030 plan.



2020-2022 Avery operational carbon emission/unit in metric tons (2024). Source/ Graphic: William Kuang



2022 Avery's actual and target emission factors (2024). Source/Graphic: William Kuang

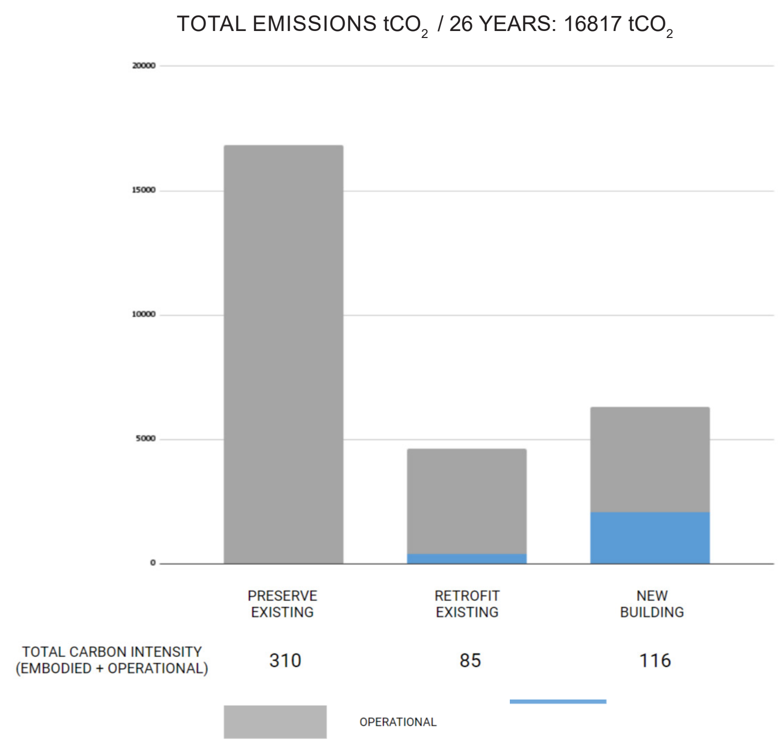
Avery Hall	185.3
Fayerweather Hall	125
Pulitzer	140.1
Kent Hall	95.4
Hamilton	67.6
Butler Library	93.1

Avery 2022 building EUI compared to other academic buildings (2024). Source/ Graphic: William Kuang

THE BEST FUTURE FOR AVERY IS RETROFITTING

The CARE Tool results show that if nothing is done to Avery and it is preserved as is, it will keep consuming excessive energy, accounting for over 15.000 tCO_2e (for both the original building as well as the extension), and will fail to meet its operational targets. If a new building were constructed in Avery's place, the CO_2 emissions would be lower, yet still a lot higher compared to keeping Avery and retrofitting the building. Research and accounting of Avery's operating and embodied carbon makes it clear that for the preservation of the planet, deep retrofits are imperative and that electrification alone is not sufficient.

It is worth emphasizing that Columbia will face $203,416 fines annually for failing to meet its carbon targets starting in 2025 according to the 2022 LL97 Report. Retrofits for Avery are needed now, and there is no time to waste.



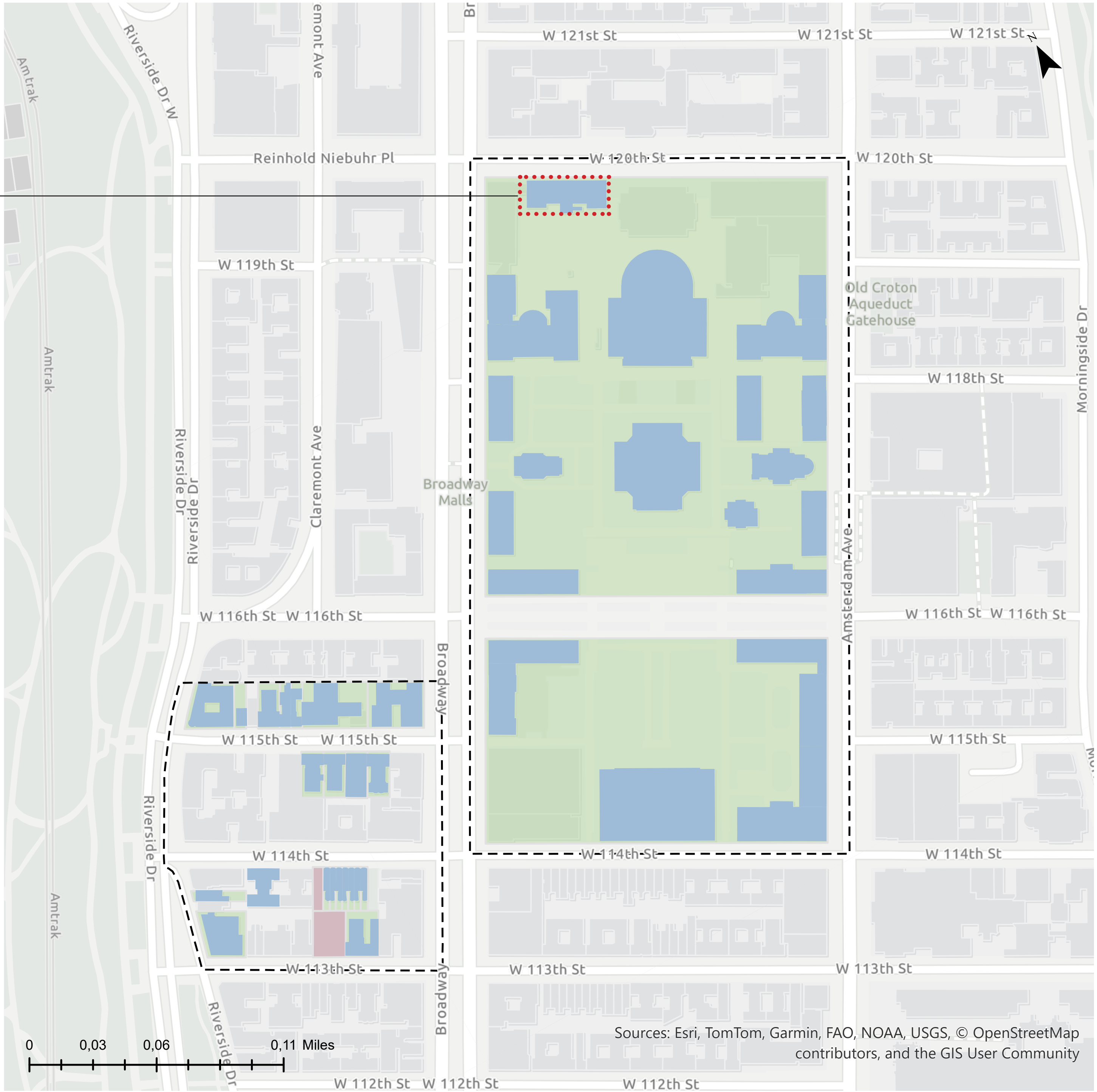
CareTool analysis of Avery (Date).Source/ Graphic: William Kuang

CASE II : PUPIN HALL

Students:
Frederick, Nicolás Moraga, Wenquin Meng

Pupin Hall, 2024.
Photo by Frederick.

CASE III: PUPIN HALL



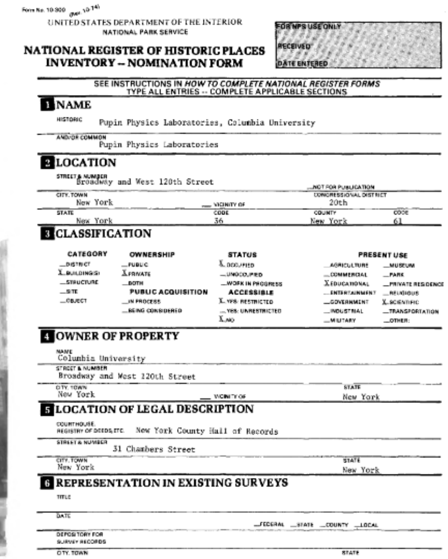
HISTORICAL SIGNIFICANCE

Pupin Hall, erected in 1927, was recognized in 1966 as a National Historic Landmark, a designation of the National Park Service and the Secretary of the Interior. The designation is due primarily to its association with the groundbreaking cyclotron magnet that used to be housed within its basement laboratory. Led by Nobel Laureate Dr. Enrico Fermi, the cyclotron achieved the historic milestone of splitting the uranium atom in 1939, marking a significant advancement in nuclear physics, notably during the Manhattan Project (McKithan 1978). However, in 2007, Columbia University made the decision to dismantle the cyclotron (Broad 2007).

In addition to its significance as a National Historic Landmark, Pupin Hall holds further distinction as a member of the "Physics Hall of Fame," with a notable legacy that includes over 45 Nobel Laureates (Columbia University Astronomy & Astrophysics Department n.d). Furthermore, it is registered as a Historic Physics Site by the American Physics Society, acknowledging the discovery of the magnetic resonance method in 1939 by another Nobel Laureate, Dr. Isidor Isaac Rabi (Levine 2008).

CHARACTER-DEFINING FEATURES

Pupin Hall has a similar building façade like other McKim, Mead & White's buildings within the campus with the dominance of materials such as Harvard brick and limestone trim. However, Pupin still can be easily distinguished from other McKim's buildings because of its towering height, as it was built during the era when Columbia started to develop its campus vertically (Dolkart 1998).
The other feature that makes Pupin stand out is the positioning of the Rutherfurd Observatory on top of the building right after it was built. While the observatory no longer serves the Columbia Astronomy Department for research, especially since the construction of the Northwest Corner Building, it is still used by the students and faculties for outreach purposes (Columbia Astronomy Public Outreach n.d.). Despite these changes, the observatory dome is still there and has the potential to symbolize Pupin Hall as a significant astrophysics site and define its distinguished characteristics.



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UNITED STATES DEPARTMENT OF THE INTERIOR
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NATIONAL REGISTER OF HISTORIC PLACES
INVENTORY -- NOMINATION FORM

SEE INSTRUCTIONS IN *HOW TO COMPLETE NATIONAL REGISTER FORMS*
TYPE ALL ENTRIES -- COMPLETE APPLICABLE SECTIONS

1 NAME
HISTORIC Pupin Physics Laboratories, Columbia University
AND/OR COMMON Pupin Physics Laboratories

2 LOCATION
STREET & NUMBER Broadway and West 120th Street
__NOT FOR PUBLICATION
CITY, TOWN New York __ VICINITY OF
CONGRESSIONAL DISTRICT 20th
STATE New York CODE 36 COUNTY New York CODE 61

3 CLASSIFICATION

CATEGORY	OWNERSHIP	STATUS	PRESENT USE	
__DISTRICT	__PUBLIC	X OCCUPIED	__AGRICULTURE	__MUSEUM
X BUILDING(S)	X PRIVATE	__UNOCCUPIED	__COMMERCIAL	__PARK
__STRUCTURE	__BOTH	__WORK IN PROGRESS	X EDUCATIONAL	__PRIVATE RESIDENCE
__SITE	PUBLIC ACQUISITION	ACCESSIBLE	__ENTERTAINMENT	__RELIGIOUS
__OBJECT	__IN PROCESS	X YES: RESTRICTED	__GOVERNMENT	X SCIENTIFIC
	__BEING CONSIDERED	__YES: UNRESTRICTED	__INDUSTRIAL	__TRANSPORTATION
		X NO	__MILITARY	__OTHER:

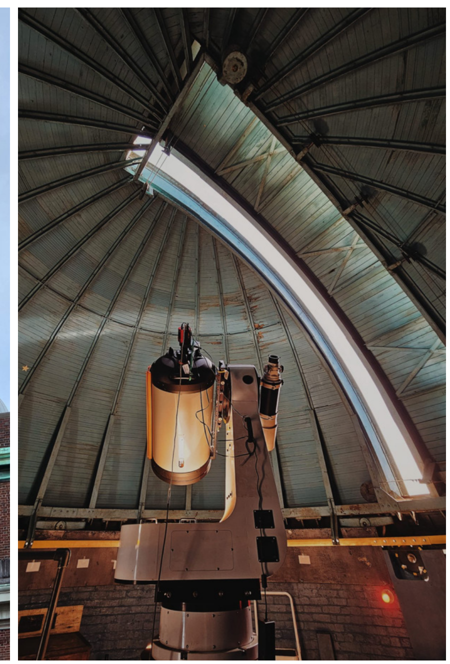
4 OWNER OF PROPERTY
NAME Columbia University
STREET & NUMBER Broadway and West 120th Street
CITY, TOWN New York __ VICINITY OF STATE New York

5 LOCATION OF LEGAL DESCRIPTION
COURTHOUSE, REGISTRY OF DEEDS, ETC. New York County Hall of Records
STREET & NUMBER 31 Chambers Street
CITY, TOWN New York STATE New York

6 REPRESENTATION IN EXISTING SURVEYS
TITLE
DATE __FEDERAL __STATE __COUNTY __LOCAL
DEPOSITORY FOR SURVEY RECORDS
CITY, TOWN STATE

Pupin Hall as a National Historic Landmark Designated in 1966
Source: U.S. Department of Interior, National Park Service, 1966

The Rutherfurd Observatory on Top of Pupin Hall. Source: Frederick, 2024



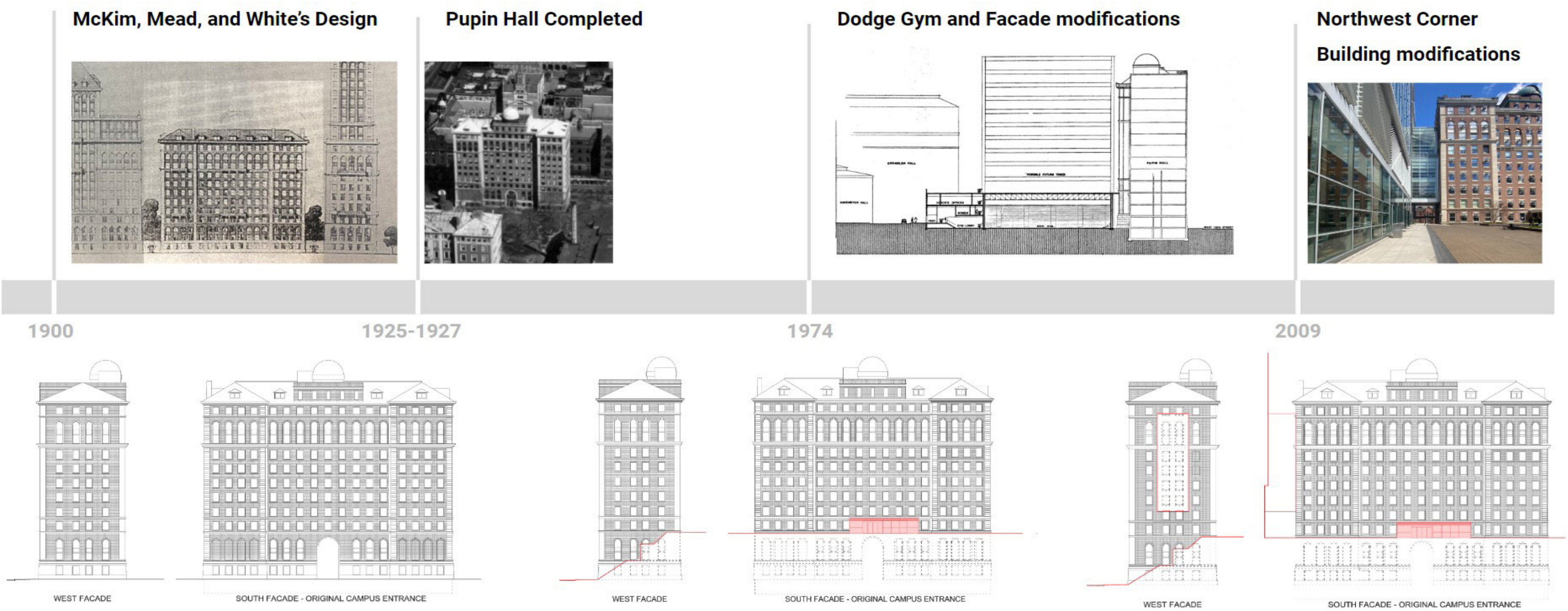
The Rutherfurd Observatory Interior. Source:: Frederick, 2024

PUPIN HALL OVER TIME: ALTERATION TIMELINE

Originally, Pupin Hall was conceived as part of a complex of highrise buildings facing 120th Street according to McKim, Mead and White's initial concepts for the Upper North Campus area. However, it remained the only freestanding built hall within "the Grove or the Green" until 1961 when the construction of the Seeley W. Mudd Building retook the University's plans for the development of the area.

A 1970 plan by I.M. Pei proposed a modern development of the north campus area. Though the plan was not realized, its concept of underground levels for new university facilities and the creation of a public plaza around Pupin Hall towards the south were incorporated when the Dodge Physical Fitness Center was designed to be underneath Pupin Hall. The construction of this building in 1974 changed the relationship between Pupin Hall and its physical context dramatically. The Dodge Gym building enclosed the first four floors of the south facade, covering all windows and changing the main entrance to the campus level on the 5th floor. Consequently, this caused the loss of natural ventilation and required the use of forced mechanical systems to improve air extraction, as well as the use of artificial light for laboratories that were located in the four lower levels of the building. Moreover, the construction of the Schapiro Center for Engineering and Physical Science Research (CEPSR) resulted in the demolition of the Peagram Laboratory, a low-rise laboratory building that was attached to the west facade of Pupin Hall.

In the following years, most of Pupin Hall's changes and modifications were made to reconfigure the building's layout by removing and reconstructing partition walls inside the building. However, the original layout of the building was not significantly affected. Most of the changes and improvements that have been made are related to upgrading laboratory equipment and mechanical systems, adapting to newer technologies. The last major modification that affected Pupin Hall's facade was the construction of the Northwest Corner Building in 2009, which attached part of the upper floors with Pupin Hall through a bridge that connects both buildings. This decision to connect the building was made so that Pupin Hall could have additional areas for new laboratory facilities.

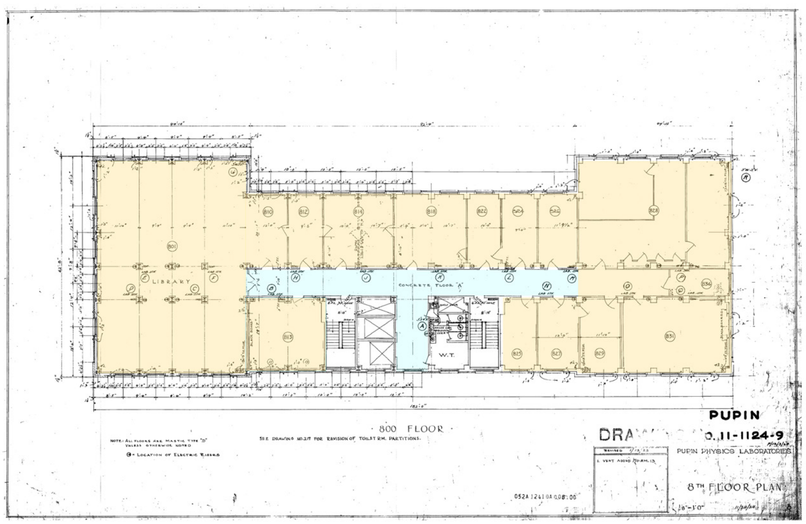


Pupin Hall Alteration Timeline. Source: Diagram by: Nicolás Moraga, 2024. Photo by: Frederick, 202

CONSTRUCTION TYPOLOGY AND ARCHITECTURE LAYOUT

Pupin Hall incorporates technology features of high-rise buildings that were typical of early twentieth-century building construction in New York City, with the use of a steel skeleton structure encased by concrete and cinder blocks for fire protection, alongside cinder concrete draped-mesh floor slabs. The use of this structural system allowed larger interior spaces with ideal natural light conditions for use as study areas, auditoriums, and laboratories.

Even though its structural typology reflects modern construction methods, Pupin Hall kept most of the characteristics of the previous buildings designed by McKim, Mead, and White, such as the use of a symmetrical layout floor plan. Originally, the building's main access was on its second floor, leading to a main hall located in the center of the building plan. This central hall typically distributes to the stairs and elevator core and orthogonally leads to a central corridor with office spaces facing to north and south facades. Both sides of the corridor are finished by larger common areas, used for lecture auditoriums, libraries, and study areas for students among the different floors.



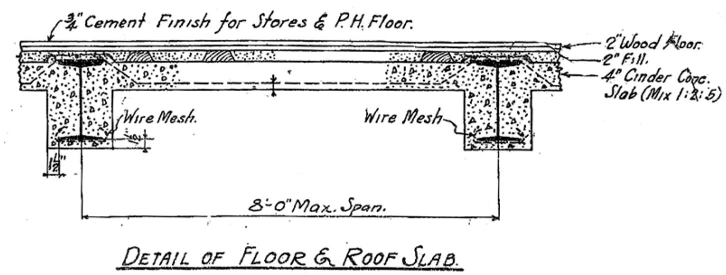
Typical floor plan of Pupin Hall. Cyan color represents circulation corridors, white services, stair and elevator cores, and yellow indicates student and faculty areas.
Source: Columbia University Facilities and Operations.

EMBODIED CARBON ANALYSIS

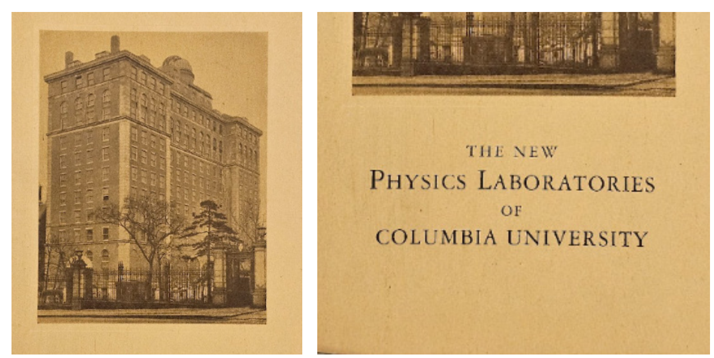
Structural Material Overview

Steel and concrete are typically considered to be embodied carbon-intensive structural materials, and Pupin Hall, a 15-story steel-framed building with concrete floor systems, is no exception. The building's brochure from the opening date of Pupin Hall in 1927 stated that the structural live load capacity for Pupin was 120 pounds per square foot on the first seven floors and 70 pounds per square foot for those above (Columbia University 1927). Therefore, calculating the total replacement embodied carbon of Pupin's structural materials is not as complicated as it may seem, as the floors are typical and repetetive.

The building's brochure also provided insight into the fireproofing system of Pupin Hall, with the beams and girders fireproofed with cinder concrete, columns fireproofed with hollow tiles, and floor slabs of 4-inch cinder concrete reinforced with heavy woven wire mesh (Columbia University 1927).



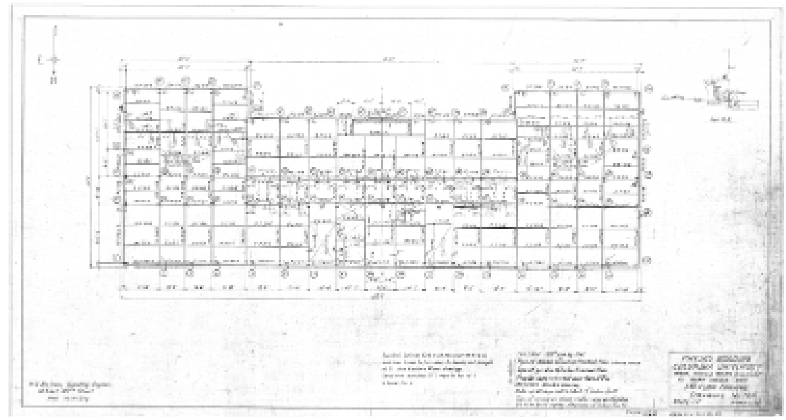
Cinder Concrete Flooring Detail.
Source: Historical Building Construction, Donald Friedman



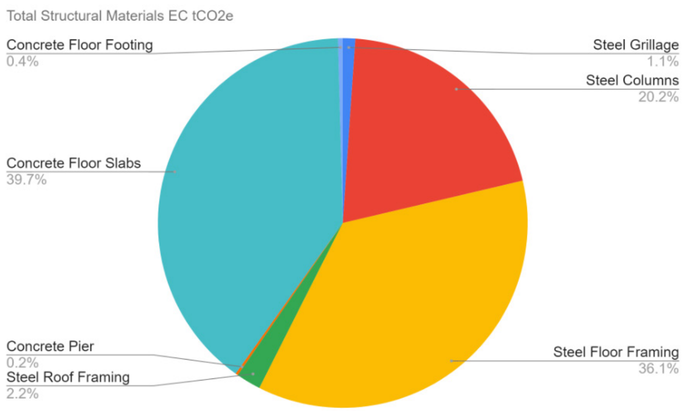
Pupin Hall Building Brochure in 1927.
Source: Columbia RBML, 1927.

Structural Materials Replacement Embodied Carbon Calculation

Based on the available structural drawings of Pupin Hall, the steel elements (grillage, structural columns, floor framing, and roof framing,including the observatory dome framing) account for a total replacement embodied carbon of 8,300 tCO_2e. For concrete, the concrete pier/foundation footings, floor slabs, and floor beam footings were identified, with a total replacement embodied carbon of 5,500 tCO_2e. The total embodied carbon from structural materials is 13,800 tCO_2e. This means that steel as a structural material contributes to slightly more than 60 percent of the total structural embodied carbon, with the rest being reinforced concrete.



Pupin Hall Floor Plan Structural Drawings.
Source: Columbia Facilities and Operations.



Pupin Hall Total Structural Materials Replacement Embodied Carbon Pie Chart.
Source: Frederick, 2024

Structural Embodied Carbon	Material EC tCO2e
Steel Grillage	150
Steel Columns	2,800
Steel Floor Framing	5,000
Steel Roof Framing	300
Concrete Pier	30
Concrete Floor Slabs	5,500
Concrete Floor Footing	58
Total	13,800

Pupin Hall Total Structural Materials Replacement Embodied Carbon Chart.
Source: Frederick, 2024

Material	Ext. or New	Volume (m3)	Density kg/m3	Mass (kg)	Embodied Carbon Factor (kgCO2e/kg)	Replacement Cycle (year)	Total Material EC tCO2e
Steel Grillage	Existing	-	7850	88000	1.74	200	155
Steel Columns	Existing	-	7850	1600000	1.74	200	2,800
Steel Floor Framing	Existing	-	7850	2900000	1.74	200	5050
Steel Roof Framing	Existing	-	7850	170000	1.74	200	295
						Total EC on Structural Steel	8,300

Pupin Hall Structural Steel Replacement Embodied Carbon Table.
Source: Frederick, 2024

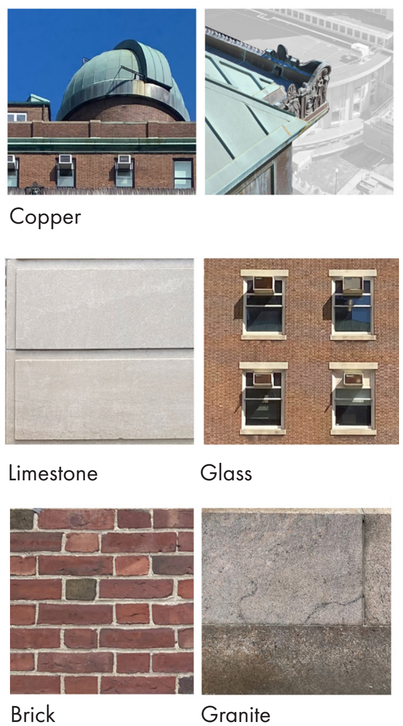
Material	Ext. or New	Volume (m3)	Density kg/m3	Mass (kg)	Embodied Carbon Factor (kgCO2e/kg)	Replacement Cycle (year)	Total Material EC tCO2e
Concrete Pier	Existing	95	2400	228000	0.126	200	30
Concrete Floor Slabs	Existing	18000	2400	43200000	0.126	200	5450
Concrete Floor Footing	Existing	190	2400	456000	0.126	200	58
						Total EC on Structural Concrete	5,500

Pupin Hall Structural Concrete Replacement Embodied Carbon Table. Source: Frederick, 2024

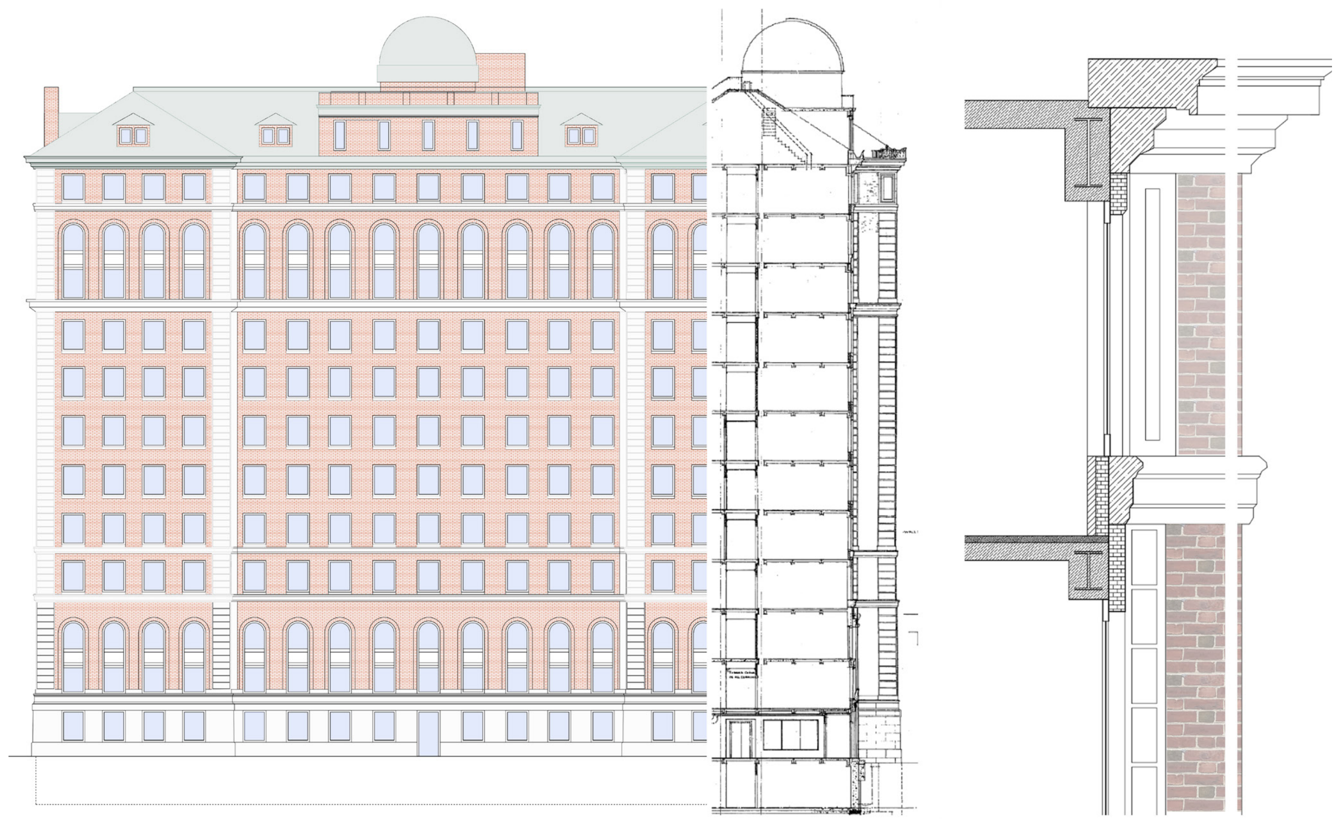
Architectural Materials Overview

As a way to contextualize all the buildings within the Columbia campus, McKim, Mead, and White incorporated materials and ornaments just like they did at the original building halls in the first development phase of the Morningside Heights Campus. At the base of the building there is a granite plinth (that is now only still visible from the 120th Street facade) and limestone encrustations in quoins, window sills, and lintels. Meanwhile at the roof level copper is used heavily as can be observed in cornices, flashing, as well as the roof cladding of the building and the Rutherford Observatory dome.

On the interior, the original partition walls are made of cinder blocks (concrete) and plaster. The auditorium and old classrooms still exhibit the use of hardwood paneling. Furthermore, some material refurbishment has been carried out in spaces like laboratories, libraries, and the Astronomy department facilities, incorporating new materials such as plaster boards, panels and ceiling tiles.



Materials Diagram of Pupin Hall South Facade
Source: Drawing by: Nicolás Moraga, 2024. Photo by: Frederick, 2024



Pupin Hall South Facade Elevation, Section and Facade Detail, based in original drawings.
Source: Drawing by: Nicolás Moraga, 2024.

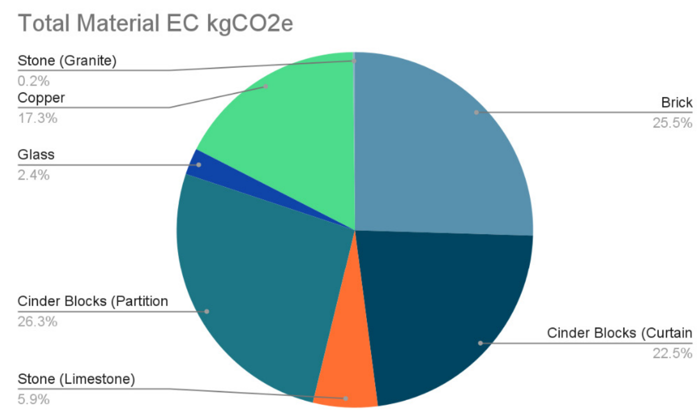
Architectural Materials Replacement Embodied Carbon Calculation

The calculation of replacement embodied carbon included in this report is related to the original state of the building, according to documents provided by Columbia University Facilities and Operations. The elements included in the architectural materials are distinguished for structural elements, including all elements and materials present in the building's facade and roof components. Moreover, floor systems and other structural materials are taken into account as structural materials and would be part of the total replacement of the Embodied carbon calculation of Pupin Hall.

Concrete or cinder blocks account for most of the replacement embodied carbon emissions of architectural materials with 48.8 percent, including the concrete present in interior partition walls (26.3 percent) and curtain walls (22.5 percent). This is followed by brick masonry (25.5 percent) and copper (17.3 percent). In a lower position of embodied carbon emissions are stone elements such as limestone (5.9 percent) and granite (0.2 percent). Windows materials (wood and glass) are in the last place (2.4 percent). All architecture elements result in a total of 5.900 tCO_2e.

Material	Total Material EC tCO2e
Brick	1500
Cinder Blocks (Curtain wall)	1300
Stone (Limestone)	350
Cinder Blocks (Partition Walls)	1500
Glass	150
Copper	1000
Limestone	10
TOTAL	**5,900**

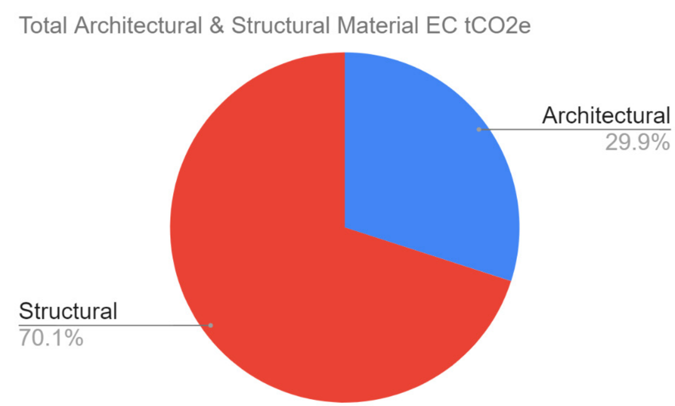
Architectural Materials Replacement Embodied Carbon Pie Chart
Source: Nicolás Moraga, 2024.



Architectural Materials Replacement Embodied Carbon Pie Chart
Source: Nicolás Moraga, 2024.

Total Replacement Embodied Carbon

Pupin Hall contains a substantial amount of embodied carbon, totaling 19,700 tCO_2e. Structural steel and concrete account for slightly more than 70 percent of this carbon, highlighting their significant contribution to the building's carbon footprint. To put this into perspective, according to Greenhouse Gas Equivalencies Calculator by The U.S. Environmental Protection Agency, the embodied carbon in Pupin Hall is equivalent to the CO_2 and greenhouse gas emissions generated by various sources: 50 million miles driven by an average gasoline-powered passenger vehicle, the energy use of 2,500 homes for one year, or the greenhouse gas emissions avoided by 5 wind turbines running for a year (U.S. Environmental Protection Agency 2024).



Pupin Hall Architectural VS Structural Materials Replacement Embodied Carbon Pie Chart. Source: Frederick, 2024

These comparisons underscore the magnitude of Pupin Hall's embodied carbon and emphasize the importance of taking the past carbon investment into account when considering the efforts to reduce the building's environmental impact. As such, strategies to mitigate future embodied carbon expenditures in buildings like Pupin Hall are essential for advancing sustainability goals and minimizing contributions to climate change, all while respecting the integrity of the existing historic structure.

CHALLENGES OF DECARBONIZING LABORATORIES

The U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy published guidelines for low-energy laboratory design in 2003, 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 astro-physics laboratory building, Pupin Hall houses over a hundred laboratories since the beginning of when it was built.


Laboratories for the 21st Century:
An Introduction to Low-Energy Design

As a building type, the laboratory demands our attention: what the cathedral was to the 14th century, the train station was to the 19th century, and the office building was to the 20th century, the laboratory is to the 21st century. That is, it is the building type that embodies, in both program and technology, the spirit and culture of our age and attracts some of the greatest intellectual and economic resources of our society.

Unfortunately, a laboratory is also a prodigious consumer of natural resources. For example, laboratories typically consume 5 to 10 times more energy per square foot than do office buildings. And some specialty laboratories, such as clean rooms and labs with large process loads, can consume as much as 100 times the energy of a similarly sized institutional or commercial structure.

The challenge for architects, engineers, and other building professionals is to design and construct the next generation of laboratories with energy efficiency, renewable energy sources, and sustainable construction practices in mind. And to do so while maintaining — and even advancing — high contemporary standards of comfort, health, and safety.

If we are successful, the benefits will be significant. Assuming that half of all American laboratories can reduce their energy use by 30%, the U.S. Environmental Protection Agency (EPA) estimates that the nation could reduce its annual energy consumption by 84 trillion Btu. This is equivalent to the energy consumed by 840,000 households. An improvement of this magnitude would save $1.25 billion annually and decrease carbon dioxide emissions by 19 million tons — equal to the environmental effects of removing 1.3 million cars from U.S. highways or preventing 56 million trees from being harvested.

Daylighting enhances the scientists' work space at the Fred Hutchinson Cancer Research Center in Seattle, Washington

With these benefits in mind, this publication describes some energy-efficient strategies for designing and equipping the laboratories of the 21st century. It introduces the basic issues associated with energy consumption in the laboratory and summarizes key opportunities to improve or optimize energy performance during each phase of the design and acquisition process. Both standard and advanced new technologies and practices are included.

EPA United States Environmental Protection Agency

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Federal Energy Management Program

Laboratories for The 21st Century Guidelines
Source: The U.S. Environmental Protection Agency, 2003

During a visit to Pupin in 2024, it was observed that most classrooms and offices still rely on the heating and cooling systems from the university's main boiler and central plant. Simultaneously, the majority of laboratories in Pupin require strict air regulation and temperature control as part of their operational requirements. Consequently, in 2015, Columbia installed additional heavy-duty air conditioning units to meet these needs. Furthermore, dozens of single air conditioning units are visible from Pupin's facade.

Moreover, 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 within laboratory buildings like Pupin Hall to decarbonize.

Additional Heavy Duty Air Condensing Indoor Units For Laboratories at Pupin
Source: Frederick, 2024


Fume Hood Exhaust Fans at Pupin's Roof
Source: Frederick, 2024

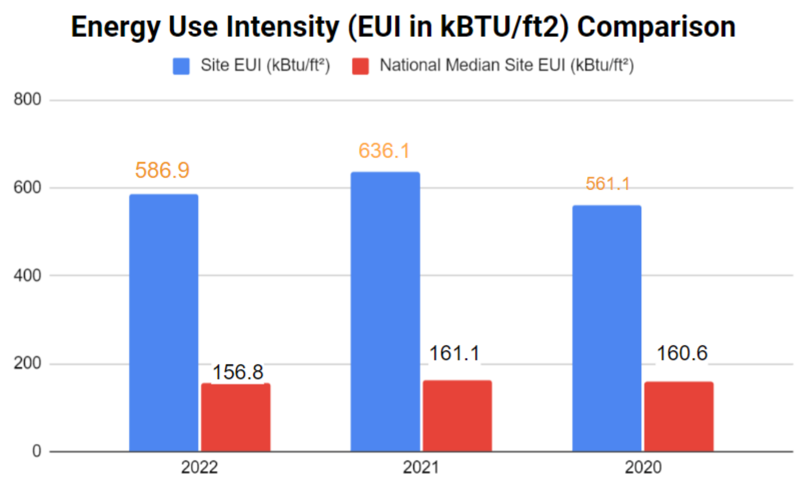
ENERGY USE AND OPERATIONAL CARBON ANALYSIS

Applicable Government Policies

Since the size of Pupin Hall is over 25,000 square feet (standard for LL84/133 and LL97), 50,000 gross square feet (standard for LL87), Pupin Hall has been reporting energy use data to comply with a range of New York City climate policies, including LL84/133 Benchmarking Law, LL87 Energy Audits and Retro-commissioning in 2020, LL97. and the Facade Inspection Program mandated by Local Law 11. This shows that even though Pupin Hall is a National Historic Landmark, Columbia needed to comply with these Local Laws.

Energy Use Intensity (EUI) Comparisons

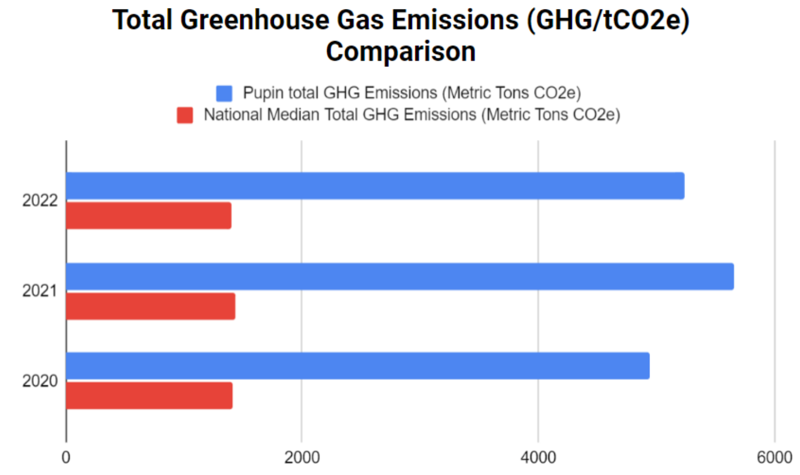
Energy use intensity (EUI) serves as a crucial metric for evaluating a building's energy efficiency. A comparison of Pupin Hall's EUI with the national median site EUI for the years 2020, 2021, and 2022 reveals significant disparities. Pupin Hall consistently exhibits substantially higher EUI scores compared to the national average, potentially indicating inefficiencies in energy consumption. Furthermore, Pupin Hall's EUI surpasses that of the other studio buildings by nearly fivefold, underscoring the magnitude of its energy usage relative to similar structures.



EUI Comparison Graph Based on LL84
Source: Wenqin Meng, 2024

Operational Carbon Analysis

Operational carbon emissions are pivotal in assessing a building's environmental impact. Analysis of the total greenhouse gas (GHG) emissions from Pupin Hall further underscores its environmental footprint. The comparison with the national median highlights Pupin Hall's disproportionately high operational carbon emissions. This finding suggests a pressing need for interventions to mitigate the building's carbon footprint and enhance its sustainability performance.



Total GHG Emissions Comparison Between Pupin Hall and National Median
Source: Wenqin Meng, 2024

Identification of Contributing Factors

Research and consultations with faculty members revealed potential factors contributing to Pupin Hall's high energy use intensity. The presence of physical laboratories within the building is identified as a significant contributor. The specialized equipment and experimental setups in these laboratories likely account for a substantial portion of Pupin Hall's energy consumption. Consequently, reclassifying Pupin Hall as a laboratory building rather than a standard university building may provide a more accurate representation of its energy profile.

Implications of Reclassification

Reclassifying Pupin Hall as a laboratory building carries implications for regulatory compliance and funding accessibility. According to Local Law 97 of 2019 Energy Star Portfolio Manager (ESPM) Reference Guide, laboratory buildings are subject to different emission target factors compared to university buildings (NYC Department of Buildings 2023). The 2024-2029 ESPM building Emission Factors for College/ University is 0.00987 tCO_2e/sf and for laboratories is 0.02381 tCO_2e/sf. Thus, the laboratory's target factor is more than double that of college/university's target factor, meaning that based on NYC's LL97 the building's carbon budget would be more than doubled if the building were classified as a laboratory.

Failure to meet the target emissions may result in penalties, highlighting the importance of compliance with regulatory requirements. However, adherence to the laboratory classification may limit access to government funding opportunities, posing additional challenges for sustainability initiatives within the university.

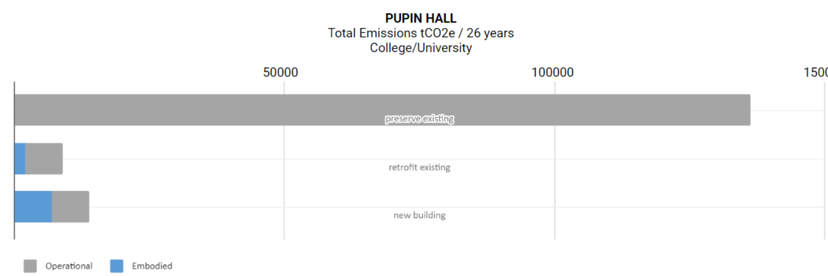
TOTAL EMISSIONS ESTIMATION SCENARIOS

Based on the embodied and operational carbon analysis, Pupin emerges as an energy-intensive structure distinguished by its extensive and sophisticated laboratories,. The CARE Tool was employed to estimate total emissions under two scenarios in order to assess the building's environmental impact and to explore mitigation strategies. In the first scenario, considering Pupin as a college/university building, projections indicate a staggering consumption of 150,000 tCO_2e over the next 26 years if no action were taken. This underscores the urgent need for retrofitting to align with energy targets. On the other hand, constructing a new building would entail additional embodied carbon, while the ongoing energy demands of the physics laboratories remain substantial. Categorizing Pupin as a college/university building and meeting its energy targets presents a formidable challenge, requiring a daunting 91 percent reduction in energy use through retrofitting. Failure to address this issue could result in significant financial penalties under LL97 energy targets, with Columbia facing an accumulated fine of $35 million by 2050 at the current rate of $268 per-$tCO_2e$ emitted above the target.

Energy Star Portfolio Manager (ESPM) Property Types	Building Code (BC)	Section 28-320.3.1 Item #	2024 – 2029 BC Building Emissions Intensity Limit (tCO_2e/sf)	Section 28-320.3.1 Item #	2024 – 2029 ESPM Building Emissions Factor (tCO_2e/sf)
College/University	B	2	0.00846	8	0.00987
Laboratory	B*	6	0.02381	6	0.02381

Target Emission Factor Comparison Between College/University and Laboratory. Source: Energy Star Portfolio Manager, 2019

Pupin Hall's Lecture Auditorium
Source: Frederick, 2024



Pupin Hall Total Emissions tCO2e for 26 years as a College/University Building
Source/Table: Frederick, 2024

Alternatively, categorizing Pupin as a laboratory building, benefiting from larger energy usage allowances under ESPM Building Emissions Target Factors, would result in a substantially lower target reduction of only 4 percent through retrofitting. This significantly more manageable goal enhances feasibility of compliance. Under this classification, failure to address this issue would still result in significant financial penalties under LL97 energy targets, with Columbia facing an accumulated fine of $18 million by 2050 at the current rate of $268 per-t$CO_2$e emitted above the target.

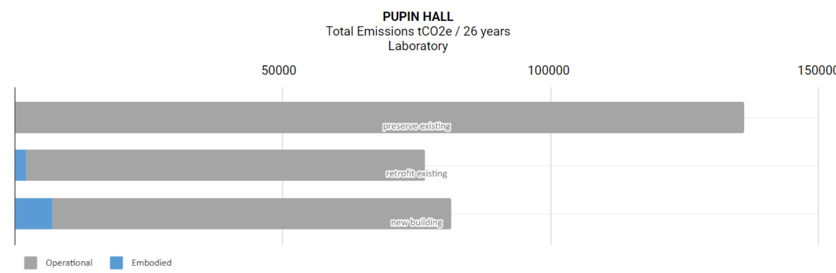
<u>Decarbonization Opportunities</u>

Pupin Hall stands as a symbol of historical significance, offering a platform for ongoing research and innovation in the fields of physics and astronomy. To ensure its continued relevance and honor its legacy, addressing the decarbonization challenges posed by high-energy consumption in laboratories is imperative. By embracing modern technologies and sustainable practices, Pupin can enhance its functionality and efficiency, thereby reducing its environmental footprint while meeting energy reduction targets outlined in LL97 regulations.

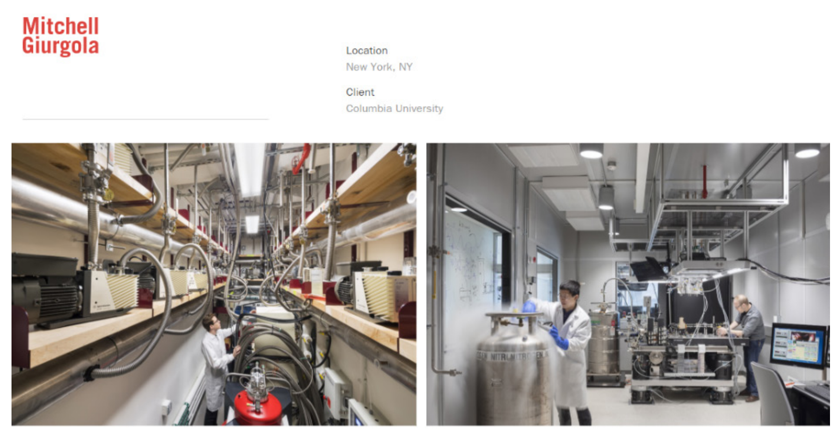
Integration of energy-efficient laboratory equipment, utilization of renewable energy sources, and implementation of advanced building systems are crucial steps in this process. Collaborative efforts with lab design experts offer opportunities for innovative design strategies that optimize energy performance while preserving the building's historical integrity. This may involve retrofitting the physical fabric of the building with improved insulation and high-performance windows.

Furthermore, continuous monitoring and optimization of energy usage are essential to identify areas for improvement and maximize efficiency. Through strategic preservation efforts and a commitment to sustainability, Pupin Hall can continue to thrive as a leading center for physics research while advancing broader sustainability goals.

Pasupathy Lab at Pupin Hall
Source: Photo by Alexander Severin, 2023



Pupin Hall Total Emissions tCO_2e for 26 years as a L:aboratory Building
Source: Table by Erica Avrami & Frederick, 2024



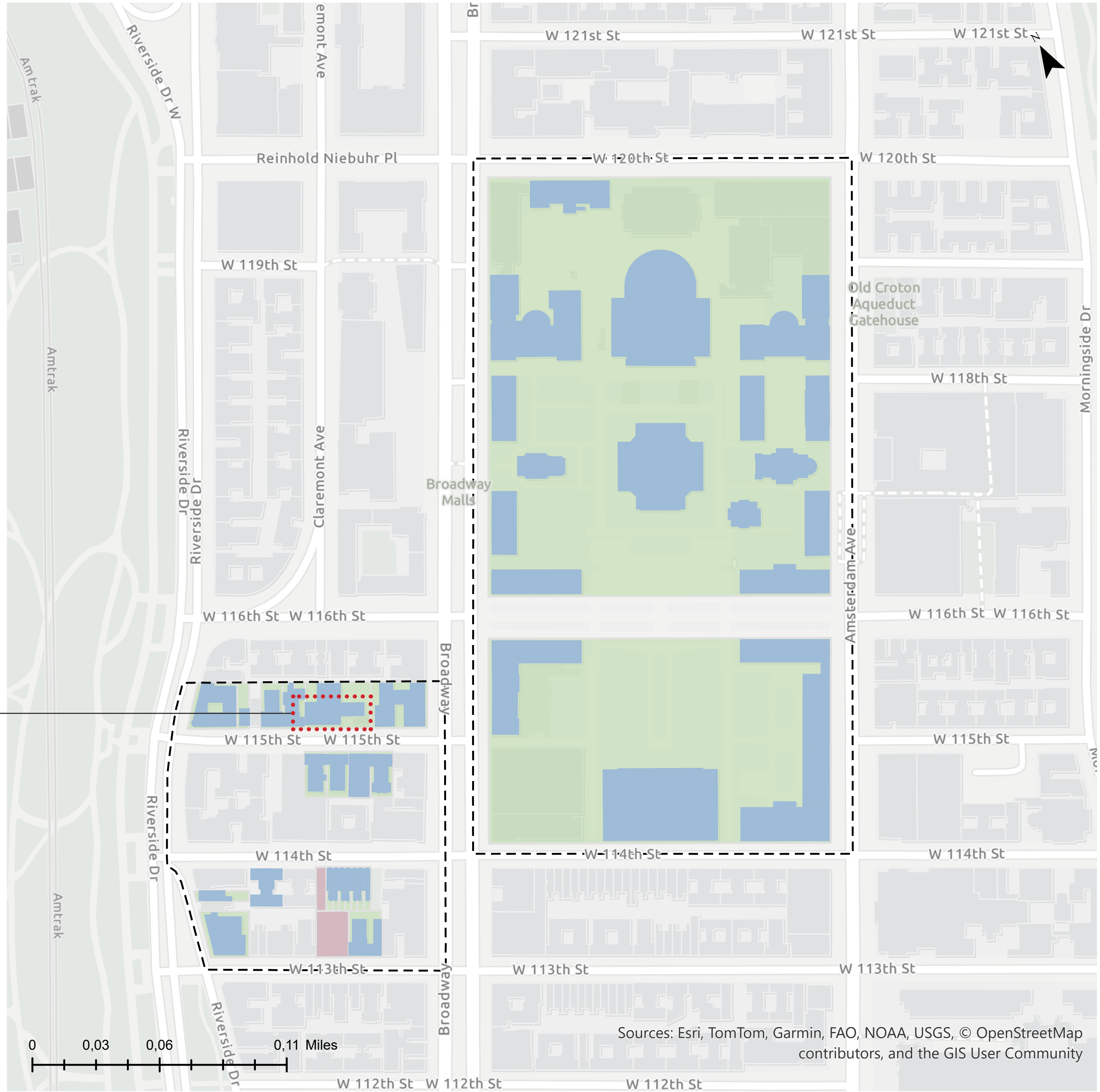
Laboratory Renovations at Pupin Hall
Source: Mitchel Giurgola Architects

CASE III : SCHAPIRO HALL

Students:
Charlotte Crum, Liza Hegedűs, Brandy Nguyen

Schapiro Hall
Photo by Charlotte Crum

CASE III: SCHAPIRO HALL



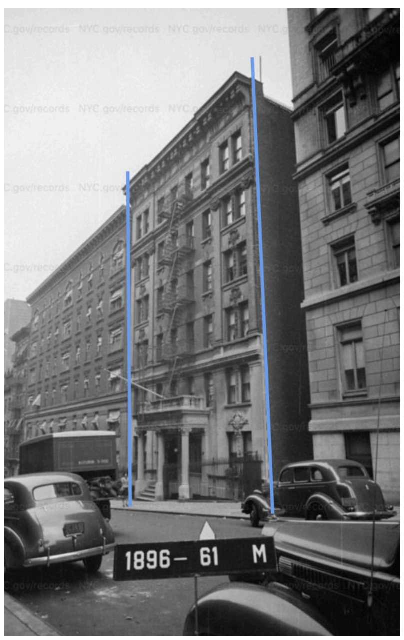
HISTORICAL OVERVIEW

Applicable Government Policies

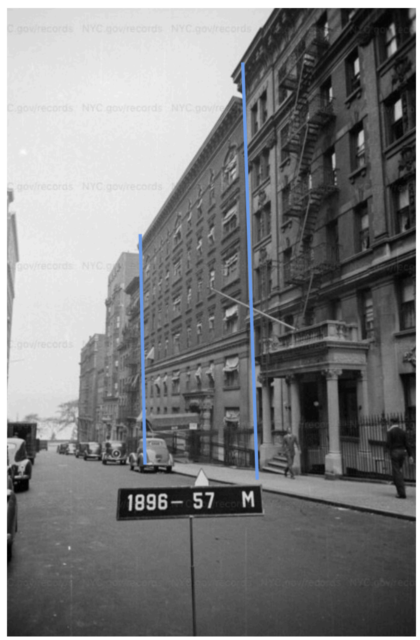
Before Schapiro, there were two adjacent apartment buildings at 605 and 609 West 115 Street, known as "The Bellemore" and "Annamere Court", these new law tenements were constructed in 1903 and acquired by Columbia in 1966. They were eventually demolished in 1977 and stayed vacant until 1987. The lots were later merged, leading to the construction of Schapiro Hall in 1988.

Since the Bellemore and Annamere Court no longer exist, the studio team also utilized River Hall for some parts of the analysis. River Hall, located at 628 West 114 Street, is a current Columbia University-owned new law tenement that was reconfigured into student housing. The team chose to use River Hall as an existing new law tenement example with similar square footage space under the assumption Annamere Court and The Bellmore were not torn down, but rather followed a similar trajectory to be reconfigured as student housing.

Entry to Schapiro Hall.
Source: Columbia Housing.

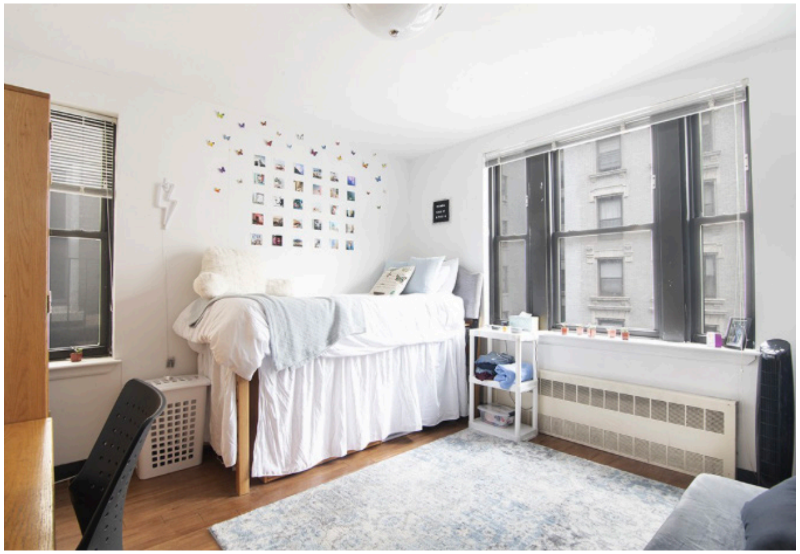


1940s tax photo of the Bellemore. Source: Works Progress Administration/New York City Tax Department



1940s tax photo of Annamere Court. Source: Works Progress Administration/ New York City Tax Department

1980s tax photo of the vacant lot formerly occupied by the Bellemore and Annamere Court.
Source: Works Progress Administration/New York City Tax Department



Typical bedroom in River Hall.
Source: Columbia Housing.

Front facade of River Hall.
Source: Columbia Housing.

Typical floor plan in River Hall.
Source: Columbia Housing.

NEIGHBORHOOD CONTEXT

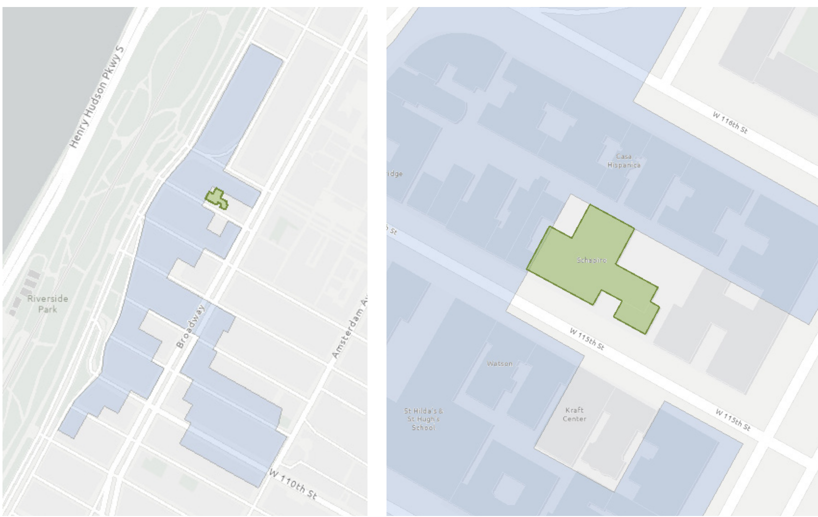
Neighborhood Before Demolition

According to an article from The New York Times, several buildings in the West District, if not the neighborhood as a whole, was considered "run-down" by the late 1960s (Fraser 1968). Though neither Annamere Court or the Bellemore were listed as blighted or single-room occupancy properties by Morningside Heights, Inc., it is important to recognize that Columbia's acquisition of the properties was part of a larger pattern of neighborhood redevelopment and urban renewal.

Annamere and Bellmore were cited with multiple violations for the construction of unpermitted interior partitions, and 1950 census records indicate that several units were crowded with several more occupants than originally designed for. The poor management of both buildings, as well as the neighborhood's negative reputation throughout the late twentieth century, may be critical reasons for why Schapiro Hall was designed to be strikingly different from its context in the West District. The studio team maintains that Schapiro's streamlined, monumental appearance remains as an important, symbolic remnant of its historic context.

Impact of Schapiro on the Neighborhood

Had the buildings of Annamere Court and the Bellemore not been demolished in 1977 and retained their historical integrity, it is likely both buildings would be eligible for inclusion in the NYC Landmark Preservation Commission's Morningside Heights Historic District and the National Register of Historic Place's Broadway-Riverside Drive Historic District. Designated in 2017, the NYC Morningside Heights Historic District was unable to protect these characteristic New Law Tenement properties, which would have been one of the 115 buildings built in the late nineteenth and early twentieth century that define this district, including the nearby comparison case of River Hall. Other character-defining features of this neighborhood are the earthy hues of red, brown, and white of common materials like brick, brownstone, limestone, and terracotta, designed in the popular revival styles of the era, including Colonial revival, Georgian revival, and Renaissance revival (Percival 2017).



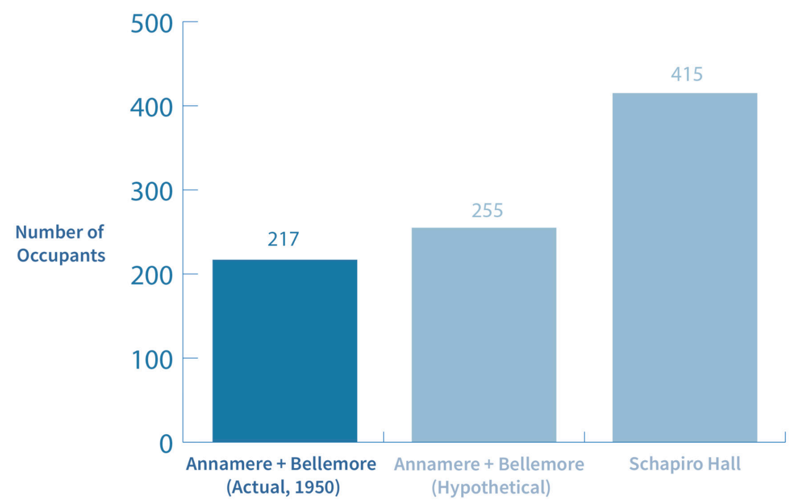
NYC Morningside Heights Historic District and Close-Up of Boundary Near Schapiro Hall.
Data Source: NYC LPC, NYC Open Data. Mapper: Studio II Mapping Group.

Mapping evaluations show how carefully the boundary of the LPC historic district was drawn to exclude Schapiro Hall. This is unsurprising, as the building lacks the architectural character, scale, or age of its surrounding buildings. Furthermore, many preservationists consider it an eyesore which disrupts the historic neighborhood fabric. However, the architects of Schapiro Hall shared a different perspective. Upon the announcement of the opening of the dormitory for the 1988-1989 school year, Fred Knubel, Director of Columbia's Office of Public Information writes, "The building, designed by Gruzen Samton Steinglass... was built on land long used as a University parking lot. Its 17-story red-brick tower and two nine-story limestone-colored wings blend with the residential character of the surrounding neighborhood and echo the tones of Columbia's historic McKim, Mead, & White buildings. 'The building is a very good neighbor to its block,' says GSS partner Peter Samton. The building's bay windows, characteristic of Upper West Side residential architecture, permit views of the main campus, and from higher floors, the Hudson River and Manhattan" (1988, 4).

DEMOLITION OF ANNAMARE AND BELLMORE: HISTORICAL ANALYSIS OF TRADE-OFFS

According to census records from the 1950s both Annamere and Bellemore were largely occupied by students, faculty, and staff (with some other professionals listed). Several of the units were occupied by 7-8 students which suggests that major interior configurations had already occurred before Columbia acquired the buildings in 1966.

Actual 1950 Census: Thus, in 1950 Annamere Court had 129 residents and Bellemore had 88 residents totaling 217 students.



Actual number of occupants in Annamere Court and the Bellemore, 1950.
Data source: 1950s US Census.

Hypothetical: The existing River Hall has six residential floors with 31,906 square feet and 127 single rooms. This means that there is roughly 251 square feet of space per student. Annamere Court was 43,056 square feet meaning there would have been space for roughly 171 students. The Bellemore was 21,132 square feet meaning there would have been space for roughly 84 students. This shows that hypothetically 255 students would have been accommodated had Annamere Court and Bellemore not been torn down.

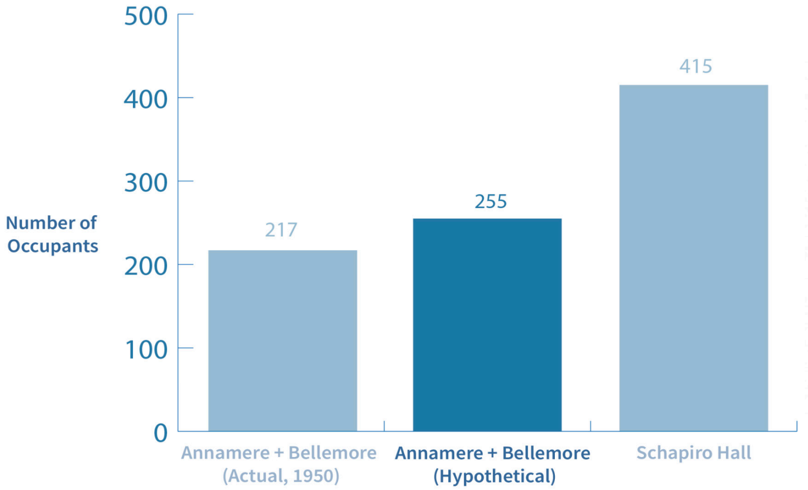
Schapiro: Schapiro Hall is 17 floors and 115,000 square feet. The residence hall has 245 single and 85 double rooms with shared gendered bathrooms available on each floor. This means that Schapiro Hall can fit up to 415 students and provides roughly 277 square feet of space per student.

Benefits Beyond Beds

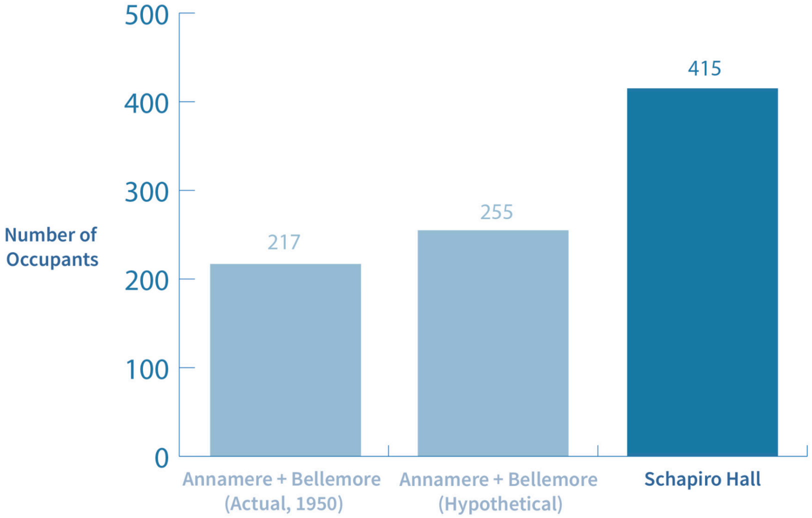
It is evident that Columbia did not just build Schapiro to increase the number of beds. Schapiro hall also incorporates multiple kitchens per floor, shared gendered bathrooms, many lounges, two theaters, music rooms, computer labs, and study rooms. These extra spaces are necessary accommodations for students and still, to this day, Columbia lacks space for these necessities. Although Annamere and Bellemore fit 217 students, it is evident that Schapiro provides additional accommodations for students that would otherwise not have been possible. Furthermore, based on Columbia's housing website and discussions with students during the team's site visit, it is clear that students have positive experiences living in Schapiro Hall.

Typical shared kitchen in Schapiro Hall.
Source/photographer: Liza Hegedűs.

Actual number of occupants in Annamere Court and the Bellemore, 1950.
Data source: 1950s US Census.



Hypothetical number of occupants able to occupy Annamere Court and the Bellemore, based on density of River Hall.
Data source: Apartment Houses of the Metropolis (New York: G. C. Hesselgren Publishing Co, 1908) and Columbia Housing

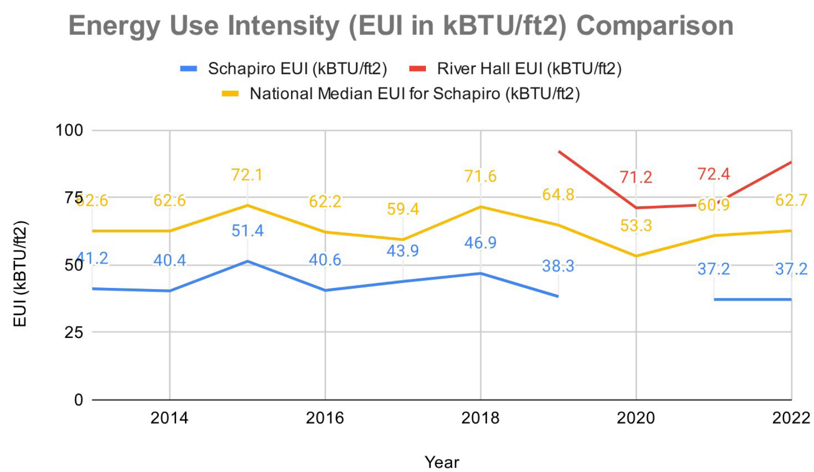


Hypothetical number of occupants able to occupy Annamere Court and the Bellemore, based on density of River Hall.
Data source: Apartment Houses of the Metropolis (New York: G. C. Hesselgren Publishing Co, 1908) and Columbia Housing

SCHAPIRO'S OPERATIONAL ENERGY

Pulling from data collected by NYC LL84, the energy use intensity of Schapiro Hall (on this graph in blue) is better compared to the national median (on this graph in yellow). LL84 data for River Hall only began being reported in 2019 (on this graph in red), illustrating the inconsistency of this reporting data. However, over the last four years Schapiro Hall has performed much better compared to the hypothetical case of River Hall (on this graph in red). Schapiro's EUI has remained fairly consistent since the data began getting reported in 2013.

And while Schapiro currently seems to be performing well from an energy efficiency perspective, NYC does not base their allowances on this metric. LL 97 sets targets based on emissions factors. Schapiro Hall meets their emissions target through 2029, but fails starting in 2030. Columbia will need to decide whether they will update the building to meet the targets, or pay the fines associated with being over the targets, which will at a minimum total approximately $1.4 million by 2050 (New York City 2019).

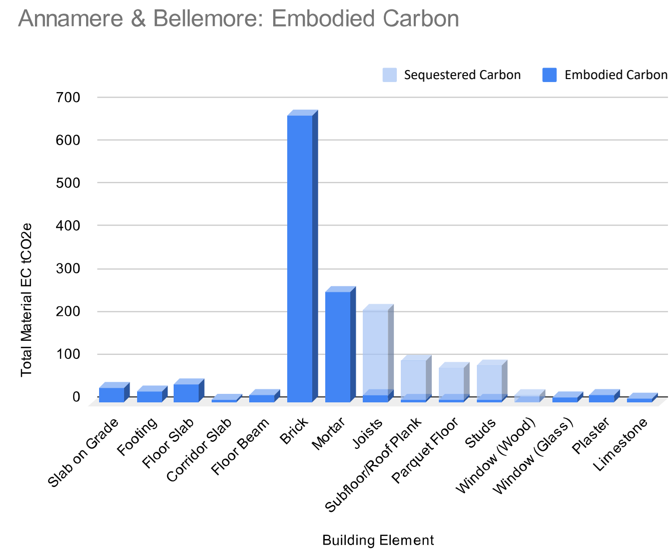


Schapiro Hall and River Hall Annual EUI, 2013-2022. Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data.

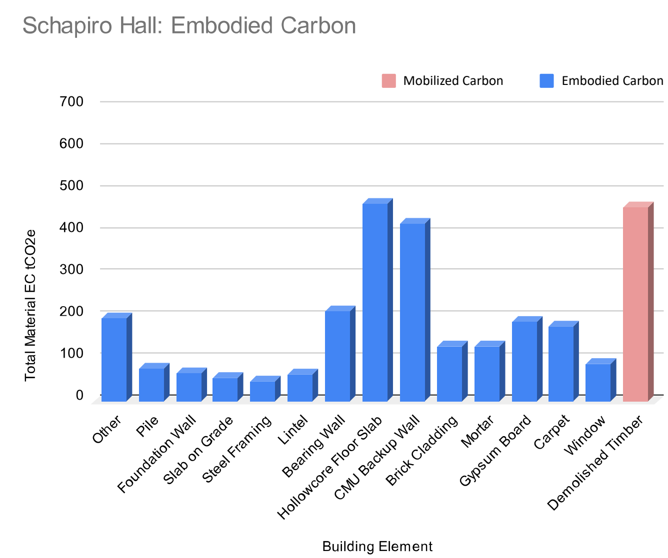
SCHAPIRO'S EMBODIED CARBON

<u>In Comparison with Annamere Court and the Bellemore</u>

This study concludes that the embodied carbon value of Schapiro Hall's construction is approximately 2,300 tCO_2e. This is six times higher than Schapiro's annual operational carbon, which was reported under Local Law 84 as 366 tCO_2e in 2022.



Combined embodied carbon of Annamere Court and the Bellemore (tCO2e) by building component. Data source: ICE DB V3.0, and IStructE.



Embodied carbon of Schapiro Hall (tCO_2e) by building component.. Data source: Ice DB V3.0, EC3, CUIN Glass, and IStructE.

As noted earlier, Annamere and Bellemore Court would have been able to hypothetically house 255 students if they remained standing. By comparison, Schapiro Hall is able to house 415 students. Therefore, one might characterize Columbia University's decision to construct a massive undergraduate dormitory as being excessive. For a building twice the size of those it replaced, Schapiro Hall ultimately houses only an additional 160 students. In terms of embodied carbon, this represents a one-time cost of about 15 tCO_2e per additional bed, the equivalent of burning 35 barrels of oil per bed.

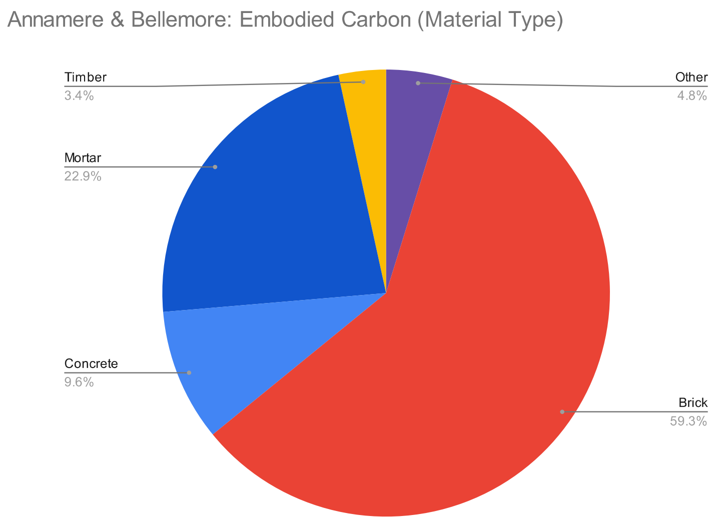
In addition to its embodied carbon, the demolition and subsequent mobilization of biogenic carbon within Annamere Court and the Bellemore's timber elements (given the strong possibility that none of these materials were recycled) represents an additional 460 tCO_2 of emitted carbon—the equivalent of driving around the Earth 47 times. This demolition-related carbon equates to 20 percent of Schapiro Hall's total construction-related embodied carbon, or 42 percent of Annamere and Bellemore's construction-related embodied carbon.

Preserving, maintaining, or reusing the wood would have delayed this CO_2 from being released into the atmosphere. This does not include the lost value of landfilled brick, stone, windows, or other reusable building materials from Annamere Court and the Bellemore, which amounts to approximately 660 tCO_2e, if not much greater, depending on brick and timber sourcing.

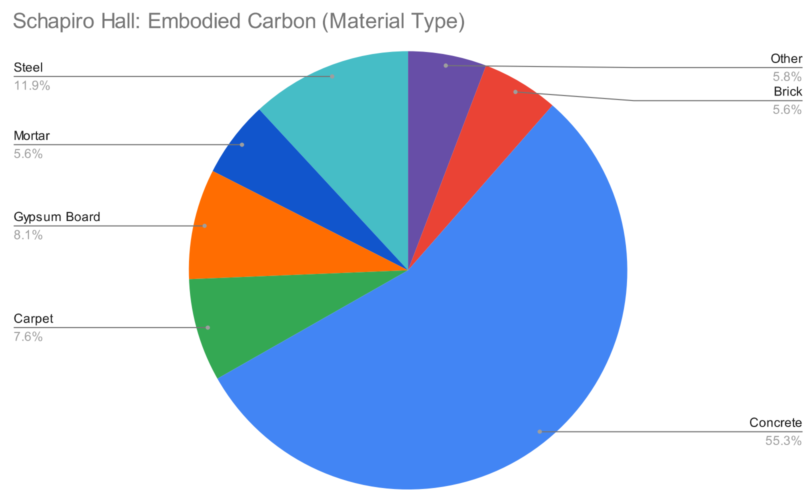
As a 17-story building encompassing over 100,000 square feet of habitable space, Schapiro Hall predictably represents a much higher amount of embodied carbon than Annamere and Bellemore Court combined. However, even when quantifying Schapiro's embodied carbon on a per-square foot basis—and especially on a per-student basis—we see that its carbon expenditure is still greater than either of the buildings it replaced.

Surprising Sources of Embodied Carbon at Schapiro

While Schapiro contains a higher concentration of concrete and steel, it lacks much more carbon-intensive building elements, such as Annamere and Bellemore's solid brick masonry walls or old-growth timber. However, Schapiro's embodied carbon per square foot value is calculated to be approximately 18 $kgCO_2e/ft2$, which remains higher than Annamere and Bellemore's 16 $kgCO_2e/ft2$.

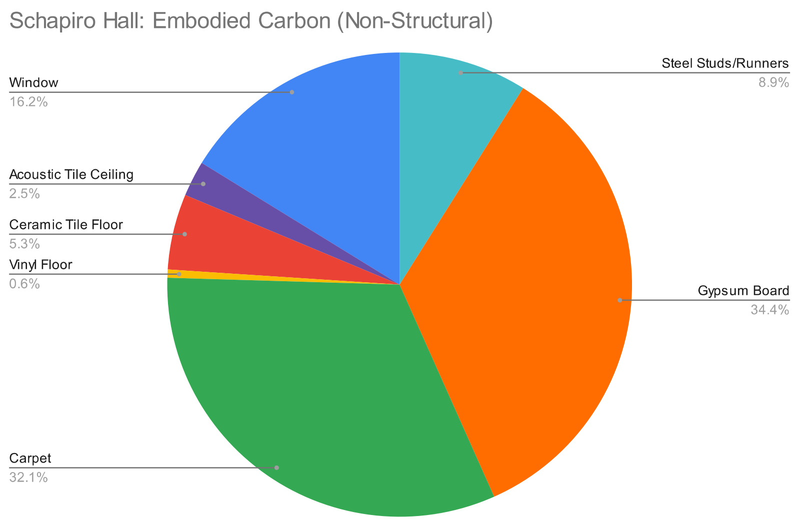


Combined embodied carbon of Annamere Court and the Bellemore (tCO2e) by material type. Data source: ICE DB V3.0, and IStructE.



Embodied carbon of Schapiro Hall (tCO_2e) by material type. Data source: Ice DB V3.0, EC3, CUIN Glass, and IStructE.

Our studio found unexpected interior components that contributed to the 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.



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.

Several of Schapiro's components, including its carpet, are especially liable to be replaced. These elements include its finished floors, ceilings, windows, and partitions. These components, even without regular replacement or maintenance, already represent nearly 550 tCO_2e, nearly a quarter of Schapiro's total embodied carbon. In this category, carpet remains one of the largest concerns, amounting to twice the embodied carbon of Schapiro's windows. Carpet currently represents six percent of Schapiro's total embodied carbon. If all the carpet were replaced even just once, the cumulative carpet-related embodied carbon would exceed that of the building's steel (assuming an average carbon-intensive replacement carpet at $20kgCO_2e/m2$). If more information were available on the interior finishes of the demolished buildings, one might also find some similarly carbon-intensive components.

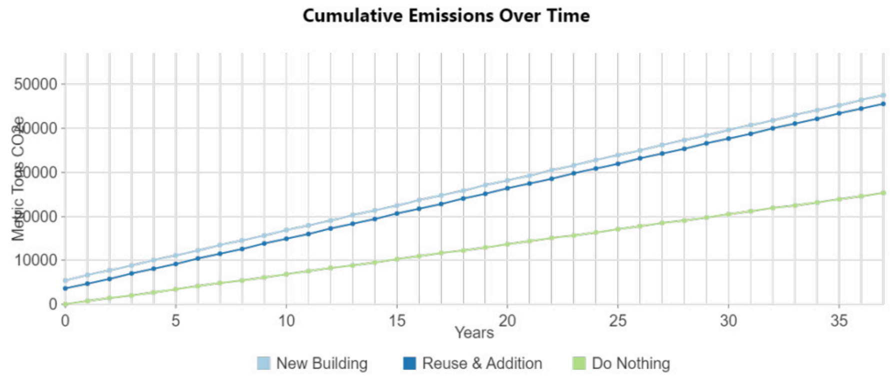
FUTURE OF SCHAPIRO

Zoning District and FAR

Schapiro's lot has an area of 15,138 square feet and a gross floor area of 107,703 square feet. The building is located in district R8 where buildings can range from mid-rise, eight to ten story buildings to much taller buildings set back from the street on large zoning lots. The floor area ratio (FAR) for height factor development in R8 districts ranges from 0.94 to 6.02 and the current FAR for Schapiro is 7.11. This FAR concludes that a bigger building could not be built on the lot. As for the original buildings, Annamere Court and Bellemore, their FAR was 4.24 which proves that the lot could have afforded a larger building.

Was Schapiro a Mistake?

Reflecting on the relationship between the operational and embodied emissions of Schapiro Hall, based on energy data and material calculations, a roughly estimated analysis was run of how Schapiro has performed given possible parameters set during its construction in the late 1980s, compared to how significant changes to Annamere and Bellemore. Because Schapiro was built 37 years ago, the analysis timeline was set to this value to assess the cumulative operational and embodied carbon emissions over the building's lifetime thus far. The "Do Nothing" as a baseline is a much lower square footage, and therefore not comparable to the increased size of scenarios two and three. The main point of this discussion is that the embodied emissions to rebuild a new building (Schapiro) when compared to the previous building, approach each other to a very similar margin over time. The rough estimate provided by the CARE tool analysis is less than 2,000 tCO_2e, or 4 percent of the new building's cumulative operational and embodied emissions, with this proportion decreasing each year that Schapiro Hall continues to operate.

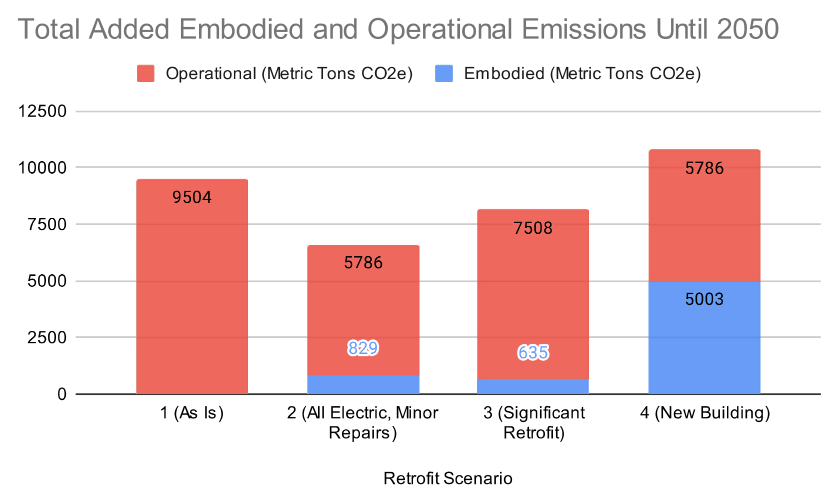


	DO NOTHING	REUSE & ADDITION	NEW BUILDING
Embodied Emissions (Metric Tons CO2e, cradle to ga	N/A	3522	5427
Operational Emissions (Metric Tons CO2e / 37 years)	25235	42124	42124
Total Emissions (Metric Tons CO2e / 37 years)	25235	45646	47551
Total Emissions Intensity ($kgCO_2e/ft^2$ / 37 years)	378	391	407

Estimated Analysis Comparing Operational and Embodied Carbon of Schapiro Hall to Annamere Court and the Bellemore with Significance Additions using the CARE Tool
Source: CARE TooL.

Schapiro's Future

Looking to Schapiro's future and its current project to exceed NYC targets by 2030, the team developed two retrofit options to compare to new construction. Because of Schapiro's current well-performing energy efficiency, if the building is electrified and the grid is clean by 2040, it will meet its required targets (as exemplified in Scenario 2). However, if the energy efficiency is not improved, there will still be a large energy consumption, which stresses whatever resources the grid pulls from (clean or unclean). In the case that Schapiro is not fully electrified (still on the steam loop) and requires significant retrofits to meet emissions targets, the team ran Scenario 3. While both retrofit scenarios perform better than a completely new building, the difference in emissions is mostly due to the operational side, dependent on factors outside of just Schapiro's energy sourcing and efficiency. Also, in running this tool on new construction, using low emissions concrete only reduced the new building's total emissions intensity by 5 percent, illustrating that low emission materials are not going to account for all the progress that needs to be made in the built environment. Instead of new construction, retrofitting existing buildings to reduce operational carbon, while using material recycling and low embodied carbon materials to conduct these retrofits may be the optimal solution given the time constraints of preventing climate collapse.



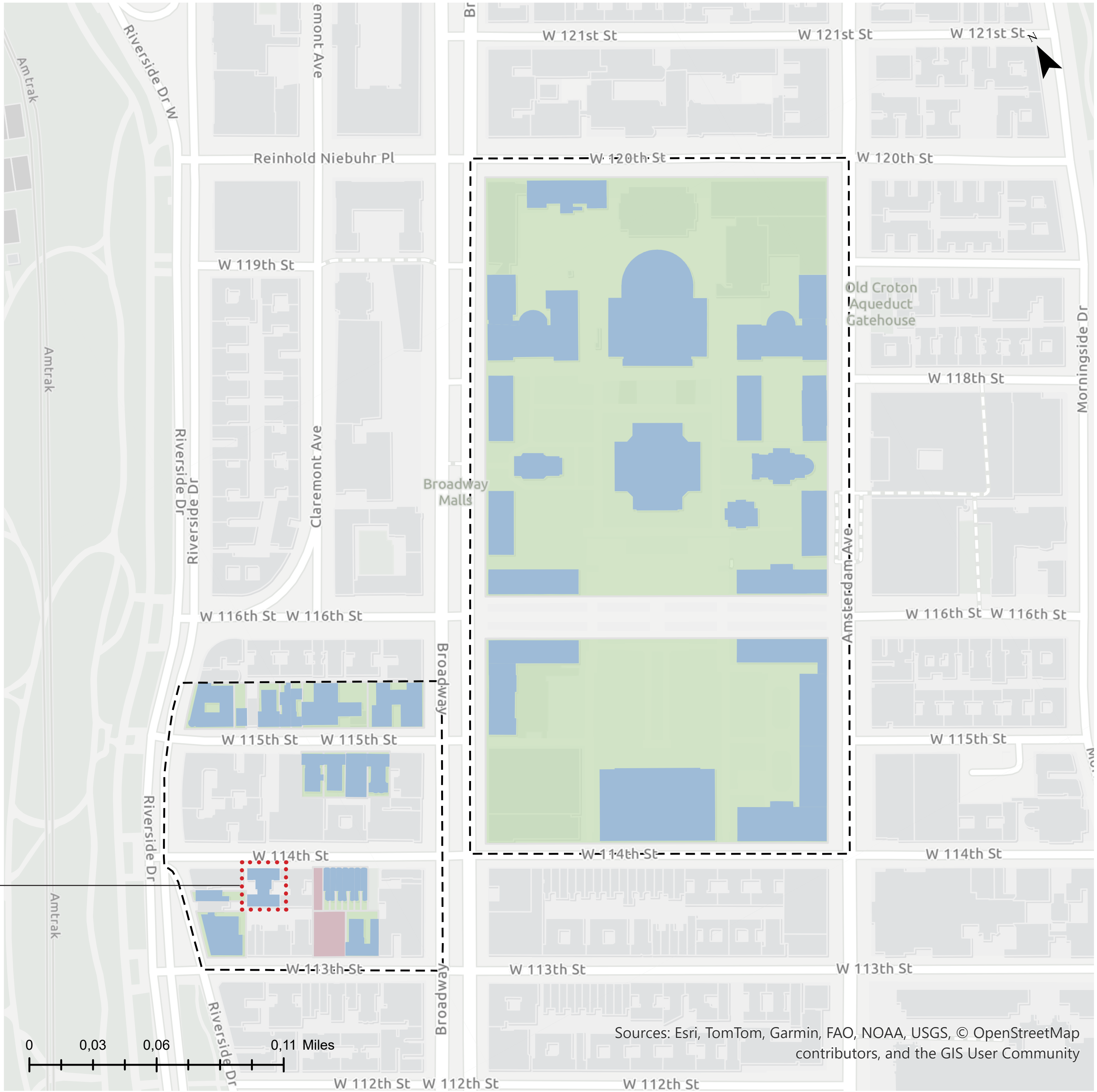
Embodied carbon of Schapiro Hall (tCO_2e) by building component..
Data source: Ice DB V3.0, EC3, CUIN Glass, and IStructE.

CASE IV: ALUMNI CENTER

Students:
Illy Auerbach, Cecelia Halle, Anne Maxwell Foster, Marieke Van Asselt

Columbia University Alumni Center, New York, NY
Source/Photographer: Alexander Severin Architectural Photography

CASE IV: ALUMNI CENTER



ALUMNI CENTER

Alumni Center is situated within the Morningside Heights Historic District and is a compelling example of an early twentieth-century Georgian Revival apartment house. However, beyond its architectural significance, the Center occupies a complicated space in discussions of reuse, LEED certification, and energy consumption, which made the building a compelling case within Columbia's building portfolio and the studio research project.

HISTORICAL SIGNIFICANCE

Located at 622 West 113th Street, and known today as the Columbia Alumni Center, is a new law tenant designed by Schwartz and erected in 1908. Initially referred to as "Victor Hall," the eight-story building exhibits typical classically inspired characteristics, such as a clearly organized facade with limestone at the first two stories, Flemish-bond red-brick cladding at the mid-and upper sections, and upper stories with additional panels and heavily molded ornament. There are ornamental iron Juliet balconies, decorative terra cotta, arched windows at the top story, and a cornice with closely spaced medallions.

Since 2017, Alumni Center has been recognized as a contributing building to the NYC Morningside Heights Historic District and is eligible for the National Register of Historic Places. The building was constructed a few years after the subway's completion at 110th St, during a period of significant residential development in the area (Dolkart 1998, 290). At an unknown date, it became an SRO or single-room occupancy residence called the Princeton Hotel. This SRO gained notoriety as a highly problematic place occupied by alcoholics and addicts and was considered "one of the worst in the area" (Dolin 1965). In October 1965, one year before being purchased by Columbia, a Columbia Spectator article revealed Colombia's plans to "clean up" the neighborhood by purchasing buildings, including this one, and relocating their residents (Dolin 1965). This purchase was part of a larger plan addressing slums in Morningside Heights. Under the "General Neighborhood Renewal Plan" of 1964, institutions in the neighborhood started to buy and redevelop SROs and other buildings. This plan made Columbia University the biggest owner in the area by acquiring more than 100 buildings during the 1950's and 1960's. By transforming the buildings either into dormitories or other usages, the institutions hoped to ameliorate poor living conditions and improve safety around campus (Bradley 2008

Victor Hall, 1910
Source: Photographer: Wurts Brothers, Museum of the City of New York

TIMELINE OF ALTERATIONS

1969

In 1969, when Columbia first purchased the building as a blighted SRO, it underwent its first adaptive reuse into an academic building. The interior partitions changed to adapt to programmatic needs. Partitions were removed at the southern end of the building to create larger seminar rooms and offices. The major impact on embodied carbon investment in building to create larger seminar rooms and offices. The major impact on embodied carbon investment in 1969 was the addition of stairs in the center of the building on both sides. The Timeline of Alterations shows the concrete used to enclose the extra set of stairs.

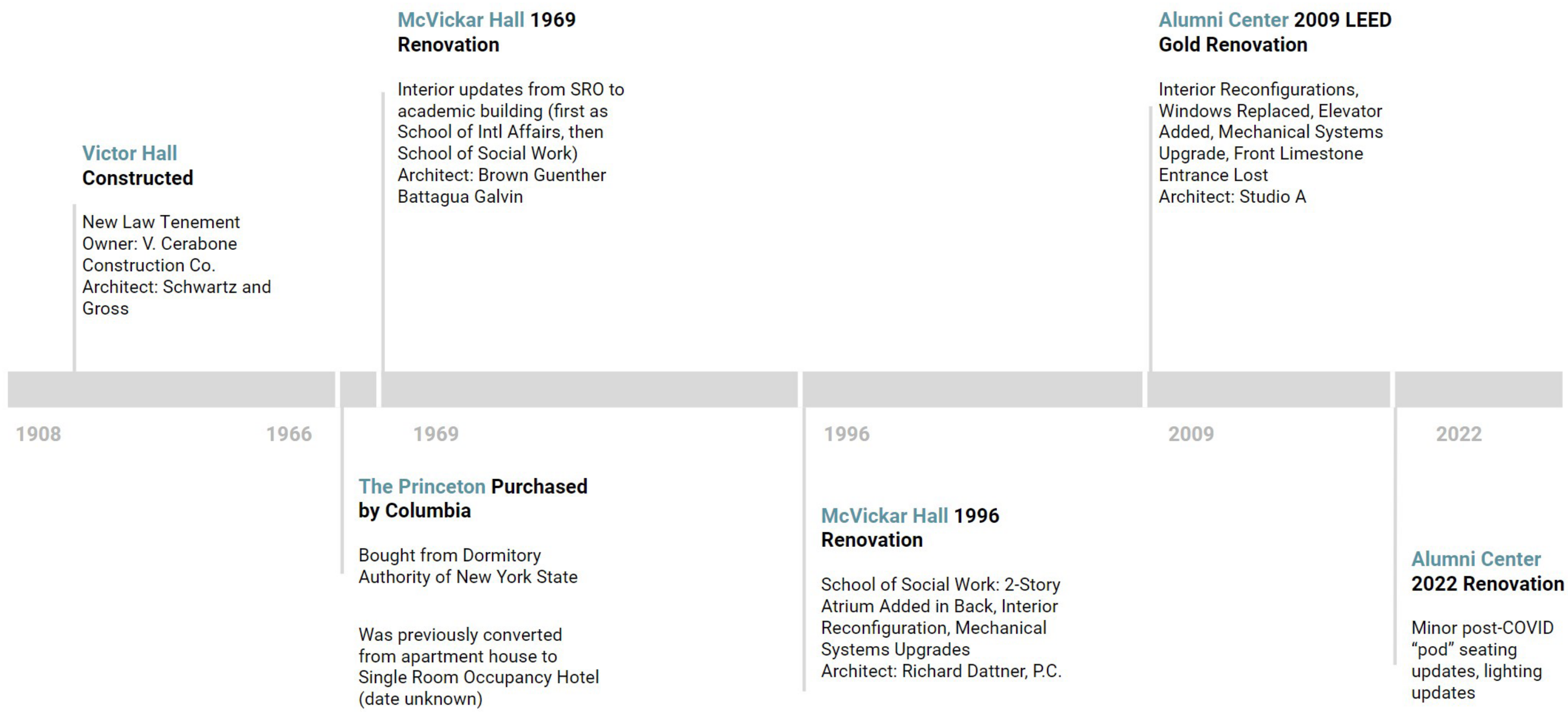
1996

The renovation in 1996 maintained its use as the School of Social Work. Again interior partitions change, creating even larger lecture and academic work spaces, and space to accommodate computers. The addition of a two story atrium outdoor space at the back South end of the building, first floor and basement levels added about 730 square feet.

2009

In 2009, the School of Social Work was moved and 622 West 113th became Columbia's Alumni Center, while undergoing this renovation, Columbia was awarded LEED Gold designation.

The greatest embodied carbon interventions in 2009 was converting the outdoor atrium area to enclosed covered space on the basement and first floors. A second elevator was added and new concrete slab infill was poured - shown in the hatched area on the first floor plan. All of the windows were replaced, the roof was completely renovated and insulation was added. The historic front entrance steps were replaced with new granite and reuse of some of the wrought iron.



Timeline of Alterations: 1908 - Present
Source: Illy Auerbach, Cecelia Halle, Anne Maxwell Foster, Marieke Van Asselt

ALUMNI CENTER: A LEED-CERTIFIED BUILDING

Alumni Center achieved LEED Gold certification on December 23, 2010, earning a total of 39 points out of 69 in the LEED program version 2.2. 39 was the minimum number of points required to attain Gold status in 2010. Some of the major features which contributed to the certification:

- New double pane windows with low-e, argon filled glass
- Exterior wall and roof insulation
- New cool roof with high solar reflectivity
- Building reuse: maintain 75 percent of existing walls, floor, and roof
- Historic facade was repaired, cleaned, and restored
- Energy efficient lighting which automatically dims with sufficient daylight
- Increased ventilation
- Interior finishes with zero or low VOC were selected
- Thermal comfort design and verification
- Mechanical system updates:
    - Steam Absorption Chiller, intended to reduce electricity demand in the summer
    - Heat Recovery Unit (HRU) which helps recover heated or cooled air from the exhaust and recirculate

10023263, New York, New York

McVickar Hall Development Offices

LEED BD+C: New Construction (v2.2)

GOLD, AWARDED DEC 2010

SUSTAINABLE SITES		AWARDED: 6 / 14
SSp1	Construction activity pollution prevention	REQUIRED
SSc1	Site selection	1 / 1
SSc2	Development density and community connectivity	1 / 1
SSc3	Brownfield redevelopment	1 / 1
SSc4.1	Alternative transportation - public transportation access	1 / 1
SSc4.2	Alternative transportation - bicycle storage and changing rooms	0 / 1
SSc4.3	Alternative transportation - low emitting and fuel efficient vehicles	0 / 1
SSc4.4	Alternative transportation - parking capacity	1 / 1
SSc5.1	Site development - protect or restore habitat	0 / 1
SSc5.2	Site development - maximize open space	0 / 1
SSc6.1	Stormwater design - quantity control	0 / 1
SSc6.2	Stormwater design - quality control	0 / 1
SSc7.1	Heat island effect - non-roof	0 / 1
SSc7.2	Heat island effect - roof	1 / 1
SSc8	Light pollution reduction	0 / 1

WATER EFFICIENCY		AWARDED: 2 / 5
WEc1.1	Water efficient landscaping - reduce by 50%	0 / 1
WEc1.2	Water efficient landscaping - no potable water use or no irrigation	0 / 1
WEc2	Innovative wastewater technologies	0 / 1
WEc3.1	Water use reduction - 20% reduction	1 / 1
WEc3.2	Water use reduction - 30% reduction	1 / 1

ENERGY & ATMOSPHERE		AWARDED: 7 / 17
EAp1	Fundamental commissioning of the building energy systems	REQUIRED
EAp2	Minimum energy performance	REQUIRED
EAp3	Fundamental refrigerant Mgmt	REQUIRED
EAc1	Optimize energy performance	5 / 10
EAc2	On-site renewable energy	0 / 3
EAc3	Enhanced commissioning	1 / 1
EAc4	Enhanced refrigerant Mgmt	1 / 1
EAc5	Measurement and verification	0 / 1
EAc6	Green power	0 / 1

MATERIAL & RESOURCES		AWARDED: 7 / 13
MRp1	Storage and collection of recyclables	REQUIRED
MRc1.1	Building reuse - maintain 75% of existing walls, floors & roof	1 / 1
MRc1.2	Building reuse - maintain 95% of existing walls, floors & roof	0 / 1
MRc1.3	Building reuse - maintain 50% of interior non-structural elements	0 / 1
MRc2.1	Construction waste Mgmt - divert 50% from disposal	1 / 1
MRc2.2	Construction waste Mgmt - divert 75% from disposal	1 / 1

MATERIAL & RESOURCES		CONTINUED
MRc3.1	Materials reuse - 5%	0 / 1
MRc3.2	Materials reuse - 10%	0 / 1
MRc4.1	Recycled content - 10% (post-consumer + 1/2 pre-consumer)	2 / 1
MRc4.2	Recycled content - 20% (post-consumer + 1/2 pre-consumer)	0 / 1
MRc5.1	Regional materials - 10% extracted, processed and manufactured regiona...	1 / 1
MRc5.2	Regional materials - 20% extracted, processed and manufactured regiona...	1 / 1
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	0 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 12 / 15
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - carpet systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	1 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	1 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	0 / 1
EQc8.1	Daylight and views - daylight 75% of spaces	1 / 1
EQc8.2	Daylight and views - views for 90% of spaces	1 / 1

INNOVATION		AWARDED: 5 / 5
IDc1	Innovation in design	1 / 1
IDc2	LEED Accredited Professional	1 / 1

TOTAL	39 / 69

LEED BD+C New Construction (v2.2)Source/ Scorecard: McVickar Hall Development Offices
https://www.usgbc.org/projects/mcvickar-hall-development-offices

LEED POINT CARBON IMPACTS

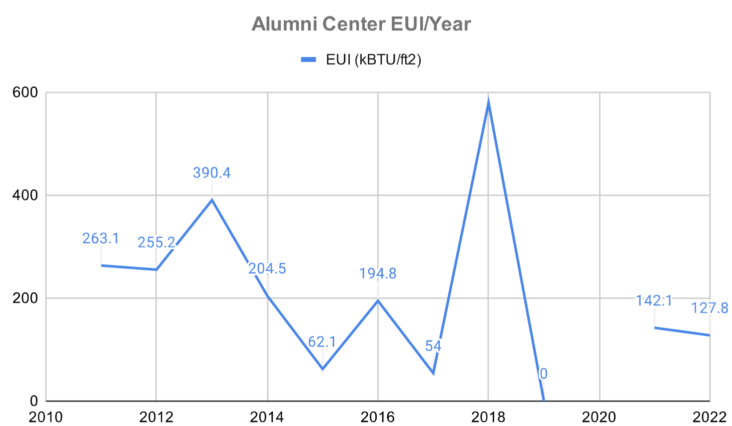
The 2009 LEED renovation made significant changes to the building envelope and mechanical, electrical and plumbing (MEP) systems that would theoretically, with consistent maintenance and upkeep, reduce energy consumption and operational carbon. Notably, the addition of exterior wall and roof insulation, new double pane low-e glass windows, and a new cool roof (nearly a decade ahead of law requirements) likely reduced Alumni Center's annual operating carbon emissions.

While achieving LEED certification begins with best intentions for sustainable construction, the rating system is flawed. Scholarship into the LEED certification program now suggests that in many or even most cases, LEED buildings perform no better than non-LEED buildings

(Clay, Severnini, and Sun 2023). In the case of Alumni Center, there are LEED points earned for its GOLD certification that could be considered "greenwashing" such as site selection and access to public transportation. Twelve of fifteen possible points were awarded for Indoor Environmental Quality which focuses on fresh air ventilation and healthy indoor material selections. These points made up over thirty percent of the total points awarded for LEED certification. These features may certainly lead to positive health and well-being implications for those using the building; however, they provide minimal to zero impact on the reduction of carbon emissions.

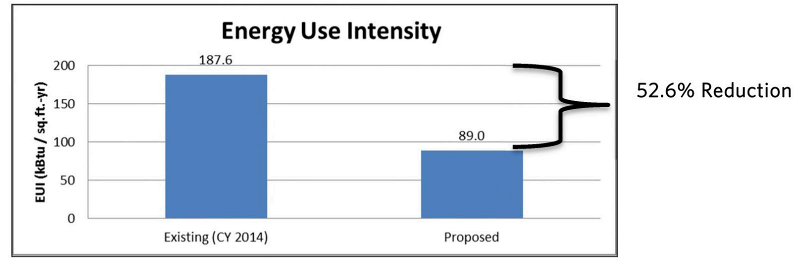
ENERGY USAGE AND OPERATIONAL CARBON ANALYSIS

While Alumni Center was awarded a LEED Gold certification, a more meaningful way to interpret the building's ongoing performance–regarding efficiency and operation emissions–is through the lens of maintenance and performance. Per building performance standards in New York, buildings above 50,000 square feet must undergo a periodic energy audit every ten years, (New York City 2009c). Alongside the audit, buildings also receive a series of retro-commissioning recommendations that must be implemented to improve building efficiency and reduce operational emissions.
The retro-commissioning report for Alumni Center published by Noresco United Technologies in 2015, highlights Energy Usage Intensity, or EUI, as a key performance indicator, and thus is useful for comparative analysis with EUI benchmarking data reported for the past twelve years.



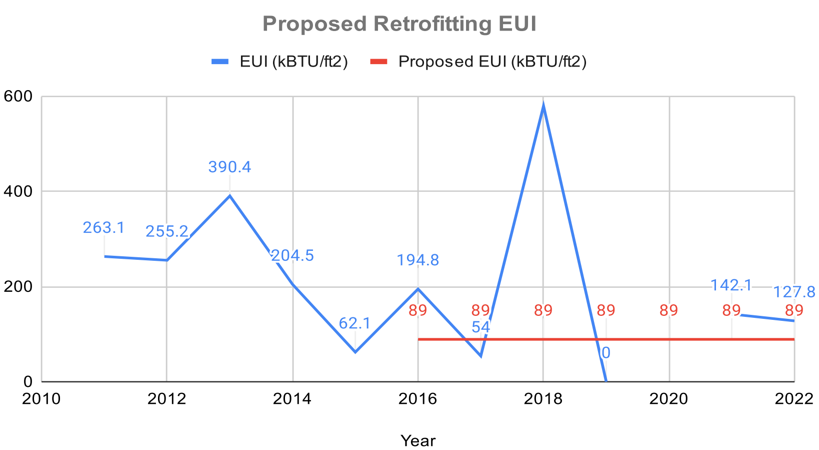
Alumni Center's Annual EUI, 2010-2022. Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data

As illustrated in the graph above, the building has reported both startlingly high and impressively low EUIs, 579 kBTU/ft2 in 2018 and 52 kBTU/ft2 in 2017, with little explanation for the inconsistency in reported data. The inconsistency in benchmarking is of particular concern for data reported after 2015, when retro-commissioning efforts should have been initiated on the site.



Proposed Energy Use Intensity Reduction, Per 2015 Retro Commissioning Report. Source/Graph: Noresco United Technologies, 2015.

The 2015 retro-commissioning recommendations included one energy conservation measure—implementing stairwell lighting occupancy sensors—and ten retro-commissioning measures—primarily focused on time-of-day utility scheduling—to reduce yearly energy consumption. If implemented, these measures would supposedly reduce EUI by a remarkable 52.6 percent to just 89 kBTU/ft^2 annually (Noresco United Technologies 2015).

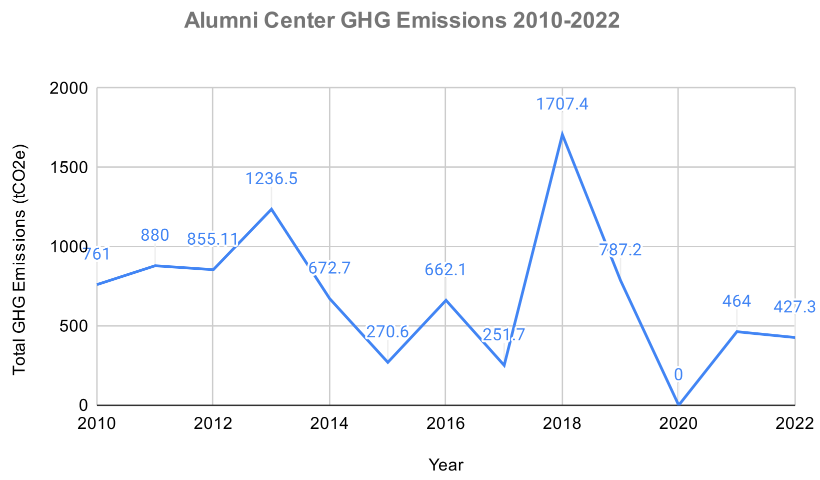


Alumni Center's Annual EUI, 2010-2022, Charted Against Proposed EUI Reduction. Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data

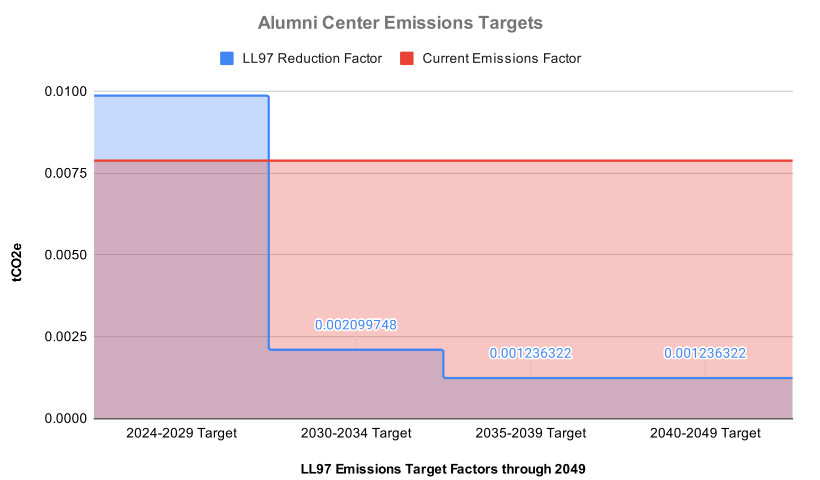
Nevertheless, in the data reported after 2016, only 2017 represents a year with a reduction that significant. While, by law, Columbia had to enact the proposed 2015 retro-commissioning measures, the reported data raises three concerns. One that the retro-commissioning report overstated the potential reductions in EUI that proposed measures could achieve, two that the recommended measures underperformed and did not adequately reduce EUI, or three, that the retro-commissioning efforts were not fully implemented or adequately maintained and thus were unable to provide consistent EUI reductions.

Because EUI quantifies energy efficiency, there is a correlation between EUI and greenhouse gas emissions over time. Thus, the inconsistency highlighted throughout its EUI reporting is accordingly reflected in the benchmarking data's similarly unpredictable emissions reporting.

As it stands, if Alumni Center continues to emit at its 2022 level, by 2030 the building will fail to meet city-mandated greenhouse gas emission reduction targets, as indicated in the bar chart above. There are significant consequences. If Columbia fails to reduce its operational emissions by 2030, the building will be fined $84,00 annually or a minimum cumulative fine of 2.1 million dollars by 2050 (New York City 2019).
Given that the building is about to initiate its next retro-commissioning cycle, the university has a unique opportunity to evaluate the initial efficacy of the 2015 retro-commissioning efforts and, more importantly, to consider the embodied carbon required to adequately reduce operational emissions—including the cost of electrification—and the approximate payoff timeline for these carbon investments. Thus, the following embodied carbon analysis explores decarbonization scenarios that consider both embodied carbon and operational emissions of the building.



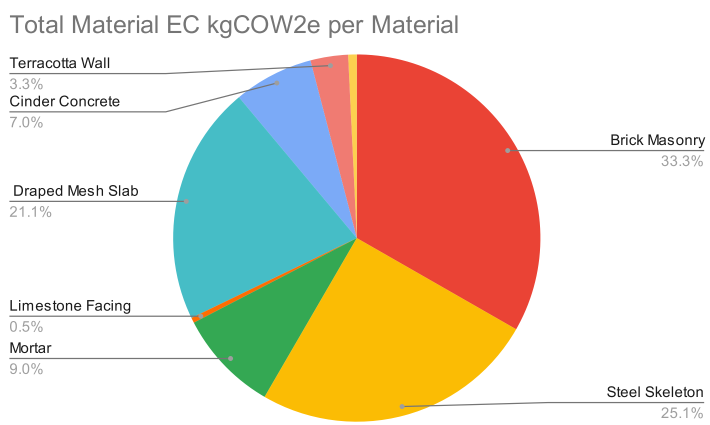
Alumni Center's Annual Greenhouse Gas Emissions, 2010-2022. Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data



Target Emissions Factors For Alumni Center Per Local Law 97. Data Source: Local Law 84/97 Benchmarking Reporting, NYC Open Data.

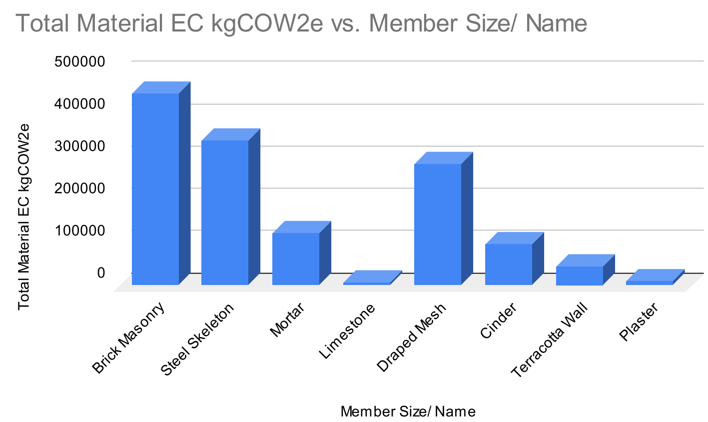
EMBODIED CARBON ANALYSIS

The total initial carbon invested to construct Alumni Center in 1908 is equal to 1,358 tCO_2e. This value represents the primary structural and architectural building elements of Alumni Center. It would take fifty forests' the size of Columbia's central Morningside Campus to sequester this amount of carbon equivalent (U.S. Environmental Protection Agency 2024). Most of the embodied carbon invested in Alumni Center is restricted to the structural elements of the building. Architectural elements, such as plaster and terra cotta interior partitions make up less than five percent of the building's overall footprint. This is corroborated by the embodied carbon value for the LEED Certified 2009 alteration which only amounts to five percent of Alumni Center's total embodied carbon value. Columbia's decision to repurpose this building over the last 60 years, rather than demolish and rebuild was a positive decision from both a preservation and carbon perspective.



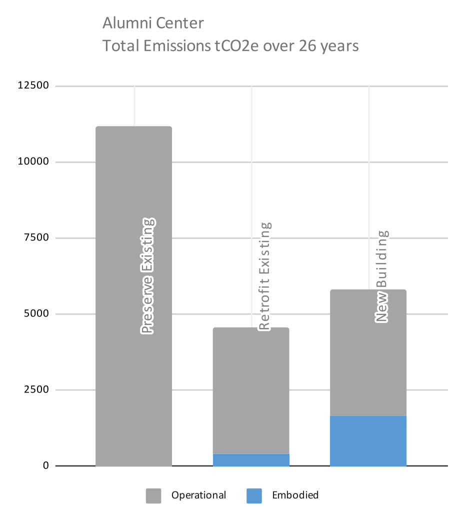
Total Embodied Carbon per Material Data Source: Circular Ecology ICE Material Database, How to Calculate Embodied Carbon v1.0 (2020) IStructE O P Gibbons, J J Orr

There are three hypothetical pathways Columbia may follow in approaching decarbonization of Alumni Center. Maintaining the existing building without any intervention, shown in the line in green, is the worst scenario, generating the greatest emissions over the next 26 years and ultimately failing to comply with the city's greenhouse gas targets. In developing these scenarios, critical assumptions were made regarding the retrofit and new building options. In both scenarios Alumni Center would be electrifying its operational systems. Accordingly, considering the grid will be decarbonized in 2040, the two blue lines taper off in fifteen years.



Total Embodied Carbon per Material Data Source: Circular Ecology ICE Material Database, How to Calculate Embodied Carbon v1.0 (2020) IStructE O P Gibbons, J J Orr

While a new building will save in operational emissions, the expenditure of embodied carbon to build anew pushes the emissions above the existing building with retrofitting options, making retrofit the better option. This is affirmed by a carbon payoff analysis, which illustrates that reusing the structure of the building has a positive climate impact in terms of avoiding more emissions. The embodied carbon invested in a replacement scenario of Alumni Center would be equivalent to thirteen years of current operational emissions.



Data Source: Alumni Center Scenario Tradeoff for Preserve Existing, Retrofit Existing, New Building Scenario Tradeoff Data Source: Architecture 2030: Carbon Avoided Retrofit Estimator Tool

Alumni Center was a significant purchase within Columbia's history of building acquisition in Morningside. The decision to repurpose over replace the center across its lifecycle to date, has been a good one in terms of limiting expended carbon. Each alteration to Alumni Center represents small investments of recurrent embodied carbon. From an embodied and a preservationist perspective, this has positive implications, however Columbia has not maintained that positive carbon stewardship on the operational side of Alumni Center. As established previously, greenhouse gas emissions for Alumni Center are high and inconsistent. These patterns may emerge from inconsistencies surrounding the building's maintenance, occupancy and operations.

MAINTENANCE, OCCUPANCY, AND OPERATIONS

Continued maintenance of operational systems is critical to decarbonizing Alumni Center. For example, a central aspect of the building's green technology, recognized in its LEED gold certification, was the Heat Recovery Unit, which is no longer in commission. Occupancy patterns are also important, following the retro-commissioning measures described earlier, Alumni center implemented time of day lighting timers. However, due to irregular work schedules these systems can be disrupted potentially leading to unanticipated energy consumption after hours. This is particularly relevant to the residential properties that surround Alumni Center, who have complained about lights on late at night in the building, resulting in informal signage posted throughout the building. Notably, the retro commissioning report highlighted issues in emissions reporting, particularly that natural gas and fuel oil usage have been erroneously reported as solely natural gas, an error that continues today. This is of particular consequence for 2018 where there is an inexplicably high usage of natural gas, and for years with surprisingly low emissions, like 2017, where neither natural gas or fuel oil usage is reported.

WAYS FORWARD

Energy efficiency measures taken during the 2009 LEED-Gold renovation like addition of insulation and complete replacement of windows, roofing, and mechanical systems were well intentioned as sustainable construction efforts implemented by Columbia well ahead of city enforced limits on greenhouse gas emissions. However, as with many LEED-certified buildings, the LEED points earned did not result in a well performing building. In addition, the lack of consistent lighting and mechanical systems upkeep are causing consistently higher energy use and carbon emissions.

To fully embrace accountability and transform the Alumni Center into an authentic "green" building befitting its status, it is recommended that Columbia University strive for LEED version 4.1 Operations and Maintenance certification (or LEED O+M). LEED O+M evaluates existing buildings and bases LEED points on high energy efficiency with ongoing tracking to ensure sustained performance and upkeep of systems over time.

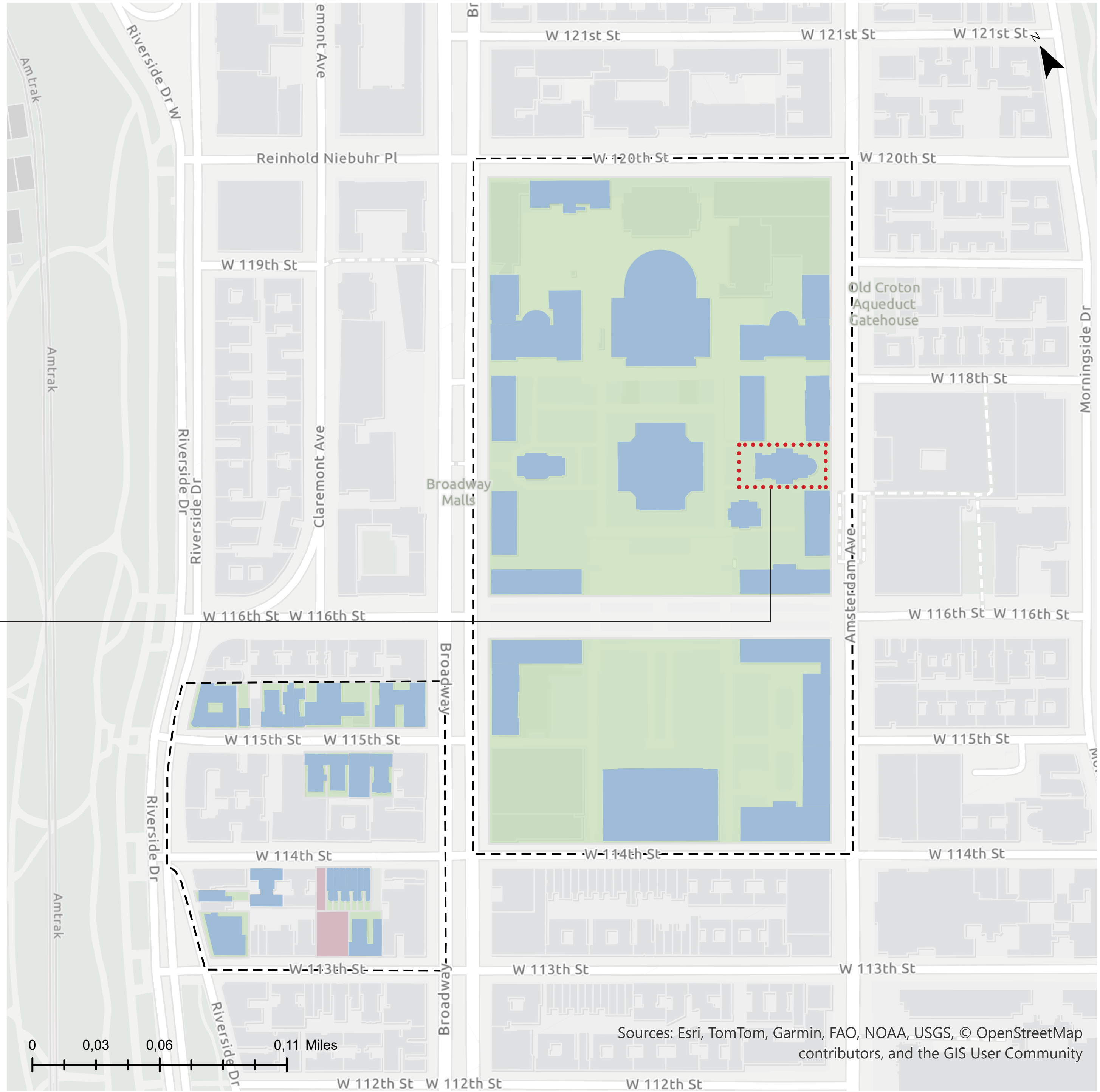
As the next mandatory retro commissioning cycle approaches in 2025, pairing LEED O+M certification with suggested retro-commissioning improvements would reduce Alumni's greenhouse gas emissions and help the university avoid the related financial penalties that are scheduled to begin in 2030. Finally, as the grid decarbonizes, so too should Alumni Center by fully electrifying mechanical systems through conversion to heat pumps, which is among the Columbia Facilities intentions.

CASE V: SAINT PAUL'S CHAPEL

Students:
Doei Kang, James Oberting, Nadir Pucinelli

North facade of Saint Paul's Chapel
Source/Photographer: Frederick

CASE V:
ST. PAUL CHAPEL



HISTORICAL OVERVIEW

The historical significance of St. Paul's Chapel lies not only within its "structurally honest," form or "treatment of the interior decoration – structural and permanent" as stated by its architect, I.N. Phelps Stokes, but in its interwoven history with the culture and commitments of Columbia University since its 1754 establishment as "an Anglican institution, [...] that was first housed in a Trinity Church schoolhouse" (Dolkart 2024). Its significance was further enshrined as the building was among the first in the city, and the first on campus, to be designated a New York City Landmark in 1966.

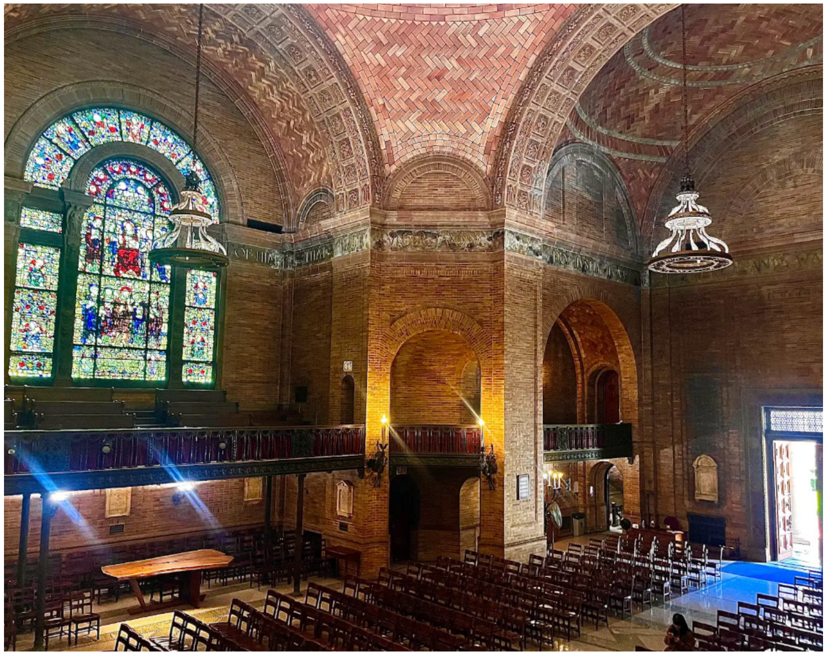
St. Paul's Chapel Facade Sketch. Source: (Avery Drawings & Archives)

St. Paul's Chapel was designed by the young architect I.N. Phelps Stokes with funding from his relatives Olivia Phelps Stokes and Caroline Phelps Stokes. Built between 1904-1907, it exists on land purchased by the University in 1894 as intended by the McKim, Mead, and White master plan for Columbia's Morningside campus. Stokes also aided in the design of neighboring Horace Mann School (now Teachers College), however, St. Paul's Chapel is recognized as his most important work in the area.

Arguably, since this project was one of his earliest commissions, Stokes' close collaboration with architect and vault expert builder Rafael Guastavino Sr. on the interior fire-proof Guastavino tile system was instrumental to its success. St. Paul's is one of the earliest examples of a church in the United States to be vaulted throughout the entire construction and reveals the full potential of Guastavino vaulting for constructive and aesthetic elements. The chapel is a prime example of high quality craftsmanship that went into Gustavino's design. This balance of engineering marvel and architectural flourish bear in mind the fact that St. Paul's Chapel ought to be admired for its unique character-defining features, many of which serve a dual function as both structural components and aesthetic elements.

Side Perspective of St.Paul's Chapel. Source: (Wurts Brothers, 1905)

The visual impact of the interior stems from the careful selection and usage of traditional materials, as the color scheme of the interior and its ornamental features are obtained mainly through constructive elements with the pink hues from the rose colored masonry tiles and roman salmon colored bricks. The openness of the interior space adds to its structural beauty. The ensemble of the interior furnishings work is completed with Stokes' thoughtful choice of skilled craftsmanship.

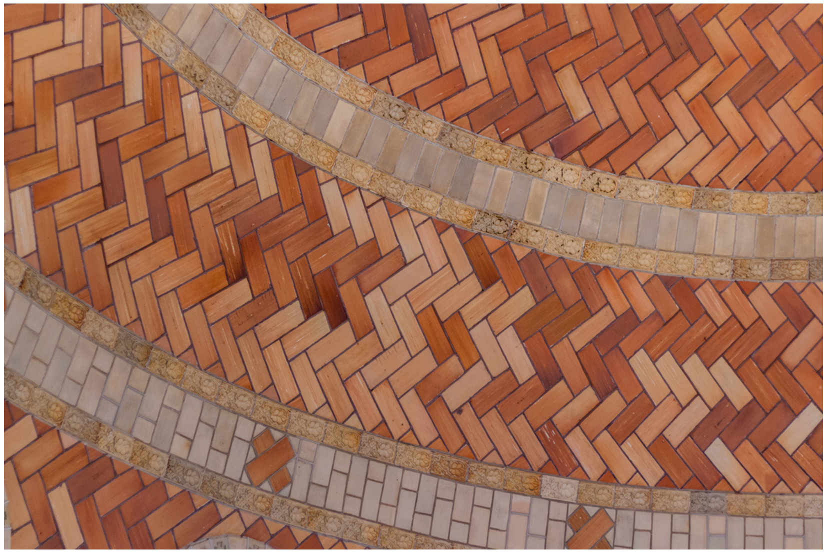


Interior of St. Paul's Chapel, open interior space with high ceilings. Source: Doei Kang, 2024

CONSTRUCTION TYPOLOGY AND MATERIALS

St. Paul's Chapel is a religious structure with a Greek cross layout. The building is mainly constituted of fired clay in the form of bricks, cast terra cotta elements, and tiles. It has high Guastavino vaulted ceilings above the nave and transept and a double Guastavino dome creating a large interior volume. These vaulted ceilings are supported by a brick masonry bearing wall construction that sits on an ashlar masonry foundation that was constructed using stones from the building site. It has concrete footings and flooring on the basement level as well as cinder concrete fill over the Guastavino vaults that support the sanctuary floor of the chapel. The roofing structure above the nave, transept and portico is supported by steel beams and almost the entirety of the roof is covered in Ludowici green glazed tiles that contrast in materiality but not in color with the copper roofs of the McKim, Mead and White master plan.

Detail of Column Capital in Triforium Source: James Oberting, 2024



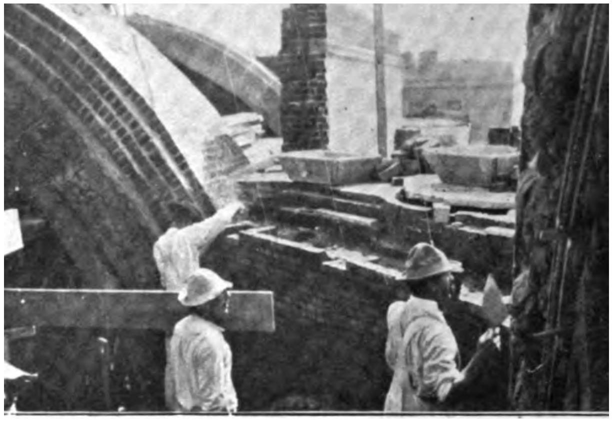
Interior dome of St. Paul's Chapel. Source: James Oberting, 2024

HISTORIC EMBODIED CARBON: SAYRE & FISHER COMPANY BRICK

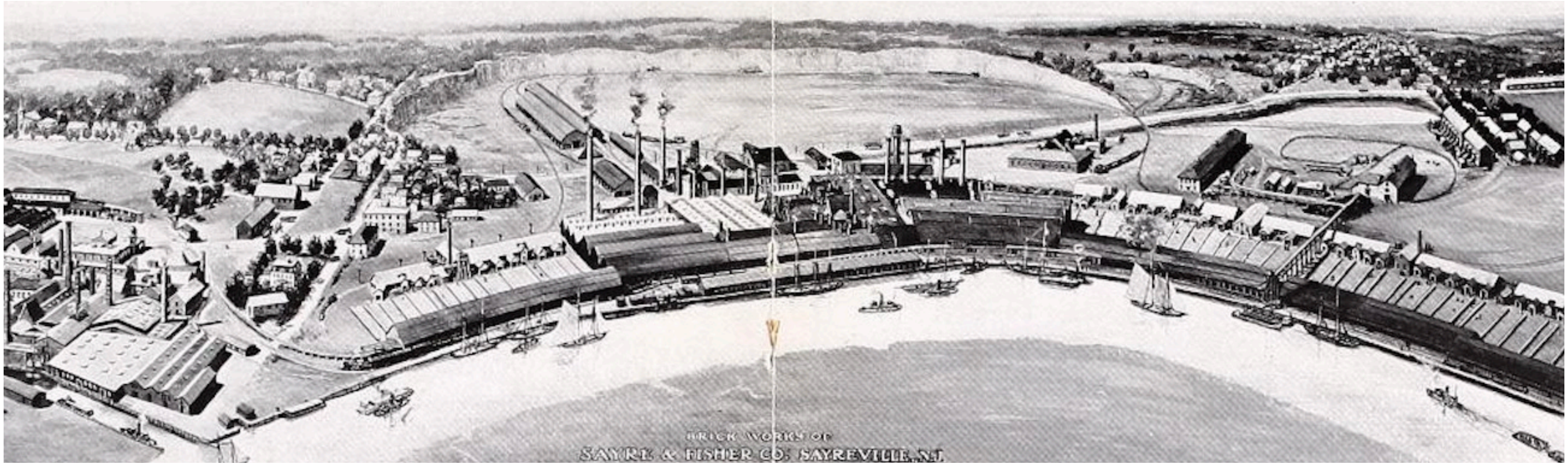
The interior roman brick of St. Paul's Chapel was selected for a qualitative analysis of the load-bearing masonry building's historic embodied carbon. The interior iron spotted brick was produced around 1904 by Sayre & Fisher, a brick manufacturing company that operated a large 2,500 acre facility in Sayreville, New Jersey. Their prime location, a two mile stretch of waterfront just across the river from New York, is rich in natural potters and fire clay deposits. It is likely that the clay used for these bricks was manually dredged from the earth, mixed potentially with manganese, molded and left to dry in storehouses. They were then packed and fired in coal heated kilns to their specified complexion and texture, which would have resulted in significant carbon emissions.

Transportation to New York harbor was potentially secured via Sayre & Fisher's fleet of shipping vessels. A coal fired tugboat would have been deployed in order to tow a barge, with a maximum load capacity of up to 350,000 bricks, the short five mile distance to the West 50th St. docks on Manhattan. Transportation of these bricks would have accounted for additional emissions resulting from loading, the cost of burning fuel (coal) onboard and offloading. Finally, transportation from the docks to Morningside Heights might have involved horse drawn carriages after which it took a total of three years for crews of skilled bricklayers to construct St. Paul's interior brick shell.

St. Paul's Chapel Construction Site. Source: George P. Hall & Son, n.d.



Building the Brick Pendentives. Source: The Brickbuilder, 1906, p. 266.

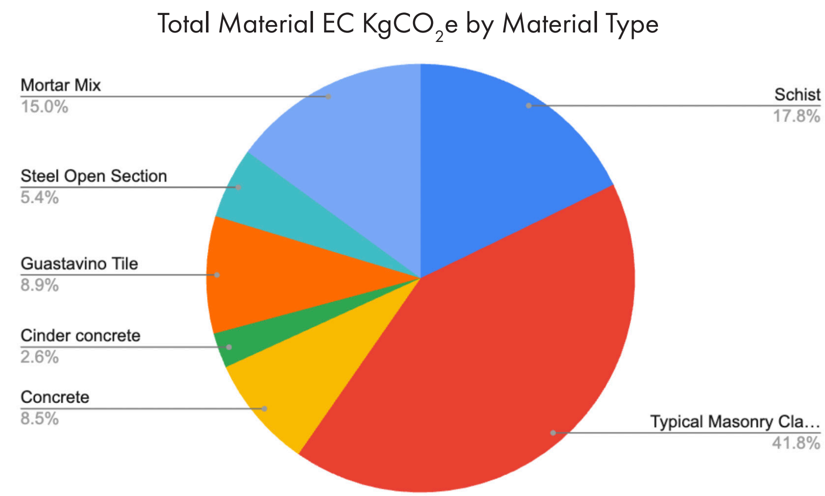


A bird's eye view of the works at Sayreville, N.J. Source: Brick enameled and front, 1914, pgs. 12-13.

EMBODIED CARBON CALCULATION

The embodied carbon of the building was calculated through a detailed breakdown of the basement, main hall and roofing systems. The studio team focused the calculations on the schist foundations, brick masonry, Guastavino tiles, concrete and cinder concrete flooring and footings, as well as the steel beams. The values on the charts represent replacement embodied carbon values of contemporary materials.

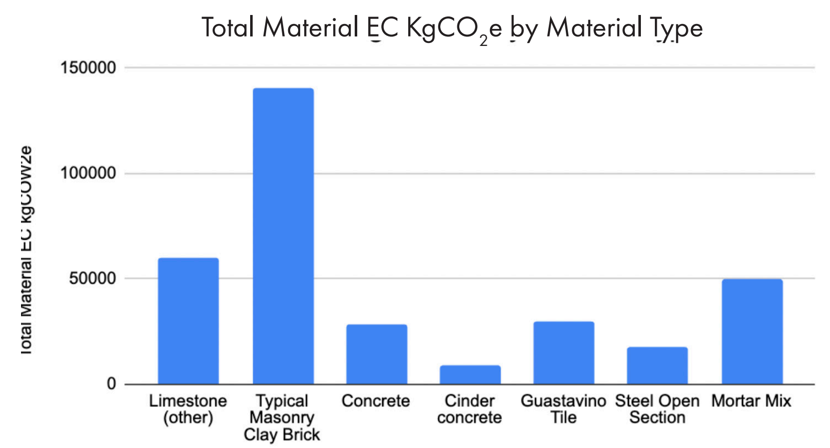
The most significant embodied carbon emissions are tied to the bricks that make up the majority of the structure followed closely by mortar and concrete. The replacement carbon values for the schist is likely considerably higher than the actually expended carbon, considering that the original stone would have been sourced from digging the spaces for the foundations of the building itself. However, to accurately account for the original carbon that was expended one would have to account for the manual labor and dynamite that was used in its demolition, which is out of the scope of this research.



Pie chart - St. Paul's total material embodied carbon (kgCO_2e) by material type. Source: Nadir Puccinelli

HIGH EMBODIED CARBON VALUE OF NEW ST. PAUL'S CHAPEL

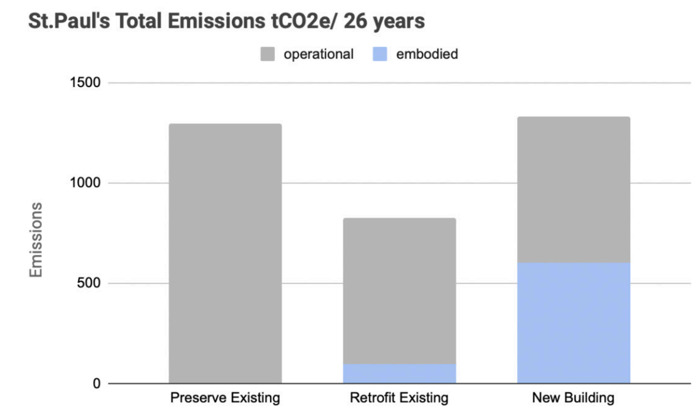
St. Paul's Chapel retains much of the character-defining features that embody the building's history and its beauty through the thoughtful usage of materials in accordance with its construction typology. The recurrent carbon for St. Paul's Chapel has been low for the past 125 years, and the anticipated embodied carbon costs for the future are low. However, if a structure like St. Paul's Chapel were constructed today, given the extensive use of diverse masonry materials and its various character-defining features, the embodied carbon would be very high.

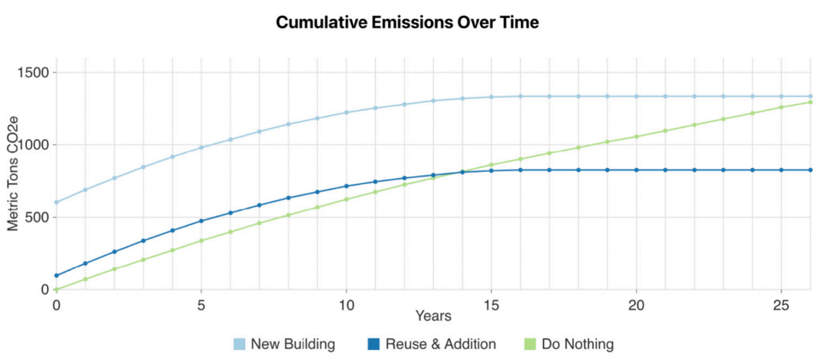


Bar chart - St. Paul's total material embodied carbon (kgCO_2e) by material type
Source: Nadir Puccinelli

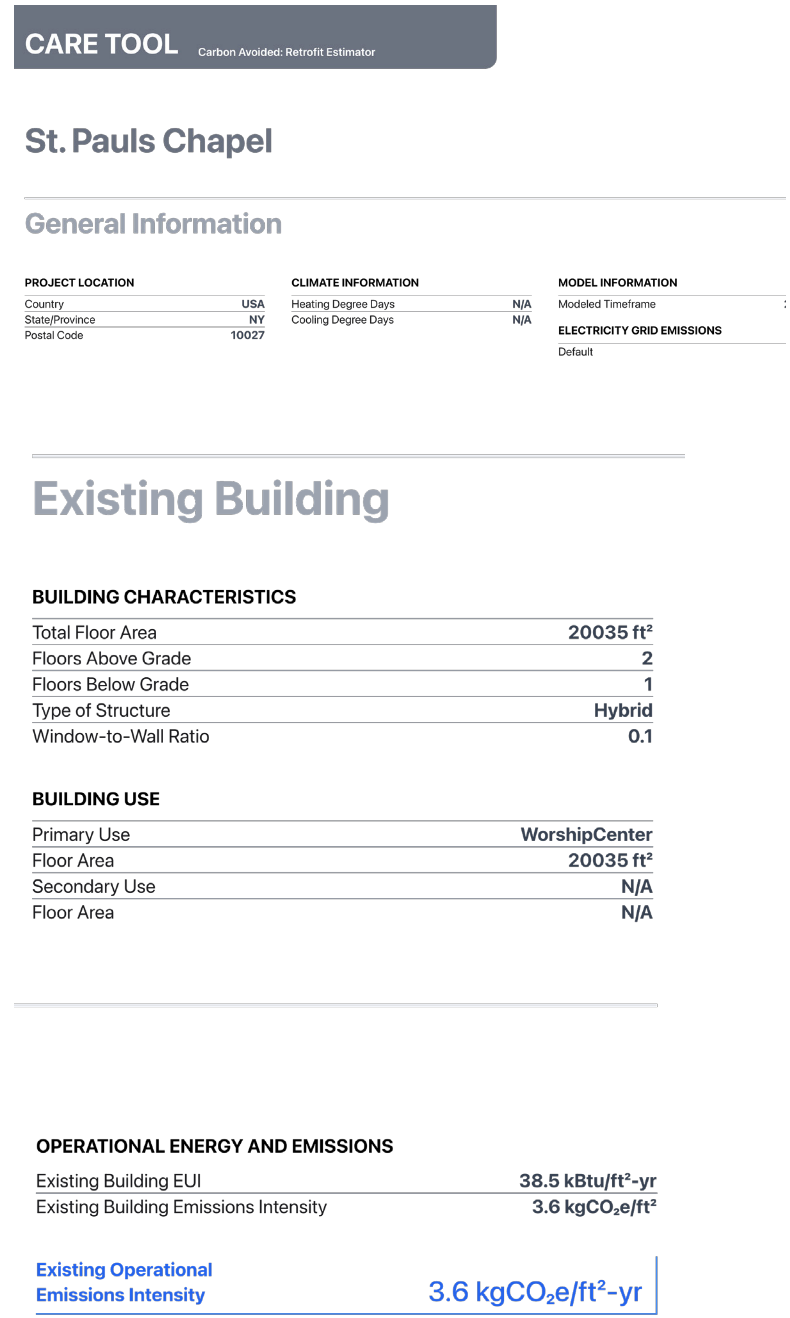
CARBON EMISSIONS OF ST. PAUL'S CHAPEL

The CARE Tool analysis shows that in the do nothing scenario (left), there are high operational carbon emissions. In the retrofit scenario, represented by the central bar, electrification of heating and cooling systems, together with the electrification of the grid would be sufficient to achieve energy targets. The final scenario, a new building, would lead to incredibly high carbon emissions. Setting aside the financial and technical infeasibility and the extensive additional embodied carbon it would take to reproduce St. Paul's, the total operational and embodied emissions of the new building would surpass the operational emissions of the do nothing scenario.





Care Tool Calculations. Source: Doei Kang, James Oberting, Nadir Puccinelli.



CARE TOOL Carbon Avoided: Retrofit Estimator

St. Pauls Chapel

General Information

PROJECT LOCATION

Country	USA
State/Province	NY
Postal Code	10027

CLIMATE INFORMATION

Heating Degree Days	N/A
Cooling Degree Days	N/A

MODEL INFORMATION

Modeled Timeframe	

ELECTRICITY GRID EMISSIONS

Default

Existing Building

BUILDING CHARACTERISTICS

Total Floor Area	20035 ft²
Floors Above Grade	2
Floors Below Grade	1
Type of Structure	Hybrid
Window-to-Wall Ratio	0.1

BUILDING USE

Primary Use	WorshipCenter
Floor Area	20035 ft²
Secondary Use	N/A
Floor Area	N/A

OPERATIONAL ENERGY AND EMISSIONS

Existing Building EUI	38.5 kBtu/ft²-yr
Existing Building Emissions Intensity	3.6 $kgCO_2e/ft^2$

Existing Operational Emissions Intensity 3.6 $kgCO_2e/ft^2$-yr

Care Tool Calculations. Source: Doei Kang, James Oberting, Nadir Puccinelli.

RENOVATIONS

There was a major renovation of St. Pauls from 2017-2019. During the renovation the entire roof was replaced with new Ludowici tiles. The Guastavino domes and vaulting over the nave and apse were retouched and cleaned. Finally, the dome's 16 stained glass windows were restored, with the installation of isothermal glazing.

Given the insufficient data for comparative analysis of pre/post renovations, it is challenging to speculate with confidence that renovations helped with the energy efficiency of St. Paul's Chapel. However, the replacement of the tiles would have only accounted for 4-6 tCO_2e of embodied carbon and the added isothermal protective glazing improved the energy performance of the stained glass windows.

OPERATIONAL CARBON

Examining the total operating emissions reported in 2022 for St. Paul's Chapel, totalling 84 tCO_2e, reveals that it is already missing its current emissions targets. A breakdown of the major sources of operational carbon emissions is predominantly tied to heating, which is provided by the central campus steam loop and electricity from ConEdison, used to power various sources of lighting 24/7. Moreover, the building has a 10 gallon, 6 kW, single phase electric hot water heater in the basement mechanical room (Grosso and Rinaldi 2014, 25).

ST. PAUL'S CHAPEL LIGHTING

"The lighting system in St Paul's was evaluated for upgrading. Based on the specialty lighting requirements of the space, low light levels and low run times there were no cost effective upgrades identified"

(Fayerweather, Earl Hall & St. Paul's Chapel ASHRAE Level II Energy Audit & Retro-Commissioning, 2014).

Roof renovation Photo (2018). Source: Walter B. Melvin Architects

Reducing the operational carbon of St. Paul's Chapel involves effective retrofits that improve its energy efficiency. The renovation drawings of the 2017-2019 project indicate that Columbia appears to have opted out of compliance with the NYC energy code by claiming the exemption afforded by St. Paul's Chapel's eligibility for the National Register of Historic Places. While emissions data from before 2020 was unavailable, it should be noted that with certain religious structures, energy use intensity is an innately elusive measure to accurately track and address due to the tradition of ecclesiastical architecture calling for a significant floor to ceiling height. However, there are a number of options that, if taken promptly, may ensure St. Paul's can meet its future carbon emission targets.

In 2014, while the building was not metered for heat or electricity, aretro-commissioning report gave an estimated site EUI of 66, placing it above the 75th percentile in the religious facility category. However, the guidance suggested that this was potentially caused by the fact that the basement of St. Paul's has "a fair amount of office space that would not normally be in use in a more traditional religious facility" (Grosso and Rinaldi 2014, 25). For the year 2022, after a major renovation, the evaluated site EUI was registered at 49.8, which is still quite high. However, it was observed that several basement level office spaces with window access have installed personal air conditioning units. Cooling these spaces complicates the breakdown of the reported energy intensity data and presents a potential for a future retrofit.

FUTURE OF ST. PAUL'S CHAPEL

St. Paul's Chapel is one of the highlights of Columbia University campus. Its significance is embodied in its use of materials that are both structural and decorative as well as its intertwined history with the University itself. St.Paul's Chapel's designation as a NYC Landmark protects the exterior facade from any modifications. However the large interior volume of the chapel, with its high vaulted ceilings that are a character-defining feature of its typology, make the building relatively energy inefficient. At this point in time, St. Paul's operating carbon targets are not met, and given the time it would take for converting Columbia's steam loop, St.Paul's Chapel faces pressing challenges in decreasing energy usage intensity.

It is estimated that assuming the fines of not meeting the targets of the GHG emissions law remains the same, the $268 for every ton of carbon emitted over the limit will amount to a minimum cumulative fine of $388,000 in 2050. This number is relatively modest compared to the cost for fully electrifying St. Paul's, which could incentivize inaction.

Design is an important factor that gives the chapel its individuality, but it also makes it difficult to implement energy reduction strategies. However, there may be opportunities to retrofit spaces that are not considered character-defining features of St. Paul's Chapel, such as the basement level. These spaces in the lower level and associated systems were identified by the 2014 retro-commissioning report as potential contributors to high energy consumption. It is worth investigating how a religious space and specific architectural typology can evolve to improve building performance for energy efficiency.

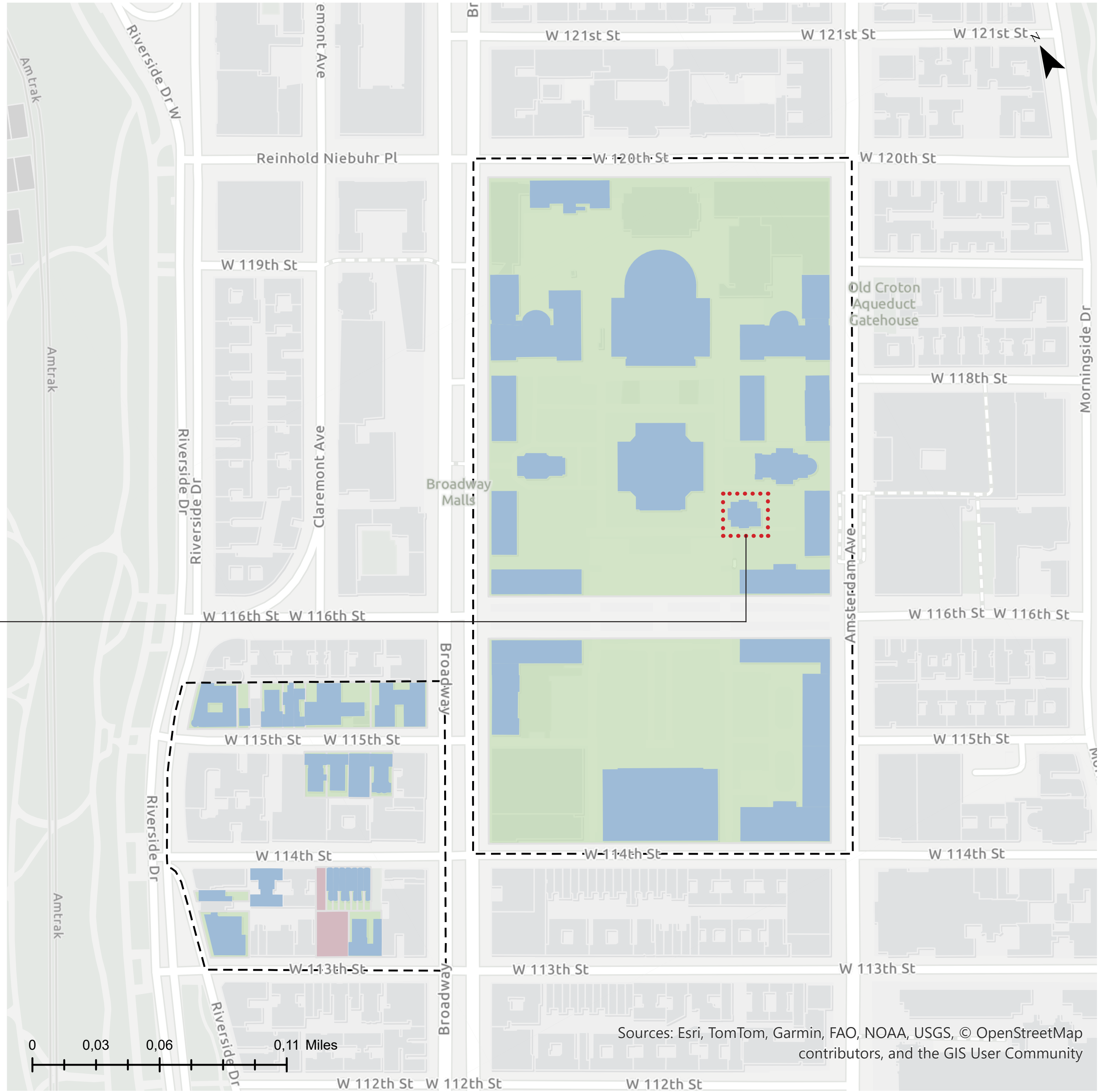
Roof renovation Photo (2018). Source: Walter B. Melvin Architects

CASE VI: BUELL HALL

Students:
Shereen Al Mater, Sophie Hass, Conrad Grimmer

Buell Hall
Source/Photographer: Frederick

CASE VI:
BUELL HALL



BUELL HALL

The small villa style building of Buell Hall sits at the east side of upper campus. It is the oldest building on campus, dating to 1885, and the last remaining structure from the Bloomingdale Asylum. Since it was acquired by Columbia in 1895, the use of Buell changed over the years, and it was relocated from lower to upper campus. The building also underwent a large renovation in the 1990s. Those factors along with the removal of some of its features made it an interesting case study for the studio study, especially concerning its materials and embodied as well as operational carbon.

1905 Postcard with Buell Hall, Porches Still Intact
Source/Photographer: Unknown, via Columbia University Archives

CHARACTER-DEFINING FEATURES

A number of character-defining features contribute to Buell Hall's significance. Buell is the smallest and the only villa-style building on campus since the demolition of its sister building, South Hall. Significant architectural elements include the slate roof, dormer windows, gable roof, interior fireplaces, symmetrical layout, and identical facades. Character-defining features that have been lost include its original location on campus (now occupied by Kent Hall) and its now removed porch and awnings.

BUELL ACROSS TIME, BEGINNING AS MACY VILLA

Buell Hall's original name was Macy Villa, built for the Bloomingdale Asylum for the Insane, part of New York Hospital. In New York Hospital Annual Reports from 1888, the hospital lauds Macy Villa for its provisions for the insane. These accounts in the Annual Reports provide an initial argument for Buell's significance: it was a place for healing and reprieve that was even favorably discussed in British medical journals, as noted in the Annual Report. The lost porch and home-like feeling of this building are central to the mental health healing significance of Buell.

The building went by many names after Columbia acquired Macy Villa, including South Building, East Hall, and the Rowing Team's Boathouse, serving many different functions before it became Buell Hall. In Buell's long and complex history, it also moved at least once from its original location on 116th street to a location higher on the campus's superblock to make room for Kent Hall. The northwest move took place in 1905 and was likely completed with the use of horsepower. It was this move that resulted in the removal of Buell's iconic porches.

Macy Villa Becomes Buell Hall as Columbia Constructs Morningside Heights Campus.
Source/Photographer: Geo. P. Hall & Son/The New-York Historical Society, via Getty Images

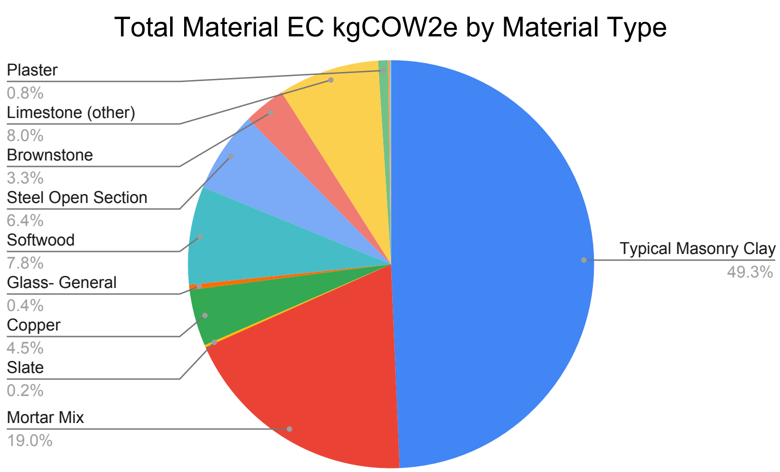
CONSTRUCTION TYPOLOGY AND MATERIALS

As noted earlier, being a villa-style building with masonry bearing wall and wooden floor joists, Buell's construction typology stands out amongst Columbia's other buildings. The material identification process for the embodied carbon analysis was guided by both in-person fieldwork and reviewing plans provided by Columbia Facilities. Key materials that were identified and largely original to the building were brick and mortar, slate, timber, brown, plaster, concrete and glass. Steel was also an identified material that was added at a later date.

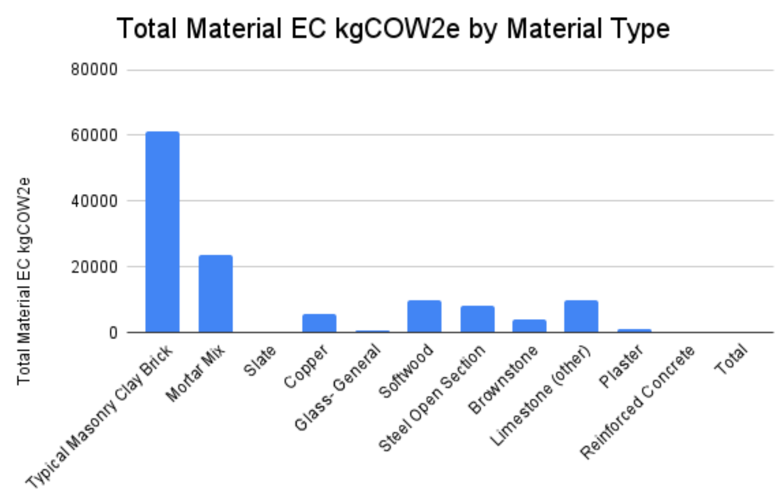
EMBODIED CARBON ANALYSIS

The methodology for determining the tCO_2e of the materials in Buell largely relied upon tracing previous plans in CAD applications to determine the area and volume of each material, and using these identified quantities within an embodied carbon calculation spreadsheet developed by the studio's faculty and teaching assistants.

Macy Villa Becomes Buell Hall as Columbia Constructs Morningside Heights Campus. Source/Photographer: Geo. P. Hall & Son/The New-York Historical Society, via Getty Images



Pie chart - Buell's total material embodied carbon ($kgCO_2e$) by material type
Source/Photographer: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024



Pie chart - Buell's total material embodied carbon ($kgCO_2e$) by material type
Source/Photographer: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024

The analysis of Buell determined that the building has approximately 124 tCO_2e of embodied carbon, with Buell's brick and mortar making up the bulk of the building's embodied carbon footprint. Additionally, the analysis confirmed that while biogenic materials such as timber, which accounts for Buell's joists, studs and windows, are a considerable amount of the building's material volume, they actually have quite a small carbon footprint due to timber's nature as a biogenic and carbon sequestering material. Similarly, other natural materials such as the slate used for Buell's roof also has an almost negligible embodied carbon footprint.

While not noted on the charts above, Buell's removed porches had a small carbon footprint of only 0.57 ton CO_2e, however this does not account for the previously sequestered carbon that may have been mobilized and released into the atmosphere if the porches were left to decompose after demolition. Nonetheless, it is apparent there is a substantial carbon investment with Buell given the value of its brick and mortar and steel.

HISTORIC EMBODIED CARBON ANALYSIS OF TIMBER

Buell's former porches served as the inspiration for investigating the historic embodied carbon of the timber that would have been to construct them, and would also allow for the timber used for Buell's windows, joists, and studs to be accounted for.

Given Buell's year of construction in 1885, the attempted carbon accounting was based upon the research done by Meinrenken and Widder into the window for Olana which was built in 1875. Southern yellow pine grown in North Carolina was used as a hypothetical timber given New York City's increased reliance on southern timber towards the latter part of the nineteenth century.

It was assumed that there would be negligible carbon output from hauling and curing of the timber due to the use of horse hauling or floating of logs for initial transportation, and natural curing processes for the wood. The milling of the lumber may have contributed carbon emissions if the sawmill was steam powered, however it may have been hydro-powered so the contribution of milling was left out as it could not be determined and may have been small.

The main historic carbon emissions would have come from the emissions released from the unsustainable forestry practices at the time that would have released emissions from the decomposition of root systems and tree branches, and from transporting the timber from Western North Carolina to New York. the studio team utilized the research by Widder and Meinrenken that estimated the embodied CO_2e of the American white oak used for the windows at Olana. Widder and Meinrenken were able to determine how many kg of CO_2e was released per kg of white oak produced. This value was adjusted assuming that the amount of sequestered carbon is directly related to the density of the material, and 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 1.89kgCO_2e/kg.

North Carolina Logging Operation
Source/Photographer: State Archives of North Carolina

Total for unsustainable forestry: 1.89kgCO_2e/kg (preliminary estimate)
American white oak, 3.33kgCO_2e/kg (Widder & Meinrenken 2024)
Density (kg/m^3) of American white oak/of yellow pine = 740/420 = 1.76
3.33kgCO_2e/1.76 = 1.89kgCO_2e/kg

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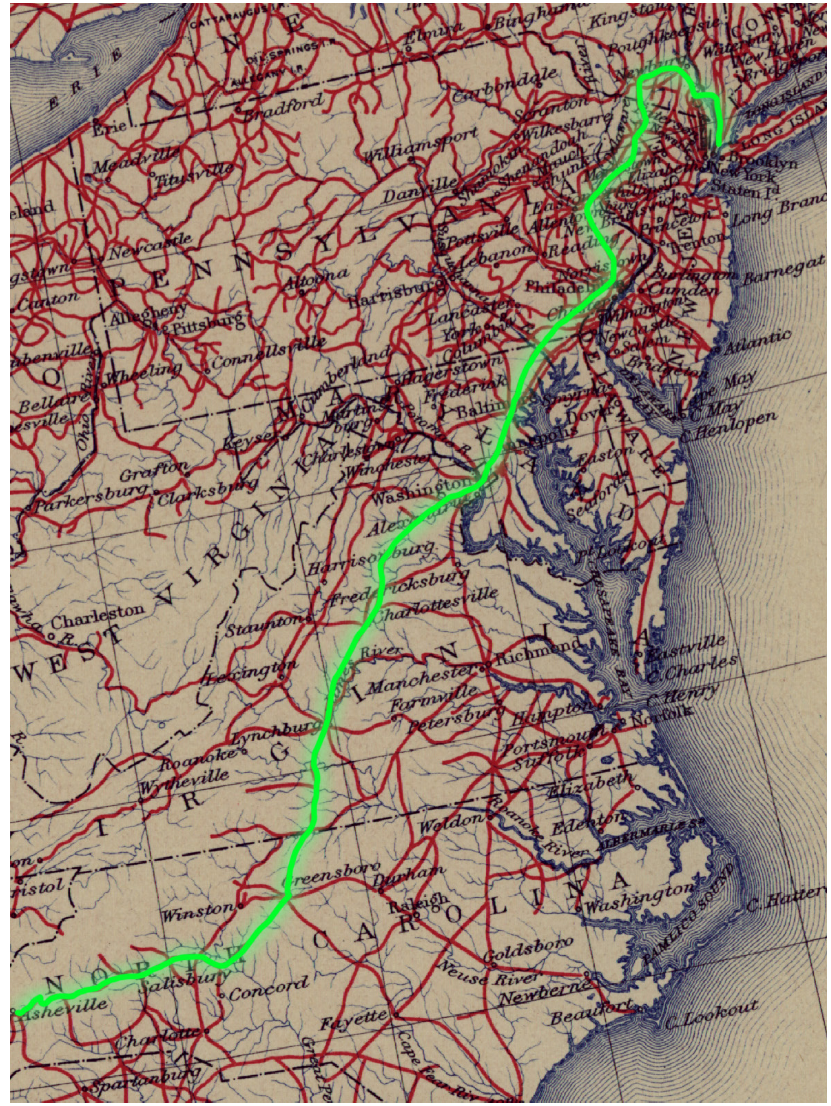


1890 Railroad Map of the United States (annotated)
Photographer: Henry Gannett, United States Department of the Interior

Humpback Mountain, North Carolina (1908)
Source/Photographer: State Archives of North Carolina

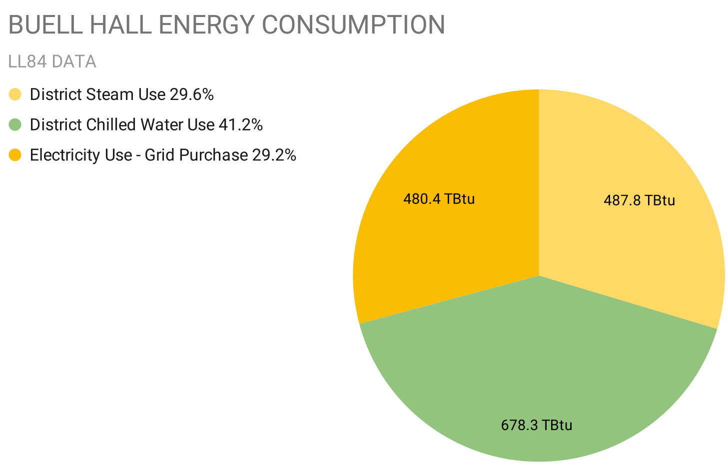
Subsequently emissions from transporting the timber to New York City were estimated. Asheville was selected as the hypothetical starting point of the timber's journey, given its place as the nearest major city in western North Carolina. The distance from Asheville to the New York City area is approximately 700 miles, and freight trains at that time would have burnt about 97.5lbs of coal per mile traveled (Llanso n.d). It was then approximated that about 12000 planks of 20 foot long 3 x 8s would have been transported in a single shipment, giving each plank an embodied carbon of 5.3kgCO2e. When assuming the weight of each plank of about 45kg, 1kg of timber would have 0.12kgCO2e.

Adding the emissions of rail transport with the embodied carbon of unsustainable forestry practices, it is concluded that the historic embodied carbon per kilogram of lumber in Buell was approximately 2.0kgCO_2e, just over four times that of the contemporary replacement value of timber. As such, the replacement embodied carbon footprint of the timber (approximately 9.6 tCO_2e) in Buell is likely a significant underestimation compared to the actual emissions associated with its construction. While this is a preliminary estimate, it nonetheless illustrates the differences between the embodied carbon of historic and contemporary timbers. This also does not account for the carbon sequestered by the timber within Buell.

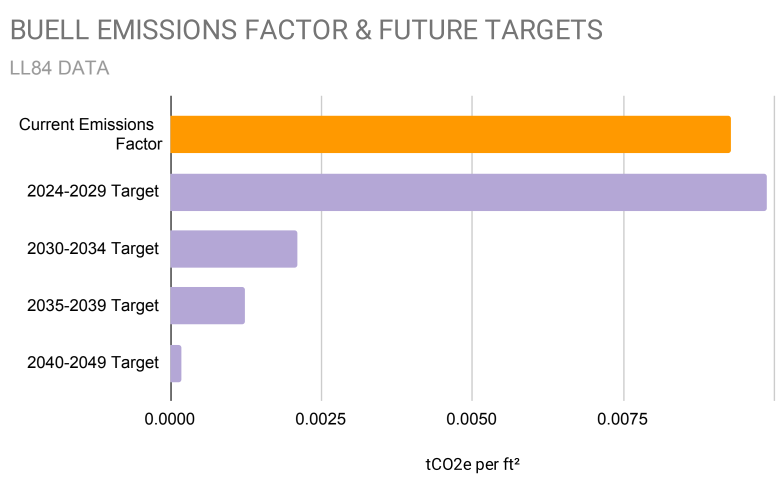
OPERATIONAL AND EMBODIED CARBON IMPACT

The operational carbon analysis for Buell started by gathering information about the energy usage of the building using the data in the Local Law 84 report. The building's annual utility consumption was 1600 TBtu, with net emissions being 109 tCO_2e, and greenhouse gas energy intensity (EUI) is 140.6 kBtu/ft2. This data was utilized to analyze whether Buell Hall is meeting emission targets which will be covered later on in this section. Further research showed that no natural gas usage data is available for the building, that Buell is National Register eligible, and that when it comes to the relevant recent NYC energy laws it is only subject to LL84 and reporting for LL87 and LL97. This information helped guide the operational carbon analysis and thoughts on possible next steps.

The "Buell Hall Energy Consumption'' graph illustrates how the 1600 Tbtu utility consumption is distributed. The usage breaks down into about 29 percent electricity use, 41 percent chilled water use and about 30 percent steam use. This information is important as the annual utility consumption must go down to meet Columbia's decarbonization plans and understanding where the energy is going is critical. The graph "Buell Emission Factors & Future Targets" shows the current carbon emission factor in perspective to the future goals Buell has to meet. Thus far the reduction in emissions are on track to avoid fines until 2029, but significant emission reductions are needed in order to meet the 2030 target.

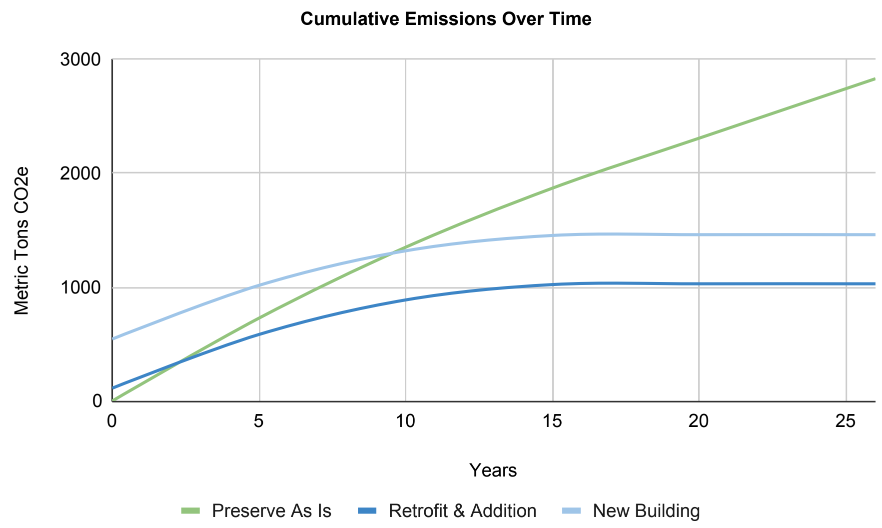


Buell Hall Breakdown of Energy Use in Tons Btu
Source: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024

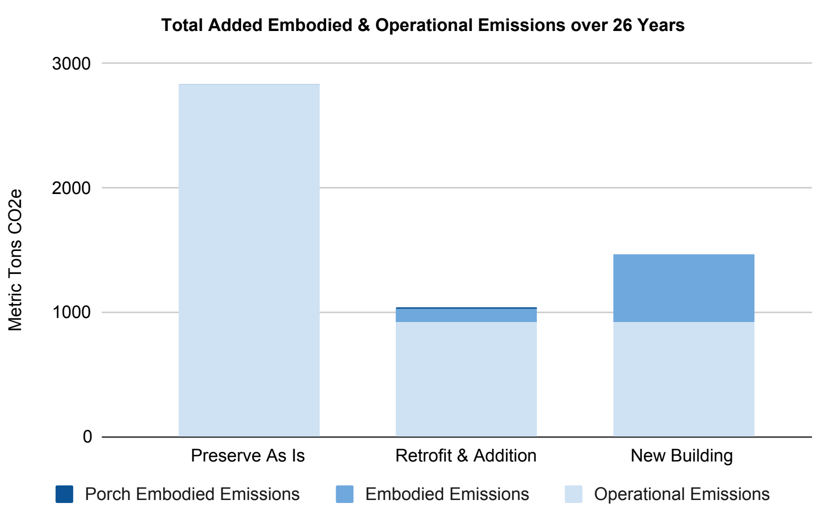


Buell Hall current and future emmissions targets.
Source: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024

In order for Buell to meet carbon targets it has to either be retrofitted or replaced with a more efficient building. It was determined using the CARE tool that a deep retrofit and a reinstallation of the front porches would produce a significantly lower amount of embodied carbon in comparison to building a new building. That is apparent in the "Total Added Embodied & Operational Emissions" graph, where preserving the building-as-is will result in keeping the operational emissions where they are, retrofitting will result in a reduction of operational emissions without emitting an excessive amount of embodied carbon, and constructing a new building will result in the highest amount of embodied carbon emissions out of all three options - while total emissions over the considered time period are still less than doing nothing. The analysis shows that retrofitting the building is the best option, even when it includes reinstalling the demolished porch. Not only that, but retrofitting the building would offset carbon emissions within three years of completion whereas a new building will only offset emissions in 9 years as highlighted by the graph "Cumulative Emissions Over Time."



Retrofitting vs New Building Carbon Emissions
Source/Photographer: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024



Retrofitting vs New Building Carbon Emissions
Source/Photographer: Conrad Grimmer, Shereen Al Mater, Sophie Hass, 2024

A POSSIBLE FUTURE FOR BUELL: RESTORED PORCHES, AN EXAMPLE OF DECONSTRUCTION POLICY, AND A MENTAL HEALTH SPACE

From this analysis it is apparent that much carbon has already been spent on Buell, and demolishing and replacing the building would waste this embodied carbon investment. As such, the building should be retrofitted, not replaced. While retrofitting, the team proposes that Buell's porches be rebuilt using reclaimed timber. Adding back Buell's porches will not only return one of Buell's most character-defining features, it will also have the added value of an outdoor space with shade, a sheltered place from rain, a smaller scale gathering space on campus that is more intimate, and a space where students can relax without relying on energy-consuming indoor climate control.

The carbon investment of re-adding these porches would be menial, especially considering the value they would add to the building. Moreover, retrofitting the building and adding porches could be a very prominent and visual campus improvement, which may be a prime naming opportunity for a donor.

Manhattanville: A Place to Reclaim Timber for Buell's To-Be-Restored Porches
Source/Photographer: Unknown, via Columbia Neighbors Website

Given Columbia's plans for Manhattanville and the additional demolition this development may require, the restored porches could even use reclaimed timber from the buildings in the neighborhood to ensure that fewer materials go to waste, and the carbon within the historic timber remains sequestered. To do so, Columbia could use New York City's Circular Construction Guidelines as an example of how to reclaim Manhattanville's timber. In doing so, Columbia could set an example with Buell of how to advance deconstruction policy for the rest of the university.

Taking this proposal a step further, one day Buell, with its new porches, though made in 2024 to meet ADA accessibility requirements, could and perhaps should be brought full circle and adaptively reused as a mental health space for students. Buell has had 17 names and 3 different locations since its construction, all of which had many uses. Columbia has made the deliberate decision to keep Buell over and over again.

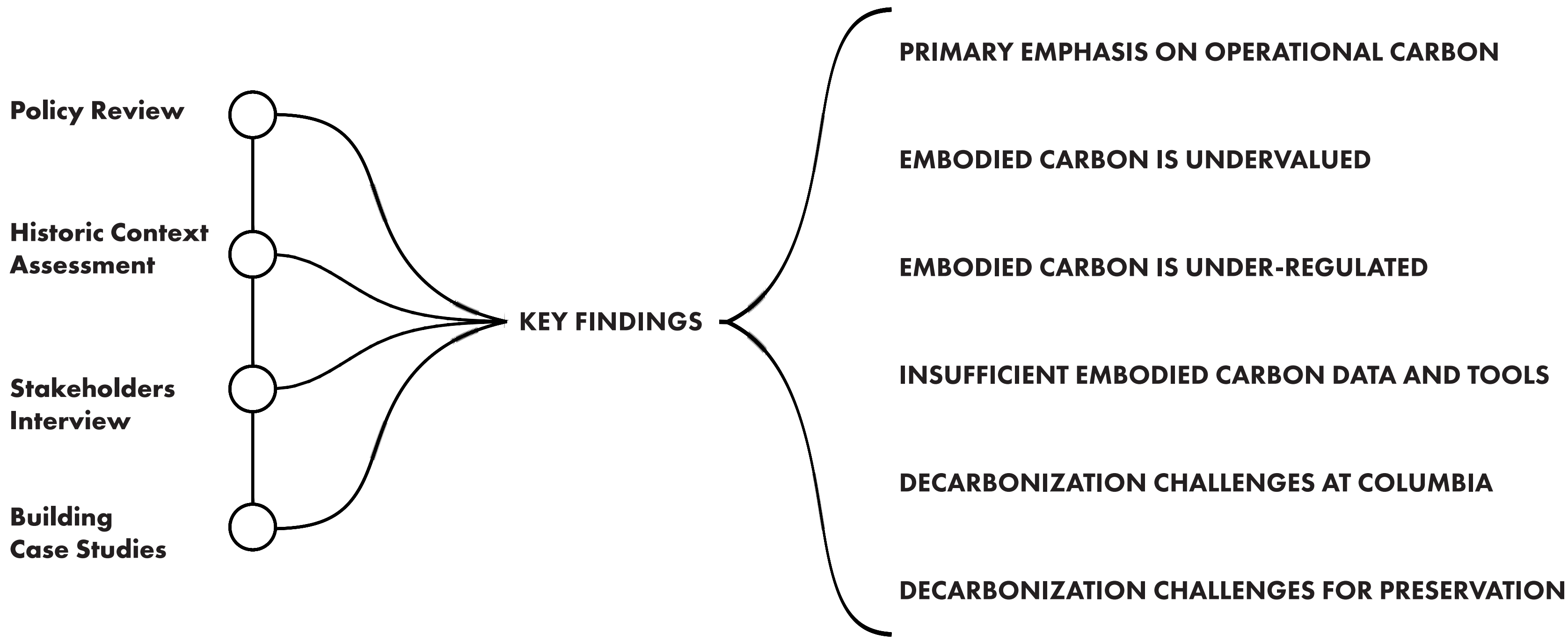
As a result, this building is clearly important and significant in the memory of the university, and restoring the original purpose of the building could go hand-in-hand with restoring the porches. The layered history of changing names and use is not new to this building, and as such Buell's significance lies in both its connection to mental health and its adaptability. As Columbia and New York City adapt to new rules regarding carbon and climate, and as universities and people everywhere become more keenly aware of the need for mental health support, Buell is a ripe case for retrofitting and for restoration. Beginning with the porches, Buell has a bright future.

Mockup of Potential Porch Re-addition
Source/Photographer: Emily Conklin, Michelle Leach and Mimi Vaughan 2022 | Conrad Grimmer 2024

Columbia Campus. 2024. Photo by Frederick.

KEY FINDINGS

The following findings have been distilled from policy analysis, historic context analysis, interviews, and case studies. The themes of the key findings range from financing considerations to campus energy transition challenges, from grid conversion to preservation ideals; each finding unravels the complexities of embodied carbon, carbon emissions, and sustainability within Columbia University's unique context.



PRIMARY EMPHASIS ON OPERATIONAL CARBON

It is important to reflect that property owners, institutions, and society as a hole have successfully navigated energy transitions in the past. The primary emphasis for reducing current carbon emissions being tied to the operational carbon of the existing built environment is clear and self-evident in rhetoric, commitments, state and local policy, and law; and shows signs of important progress. But reducing operational carbon remains a major hurdle.

ADVOCACY ORGANIZATIONS PRIORITIZE OPERATIONAL CARBON

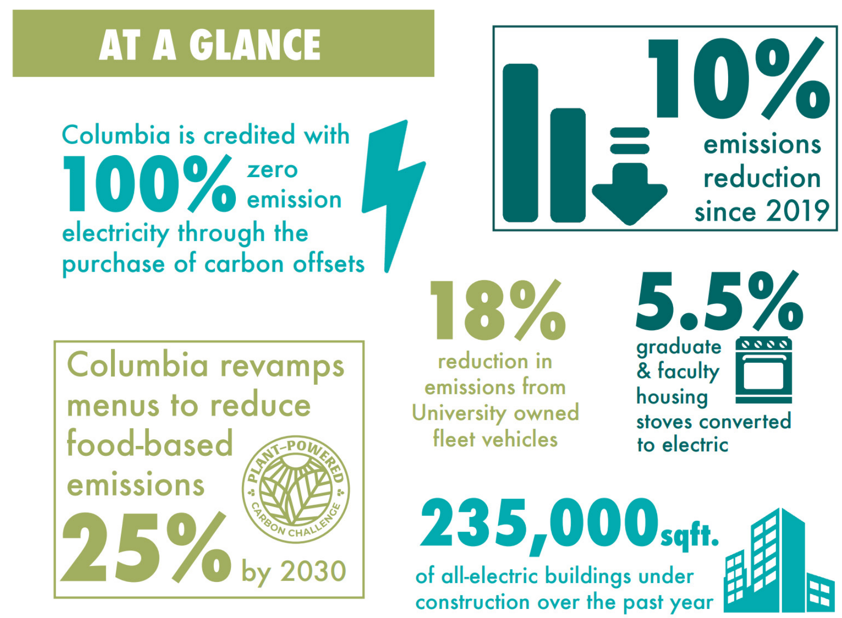
Moving from the State and City levels, the studio team conducted interviews with multiple advocacy organizations, seeking insight into their current policies and research on both operating carbon and embodied carbon. Notably, organizational policies largely mirror those at the state and city levels, placing significant emphasis on operational carbon while affording limited or no attention to embodied carbon. For instance, the Urban Green Council currently focuses the majority of its efforts toward reducing operational carbon. Their impactful initiatives, such as Local Law 84, Local Law 87, Local Law 97, and the Sustainable Roof Law, predominantly address operational aspects. Additionally, the Council's various research orientation and educational programs have historically prioritized toward operational carbon reduction.

COLUMBIA POLICY PRIORITIZES OPERATIONAL CARBON

Columbia University's institutional policies also prioritize operational carbon, as evidenced by the Columbia 2030 Plan. It sets ambitious goals for operational carbon reduction that exceed state and city-wide targets. Despite the goals for operational carbon reduction, both Columbia University and New York City lack substantial policies addressing embodied carbon.

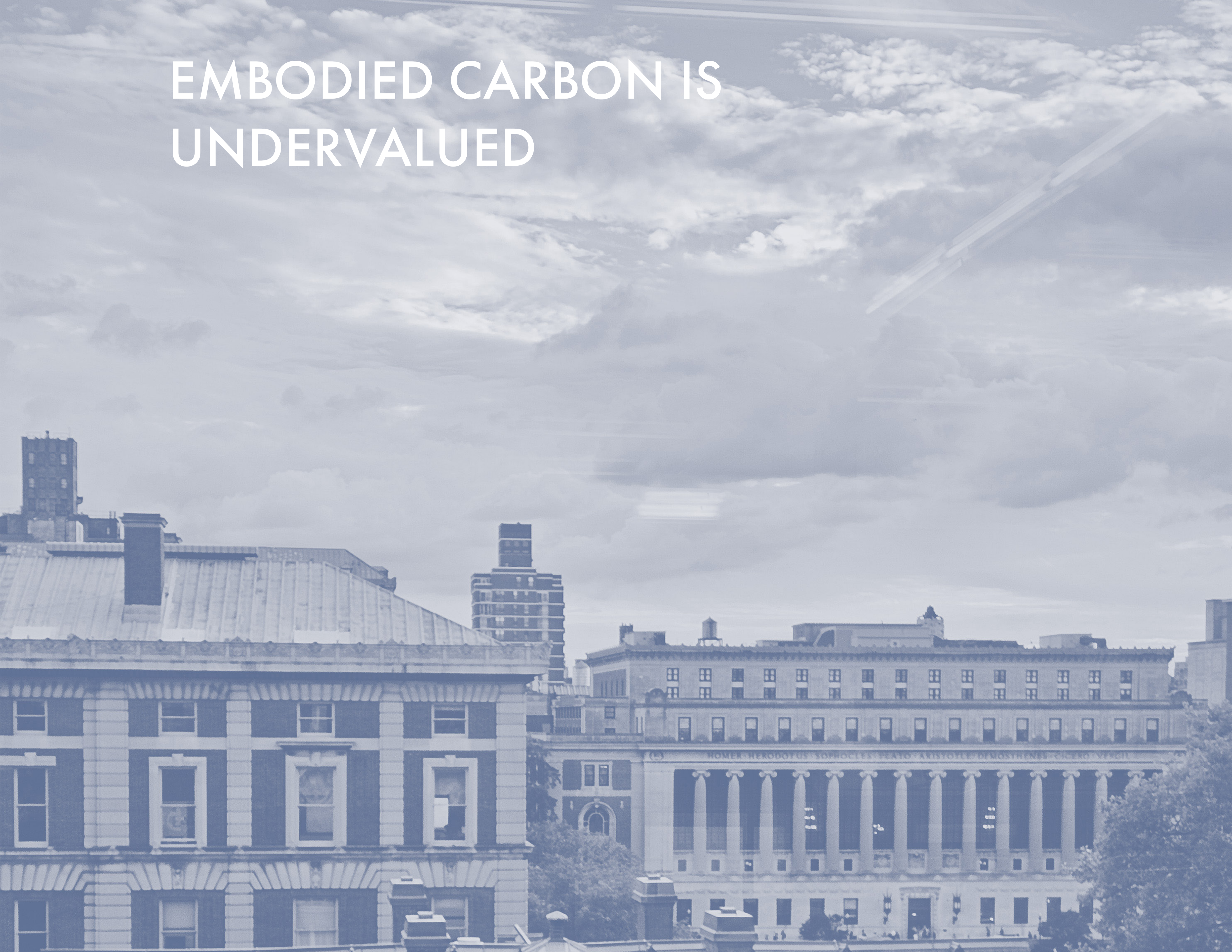
BETTER EFFICIENCY REQUIRES EMBODIED CARBON

Through current state, local, and organizational policies, the primary aim of decarbonization efforts lies in reducing operational carbon emissions, with limited attention to embodied carbon considerations. Operational carbon currently accounts for the majority of emissions over a building's life cycle, therefore, embodied carbon seems relatively less significant. However, as the grid transitions towards cleaner energy sources in the foreseeable future, the significance of embodied carbon is poised to rise. Anticipating this shift, making major energy retrofits to existing buildings, including historic ones is an urgent task. But improving efficiency requires additional investment in embodied carbon, often through new mechanical and lighting systems and building envelope interventions. Before proceeding with building retrofitting, a comprehensive analysis is essential to carefully assess the trade-offs between the existing systems and the new upgrade to determine the optimal scenario.



Source: Columbia University Sustainabilty Plan 2021-2030.

EMBODIED CARBON IS UNDERVALUED



EMBODIED CARBON AS A SUNK COST

Embodied carbon is viewed as a "sunk cost" given its initial carbon investment and small contribution to a building's life cycle emissions. However, replacement of an existing building incurs the added initial embodied carbon of new construction. New construction, even of buildings that are "net-zero" from an operational perspective, can significantly increase emissions. The upfront cost of embodied carbon is thus significant.

Embodied vs Operational emissions over a building's lifetime
Source: "The Piece the Buildings Industries' Carbon Emissions Pie We All Should be Reporting" (Savona 2024)

NET ZERO BUILDINGS AND EMBODIED CARBON

In an effort to reduce carbon emissions, net zero buildings are encouraged and are often regarded as the be-all end-all solution. However, net zero buildings do not guarantee a reduction in embodied carbon emissions. While net zero building designs aim to limit embodied carbon emissions, there are no ways to ensure that. An example of that is the new net-zero SUNY Albany building, the 246 thousand square foot building did not account for embodied emissions. And while many companies promise to offset emissions this is not a long term solution, considering the time value of carbon. This is where retrofitting buildings come into play.

Net Zero ETEC Building at SUNY Albany.
Source/Photographer: Brian Busher, Patrick Dodson

DEEP ENERGY RETROFITS AND CARBON SAVINGS

Deep Energy Retrofits (DER) involve extensive renovations to existing buildings to significantly reduce energy consumption, improve overall energy efficiency, and cut energy spending by 30-50 percent, in part because they avoid the initial embodied carbon impact of new construction (Pacific Northwest National Laboratory and PECI 2011). According to studies, building retrofits offer a practical and effective way to reduce carbon emissions associated with the built environment while simultaneously improving energy efficiency and sustainability (Less and Walker 2015).

DER typically involves multiple actions related to building's design and construction to achieve substantial energy savings, such as improving building's envelope upgrades by improving insulation, sealing air leaks and upgrading windows to minimize heat transfer from the interior and exterior of the building. Moreover, it also includes modifications on building energy supply and the adoption of clean energy use for building's operations. Looking to the case studies, deep retrofits could be a recommended approach to preserve character-defining features while achieving optimal energy efficiency in a balanced manner.

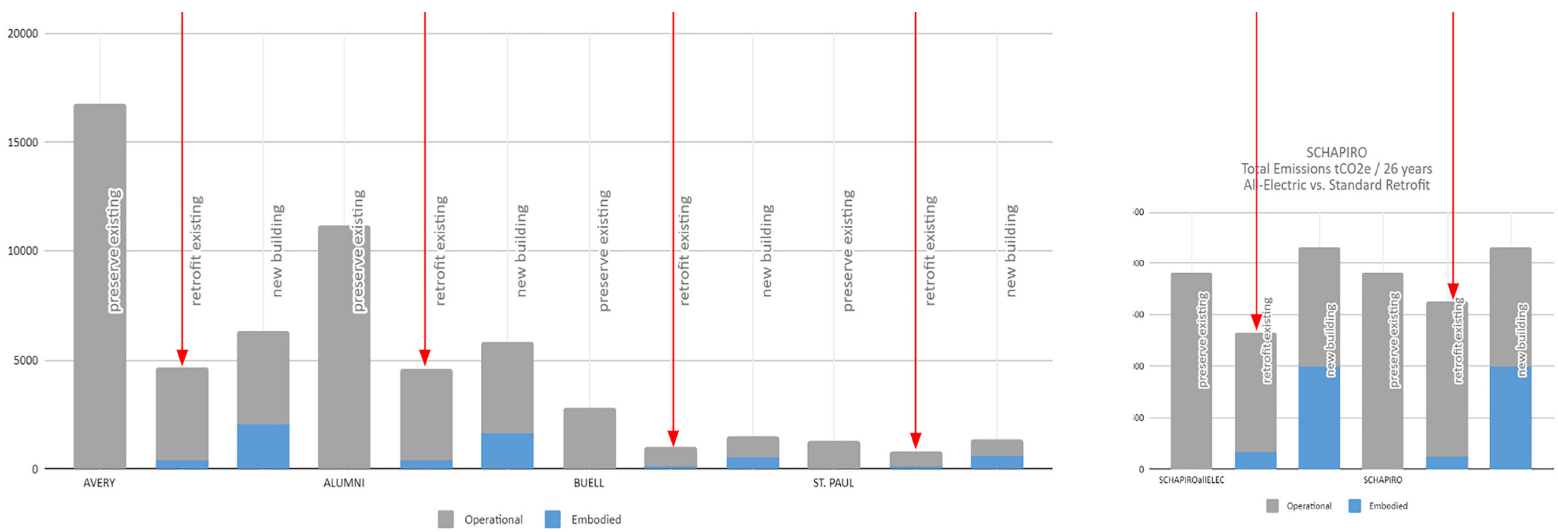
The Emerson School Deep energy retrofit project in Denver's Capitol Hill neighborhood, Colorado, is one of the cases provided by interviewees that explores this option. This is an historic building from 1885 that transformed its energy source to a geothermal system located in the basement of the building. In addition, the exterior envelope was tightened to avoid thermal leaks from the interior to exterior, as well as the repairing of all historic windows by double glazing and the adding of storm windows in specific cases. In addition, the building's passive design features were utilized, including the opening of transom windows that were covered in later modifications to improve natural ventilation. Although it was a costly investment, it allowed for a substantial reduction in energy consumption, which is reflected in reduced operating costs and carbon emissions (National Trust for Historic Preservation n.d.).

Emerson School Historic Building in Denver, Colorado. The DER in this case included the change of the energy supply system to geothermal energy combined with envelope improvings. /Source: National Trust for Historic Preservation, 2024.

STUDIO CASE STUDIES AND RETROFITTING

By comparing the results of operational and embodied carbon expenditures in different scenarios for all of the case study buildings, it is interesting to note that not taking any action and only preserving the current state would result in an exceedingly high cumulative operational footprint, a threat that counterbalances the historical status of the building over the climate impact of its operations.

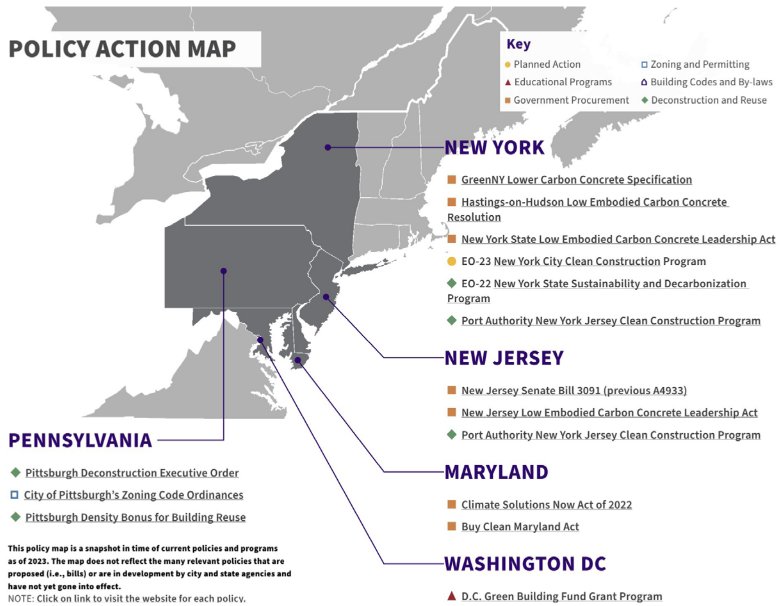
On the other hand, the alternative to demolishing and reconstructing a building with better energy and carbon standards, would lower operational carbon emissions considerably compared to preserving the building, but excessive new embodied carbon emissions would be created. Retrofitting the case study buildings is the best option for reducing both operational and embodied carbon emissions over time.



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

EMBODIED CARBON IS UNDER-REGULATED

A central issue in the exploration of embodied carbon is its notable absence from decision-making processes. This absence is driven 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.



Policy Action Map (2024)
Source: Carbon Leadership Forum

EMBODIED CARBON REGULATION IS BEGINNING ELSEWHERE

New York City has been at the forefront of climate policy action addressing building emissions through the lens of operational carbon, but they have not yet delivered any local policy which addresses embodied carbon. To date, there are no local laws overseeing deconstruction, mandating material or building reuse, nor requirements for embodied carbon calculations or Life Cycle analysis.

This policy action map was published by the Carbon Leadership Forum in 2024 highlighting areas of current embodied carbon government actions, through plans, government procurement, zoning and permitting, building codes and by-laws, and deconstruction and reuse (Kalsman, Lambert, Lewis, and Simonen 2024). As reviewed in the policy section of this report, New York State has begun regulating the embodied carbon in new construction materials such as concrete on its own state-owned construction projects through Executive Order 22 signed in 2022 titled "Leading By Example: Directing State Agencies to Adopt a Sustainability and Decarbonization Program'' (Hochul 2022). For now, this places carbon restrictions on new construction materials on state-owned projects only and is not applicable to Columbia or any other private construction projects in the state.

Additional embodied carbon regulation in New York State include:

- NYC Executive Order 23: Clean Construction Program (Planned Action, see Policy section)
- GreenNY Lower Carbon Concrete Specification (Government Procurement)
- Port Authority New York New Jersey Clean Construction Program (Deconstruction and Reuse)
- Hastings-on-Hudson Low Embodied Carbon Concrete Resolution (Government Procurement)

"Other areas of the country are further along in wider regulation of embodied carbon, such as the California Green Building Standards Code—Part 11, Title 24, California Code of Regulations—known as CALGreen. This regulation passed in August 2023 will make California the first state to address embodied carbon through a mandatory code when it goes into effect in July 2024. 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: demonstrate a 10 percent reduction in global warming potential (GWP) using whole building life cycle assessment, building reuse (45 percent or more), or use of environmental product declarations (EPDs) to comply with product GWP limits (Carbon Leadership Forum 2023). "

EMBODIED CARBON INSTITUTIONAL POLICY AT COLUMBIA

As with New York City, Columbia has also yet to develop any clear policy regarding embodied carbon in buildings. In fact, this lack of consideration could incentivize demolition. While Columbia's policy position does not explicitly incentivize demolition, their persistent focus on new, "green" buildings leaves older buildings vulnerable. With full embodied carbon accounting through whole-building life cycle assessment of the existing building stock, it would become clear that reuse, particularly that of building structure and envelope, augmented with additions and energy retrofits are the more sustainable option for truly sustainable physical growth of the campus.

CALCULATING AND CAPPING EMBODIED CARBON

Sustainable construction is a core value at Columbia. The new buildings being constructed on the Manhattanville campus have achieved LEED-Gold and Platinum certifications with stated commitments to energy efficiency and limiting carbon emissions. However, LEED certifications may be some level of greenwashing, and the demolition of existing buildings and the redevelopment of new, larger buildings may be a much greater source for carbon emissions when accounting for embodied carbon.

It is imperative that the university account for not only the carbon emissions relating to operating the buildings, but also the embodied carbon emitted during demolition, renovation, and new construction. Columbia has established stringent caps on carbon emissions as the university moves to a net-zero campus by 2050, but without embodied carbon included in total emission calculations, the total carbon numbers are significantly underestimated. Without a full embodied carbon accounting, carbon emission reporting by Columbia does not accurately reflect the university's real impacts on climate change.

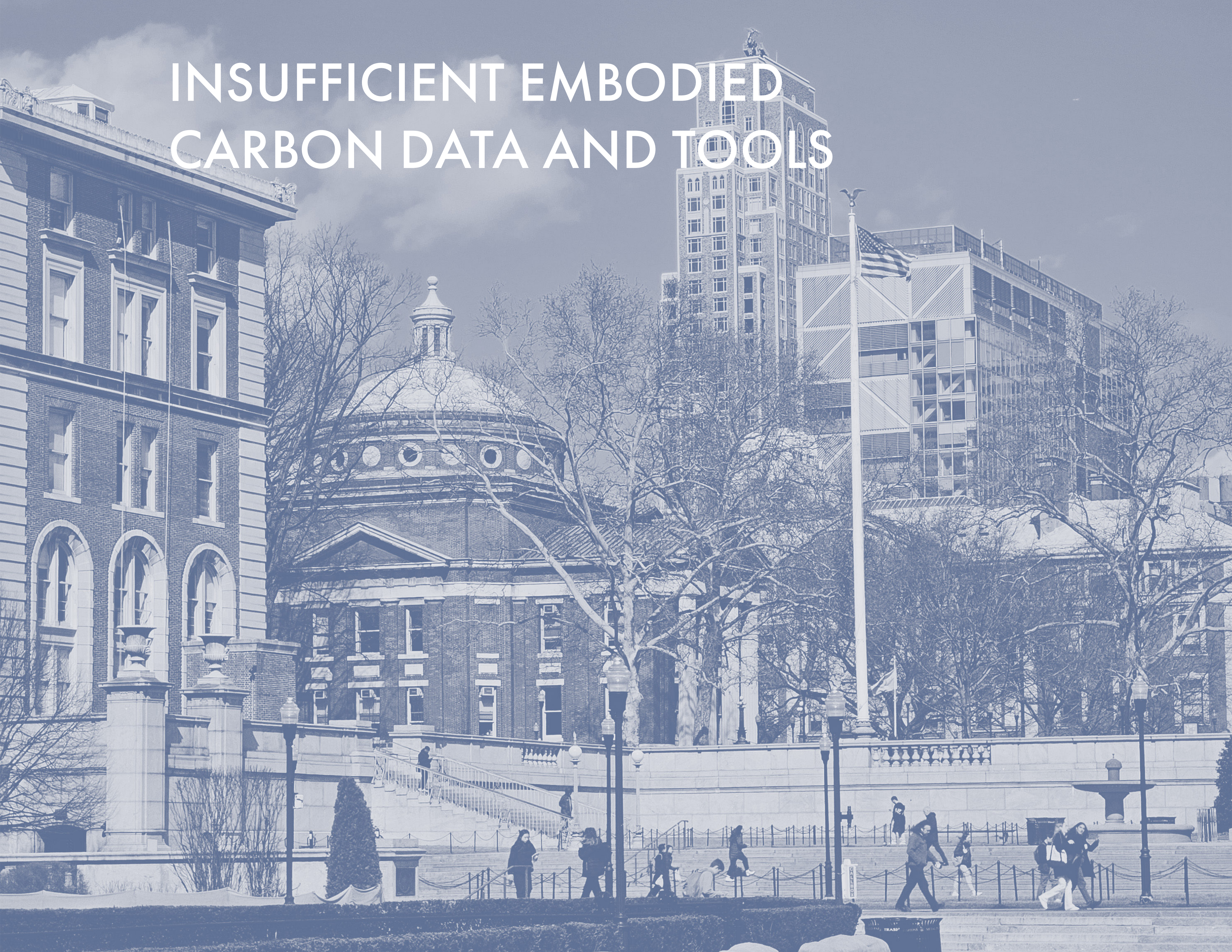
LEED AS GREENWASHING

The Leadership in Energy and Environmental Design certification program (LEED) rating system has grown to be the world's most widely used green building certification program covering over 110,000 buildings worldwide. With the lack of regulations on embodied carbon, many institutions looking to build sustainably rely heavily on green rating systems like LEED to serve as a policy substitute. The credit system that it employs for certification, however, is extremely expansive, most of which is not related to either energy efficiency, emissions reduction, or embodied carbon. Additionally, the requirements for certification are relatively limited (requiring only 50 percent of the credits for LEED Gold certification). Because of this flexibility many of the certified buildings do not have a significant reduction in their emissions. As shown in the Alumni Center case study, LEED Gold renovations have not resulted in better than average energy use intensity in the years following the intervention.

Although widely used, LEED certification at the time of construction or renovation is inadequate for evaluating actual embodied and operational carbon emissions—over time—and can be considered a form of greenwashing.

It should be noted that since this studio research was undertaken, LEED v5 has been released, and it is evolving requirements relative to embodied carbon and whole life carbon assessments.

INSUFFICIENT EMBODIED CARBON DATA AND TOOLS



The data regarding embodied carbon is insufficient to create and develop regulations. Currently, there are organizations such as NYC Economic Development corporation that put out guidelines to inform policies about addressing embodied carbon in the built environment. But these are only guidelines, and are not regulatory. The lack of baseline data, especially of NYC-specific data, makes it difficult to set policies about embodied carbon, from life cycle assessments to reuse to deconstruction. Data collection on embodied carbon is the first and biggest challenge for policy makers.

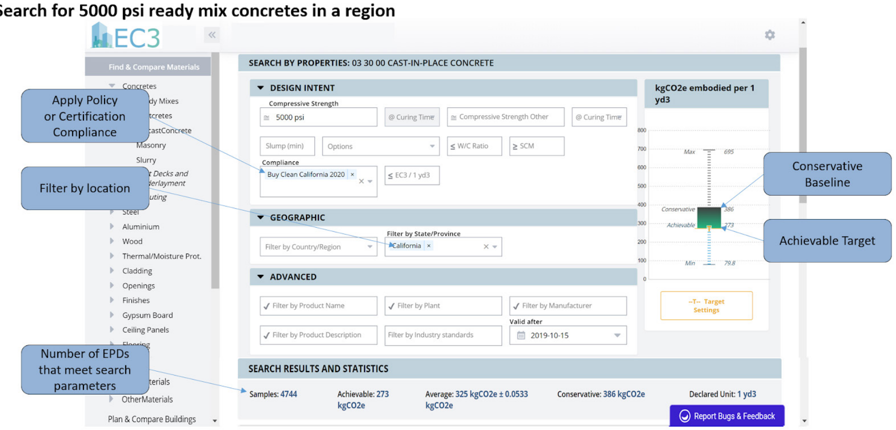
INSUFFICIENT CONSIDERATION OF HISTORICAL DATA IN EMBODIED CARBON ASSESSMENT

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 embodied carbon of existing buildings, attributable to the influence of historical factors. For instance, the determination of timber's embodied carbon in Buell Hall necessitates meticulous consideration of variables such as tree species and transportation methods. Existing carbon databases predominantly rely on aggregated data, reflecting the replacement values of contemporary materials. Thus, the embodied carbon calculations using these databases reflect the embodied carbon value associated with replacing the existing building with one of the same make-up today. Accurately assessing the actual historic embodied carbon of existing buildings mandates the incorporation of historical data into carbon databases.

CHALLENGES IN EXISTING CARBON INVENTORIES

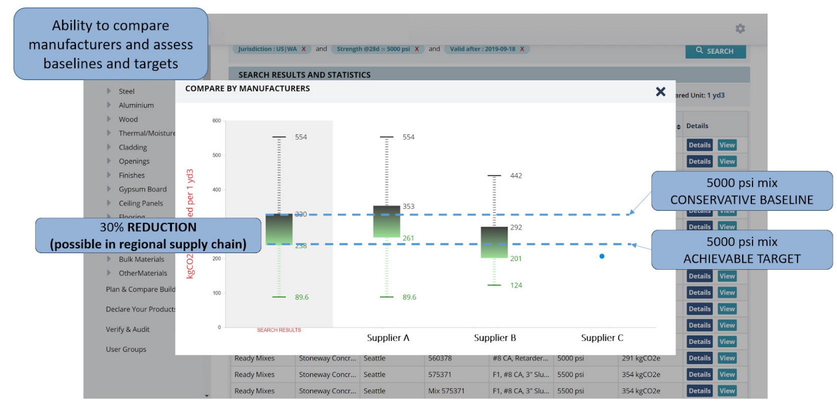
The process of assessing a building's embodied carbon entails navigating various challenges, particularly in the realm of carbon inventory development and database evolution. While carbon databases offer detailed insights into the composition of specific materials, the comprehensive evaluation of a building's carbon footprint requires the use of carbon inventories. However, existing carbon inventories predominantly rely on contemporary data, reflecting emissions associated with modern materials. This reliance on modern data stems from the

Search for 5000 psi ready mix concretes in a region



EC3 MATERIAL search.
Source: Building Transparency, 2022

Comparison of 5000 psi ready mix concretes in a region



EC3 MATERIAL Comparison
Source: Building Transparency, 2022

ease of monitoring and calculating emissions from prevalent materials. 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. Additionally, existing carbon databases exhibit notable discrepancies in embodied carbon outcomes for identical structures, highlighting the ongoing evolution and refinement of these databases. In other words, existing databases can have large variations in EC results for the same structure, such as the pictured example, ranging from 3.4 million kilograms of CO_2

equivalent to 9 million kilograms CO_2e. Despite these challenges, efforts are underway to fortify the robustness and dependability of carbon databases, aiming to provide more accurate evaluations of embodied carbon in building materials.

LACK OF STANDARDIZATION IN CARBON ESTIMATION

While there have been recent advances in standardizing Life Cycle Assessment (LCA) practices, such as ECHO and the RICS guidelines, there is a notable gap in methodologies tailored specifically for assessing embodied carbon in building materials are still in development. Notably, New York City lacks a fully standardized LCA method customized for this purpose, despite the existence of initiatives and guidelines from prominent organizations like the International Living Future Institute (ILFI) and tools such as EC3. Although several organizations have developed embodied 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, the realization of its full potential remains contingent upon overcoming existing barriers to collaboration and standardization within the industry (Carbon Leadership Forum 2023).

NO SHARED UNDERSTANDING OF EMBODIED CARBON

As this key findings section has demonstrated, there is a lack of harmonization when it comes to embodied carbon tools and data. However, this also applies to the discourse surrounding embodied carbon in general. Throughout the stakeholder interviews, there was not a shared understanding of embodied carbon across professionals. Each stakeholder had a different expertise and therefore could speak to certain themes but not to others.

The responsibility of introducing the concept of embodied carbon is that of education systems. Currently, there is very little in the training of professionals around the embodied carbon of existing buildings. This demonstrates that embodied carbon needs to be better integrated into built environment curricula to promote proficiency and shared understanding.

Three different Carbon Values for the same building! (Green Book DB, EPiC DB and ICE DB). Source: Petrass 2022

DECARBONIZATION CHALLENGES AT COLUMBIA

Columbia has clearly voiced its commitment to a greener future through not only the Columbia 2030 Plan, but also through the divestment from thermal coal (2017) and fossil fuels (2021) (Columbia Finance n.d.). However, the Morningside Heights campus still runs on a greenhouse gas emitting steam loop system, with a majority of the 30 percent emissions reductions in 2020 achieved through renewable energy credits, or RECs (Greenburg 2020). The choice to use RECs as emissions offsets has been critiqued by student environmental advocacy groups, research centers, and think tanks. This concern about Columbia's choice of monetary investment couples with these groups calls for transparency, which may go unrecognized by action players within the university.

Studio interviews suggested that Columbia student environmental advocacy and research groups are primarily concerned with:

- The transparency of institutional investments, especially in their relation to environmental impacts (direct and indirect)

- The impact of potential greenwashing to institutional decisions and use of monetary funds, as opposed to research-based carbon footprint reduction

- The unresponsiveness and unwillingness by action players and administrators to student voices expressing concerns and suggestions about institutional decarbonization

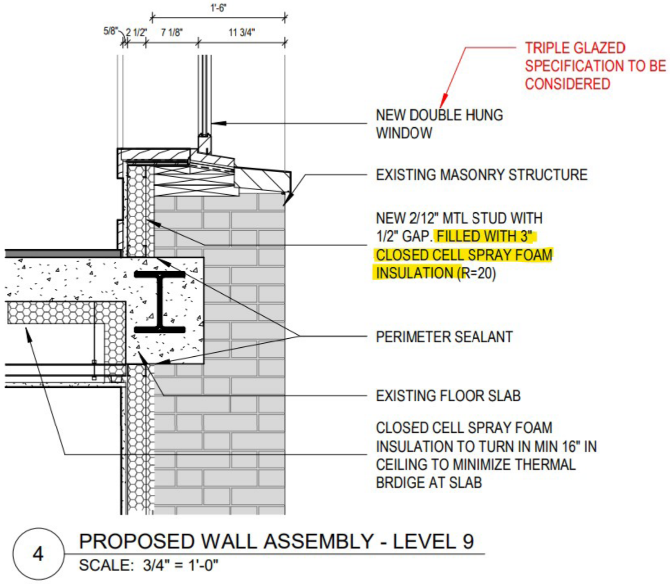
Fortunately, the conversion of Columbia's steam loop is underway, which represents a massive step forward in reducing operational carbon. Columbia's steam distribution system is massive and complex, reaching all corners of campus along with additional buildings such as Schapiro Hall. The amount of mechanical and plumbing work necessary to install the new hot water distribution system will be extensive and costly.

Conversion at the campus level will be covered by Columbia's Facilities and Operations budget. However, hot water plumbing and terminal units will still need to be installed at the building level. Individual buildings are mostly reliant on donor funds for any capital improvements, with each donor having different restrictions on what the money can be used for. If the funds are available, new plumbing and equipment is often installed whenever most convenient, usually in tandem with another construction project. Since all buildings on campus will be retrofitted at different times, it is necessary to maintain the existing steam lines alongside the new hot water system until conversion is 100 percent complete. This complicated process means extra expenditure of both embodied carbon and space.

DECISION-MAKING BEYOND CARBON

In many cases, the decision to retrofit an existing building is a tradeoff not just between energy and cost, but also space considerations. This was the case at Hartley Hall, where the addition of just three inches of wall insulation was ultimately abandoned, because the additional wall thickness on the interior meant the removal of five beds. At a campus like Columbia, the need to house more students has always been a crucial consideration. The alternative to interior insulation is to improve the building on the outside, which requires complete exterior alteration. This type of alteration is rarely permitted for locally-designated buildings and has historically been opposed by preservation advocates.

Typical bedroom in Hartley Hall.
Source: Columbia Housing.



Proposed addition of three inches of wall insulation.
Source: 1100 Architects.

In some situations, an existing building is demolished and replaced for a new one for reasons that go beyond the need for energy improvements. In New York City and beyond, the demolition and replacement of older buildings is often driven by the need for greater amenities. This threat to buildings also exists within Columbia. Schapiro Hall, as one example, created a less dense housing situation than the student-occupied apartments that it replaced. By not utilizing all of its available space to simply build more bedrooms, it instead offers ample student lounges, common areas, and even music practice rooms. Schapiro's monumental and strikingly "different" appearance might also be an intentional aesthetic move away from the West District, which had a negative reputation throughout the mid-1900s. A similar rationale may come to inform Columbia's decisions at its Manhattanville campus.

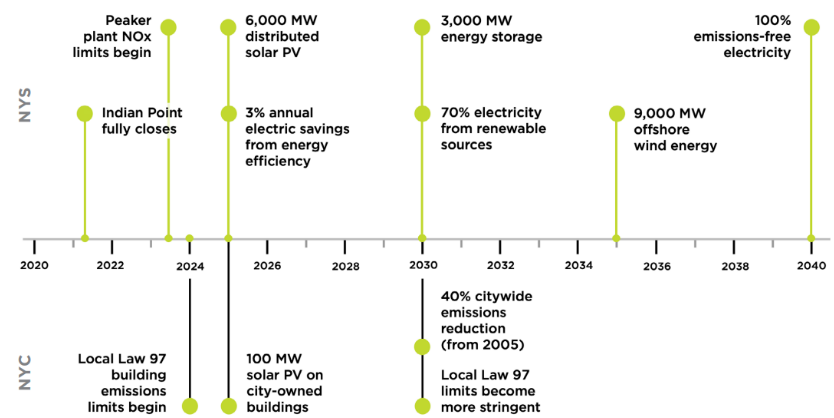
The LEED-certified renovation of Alumni Center presents another case of decision-making that is difficult to qualify. As an effective symbol of Columbia's commitment to sustainability, the renovation still does not provide promised improvements to energy performance (see "Alumni Center" case study).

Several different actors are at stake when a building is to be preserved, altered, or demolished and replaced. Many existing values surrounding historical buildings, from preservationists, building owners, and residents, change over time. Whether it is updated interior finishes, gender neutral restrooms, increased accommodations for people with disabilities,or the need to advertise a building as being "green" or more "modern," trends in user habits and occupant needs are sometimes unpredictable, which makes the cost-benefit analysis and predictability of future carbon-intensive projects even more difficult.

RENEWABLE ELECTRIFICATION IS STILL UNDERWAY

Reducing emissions at Columbia University's Morningside Heights campus is a pressing need, yet electrification poses significant challenges in achieving this goal. Despite the campus's commitment to emission reduction, conventional energy efficiency upgrades are insufficient to meet targets. Electrification appears as a viable solution, but its implementation is not as simple.

However, the current state of New York's grid presents a major hurdle. With the grid still heavily reliant on non-renewable fossil-based sources, the transition to 70 percent renewables by 2030 and a 100 percent zero-emissions grid by 2040 is still ongoing (New York State Energy Research and Development Authority n.d.). Even if the campus were to fully transition to electrification immediately, the grid lacks the capacity to support the increased demand (Karam 2023).



NYS and NYC Net Zero Timeline
Source: Urban Green Council, 2020

UNIQUE ENERGY DEMANDS FOR LABORATORY BUILDING

Furthermore, the unique energy demands of laboratory buildings present a significant challenge. Laboratories, essential for cutting-edge research, rely on energy-intensive equipment such as lasers, fume hoods, and sub-zero (down to minus 80 degree) refrigeration systems. These energy needs are characteristically not suitable with the diffuse and intermittent nature of renewable energy sources like solar and wind (Karam 2023).

Fuel	Power Density (W/m^2)
Gas	200-2,000
Coal	100-1,000
Solar (Concentrating)	4-10
Solar (PV)	4-9
Wind	0.5-1.5
Wood	0.5-0.6

Energy Density Table/Source: 1 Kent Hawkins, 2010

Moreover, the sheer scale of fossil fuel-based energy consumption across the campus is staggering. From the thousands of energy-consuming sub-zero refrigerators to the heavy-duty air conditioning units required for stringent temperature control in laboratory buildings like Pupin Hall, the campus's reliance on fossil fuels remains entrenched.

In light of these challenges, a paradigm shift is needed. Columbia University must not only pursue electrification but also address systemic issues such as grid modernization and the development of energy-efficient laboratory technologies, and consider more possibilities such as adopting energy storage or hybrid systems.

TIMING IS CRUCIAL FOR ELECTRIFICATION

Timing is crucial in navigating these challenges, especially for energy-intensive buildings like laboratories in Pupin. Electrification must occur when the grid infrastructure is prepared to handle increased demand and renewable energy sources are readily available. Rushing into electrification without considering grid limitations risks straining an already overburdened system. Therefore, strategic planning and coordination with energy providers and policymakers are essential for a smooth transition to electrification while reducing energy demands and other environmental benefits.By aligning electrification efforts with grid modernization initiatives, Columbia can set a precedent for sustainable campus development.

ALTERNATIVES WHILE WAITING FOR THE GRID TO DECARBONIZE

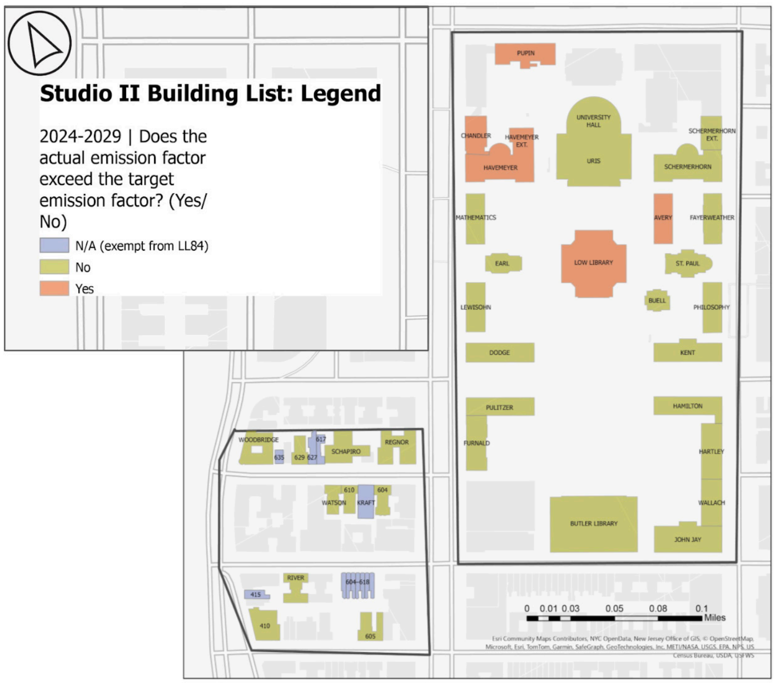
Energy Storage: Energy storage systems store excess energy generated during times of low demand and release it when demand is high. This helps balance supply and demand on the grid and ensures a stable and reliable energy supply. Energy storage technologies include batteries (such as lithium-ion batteries), pumped hydro storage, compressed air energy storage, and thermal storage systems. These systems play a crucial role in integrating intermittent renewable energy sources like solar and wind into the grid by storing excess energy for use when the sun is not shining or the wind is not blowing (Aktaş and Kirçiçek 2021).

Hybrid Systems: Hybrid energy systems combine two or more different energy sources to generate power. These systems leverage the complementary strengths of each energy source to enhance overall efficiency, reliability, and resilience. For example, a hybrid system might combine solar panels with a diesel generator or wind turbines with a battery storage system. By integrating multiple energy sources, hybrid systems can optimize energy production, reduce dependence on fossil fuels, and enhance grid stability. Hybrid systems are particularly useful in remote areas or microgrid applications where access to a reliable grid is limited or non-existent (Aktaş and Kirçiçek 2021).

COLUMBIA UNIVERSITY'S PATH TO EMISSIONS REDUCTION

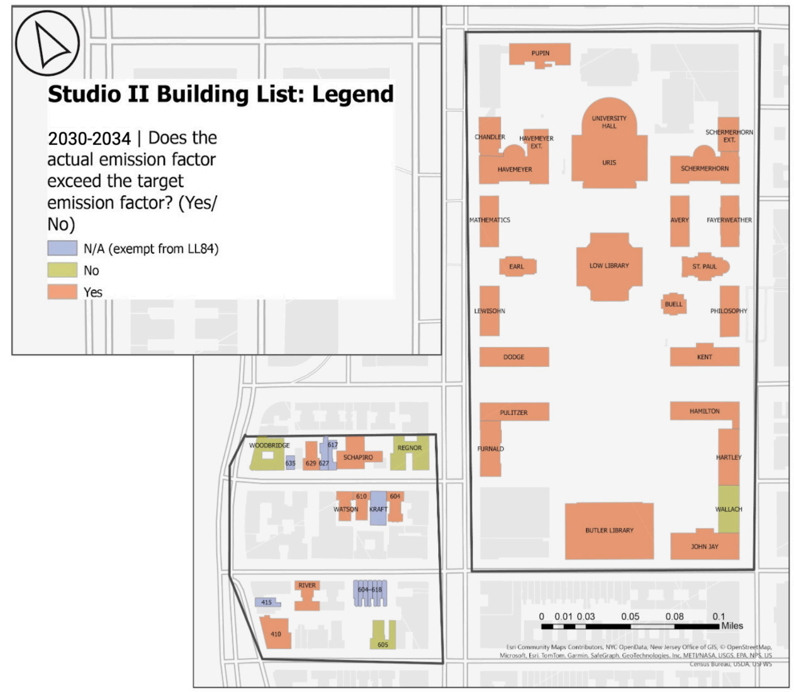
Reviewing Columbia's institutional policy, as stated earlier, the university has established a carbon budget that aims to reduce operational carbon to meet NetZero by 2050. Unlike New York's greenhouse gas law, which sets forth proportional emissions targets every five, then ten years based on square footage and property type, Columbia outlines a more-stringent reduction strategy with set emissions caps that are inflexible to Columbia's development projects and expanding footprint. Thus, with Columbia's increasing square footage, the plan positions Columbia's new construction as necessarily low or zero carbon.

Local Law 97	Columbia Plan 2030
Emissions factors established by property type, proportional to square footage.	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.



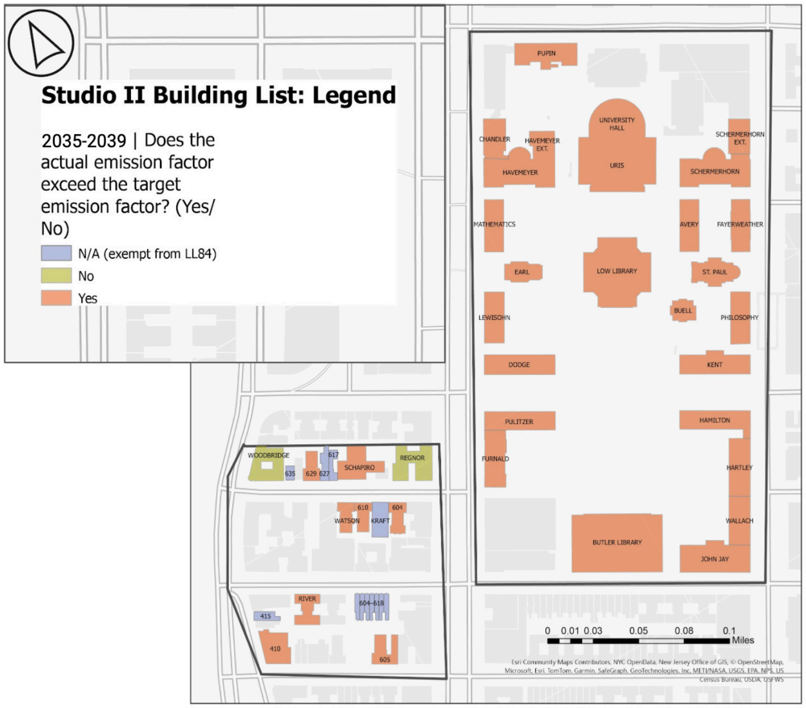
Emissions Targets, 2024-2029.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data

Looking at the emissions factors stipulated by Local Law 97, calculated from Columbia's 2022 benchmarking data, for 2024-2029, the majority of buildings (in the initially established studio building set) meet city targets, with the exceptions of current case study buildings Avery Hall and Pupin Hall. Buildings marked in green indicate those that meet city targets, buildings marked in red are those exceeding targets, and buildings marked in purple are buildings who are exempt from reporting.



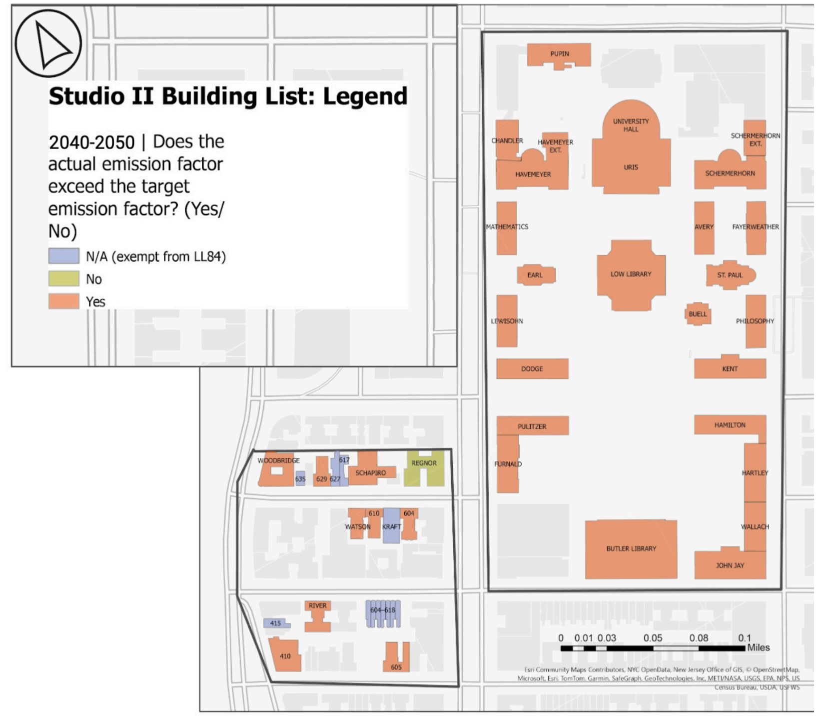
Emissions Targets, 2030-2034.
Source: Map by Charlotte Crum, LL84 Benchmarking via NYC Open Data

However, for 2030-34, only four buildings in the studio building list are on track to meet city targets: Regnor Court, 605 West 113th, Woodbridge, and Wallach Hall.



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

For 2035-2039, just two buildings are on track to meet their targets: Regnor Court and Woodbridge.



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

And for 2040-50, just Regnor Court would meet its targets. As evidenced, Columbia has a long way to go to meet the city's 2030 targets, let alone to meet the carbon cap established by Columbia.

CONSEQUENCES

The critical takeaway is that while Columbia is committed to providing annual updates to track the progress of becoming more sustainable, if these projected, more stringent targets are not met, there are no real consequences. However, at the local level, there are three financial penalty categories outlined if emissions targets are not met, which further incentivizes compliance.

Estimated Minimum Fines for the Six Case Study Buildings at Columbia University from NYC LL97. Source:Various Photographers

The cumulative fines by 2050 for the six case study buildings are as follows; Avey Hall $8,234,558, Pupin Hall $34,825,161, Schapiro Hall $1,358,761, Alumni Hall $2,136,273, St. Paul's Chapel $388,530, and Buell Hall $553,732 (New York City 2019). These are the minimum fines assuming the fines do not change over time. However, as a studio, it is speculated that these fines will only increase over time. Shockingly, for just the six case study buildings the minimum cumulative fines by 2050 total over forty-seven million dollars. A hefty fee for a small percentage of Columbia's building portfolio. Without proper retrofit and maintenance, the likelihood of LL97 compliance for currently existing buildings owned by Columbia is very unlikely, while the financial penalties will only continue to grow. This, alongside Columbia's stringent operating emissions targets, all further incentivize demolition.

DECARBONIZATION CHALLENGES FOR PRESERVATION

In New York City and beyond, it's very clear why the embodied carbon of historic materials matter. This embodied carbon is not simply a sunk cost that can be ignored as climate change continues to identify and threaten heritage all over the world. In this section, it is observed that preservation does not significantly engage with the issue of embodied carbon head-on, and fails to engage with operating carbon as well.

COLUMBIA AND THE EMBODIED CARBON OF ITS HISTORIC BUILDINGS

As noted in the earlier case studies section, a number of Columbia's buildings will require deep retro-commissioning measures to meet operational carbon requirements. In addition, Columbia's fixed carbon budget, which is set regardless of increases or decreases in square footage, also does not consider embodied carbon of its existing buildings. This may incentivize Columbia to demolish historic buildings on the campus in pursuit of their operational carbon goals. In the case of Pupin, which is listed on the National Register and a National Historic Landmark, these protections do not shield the buildings from potential demolition if it is unable to meet energy targets.

Earlier case studies have also demonstrated how Columbia has altered the character of the West District through demolition and new construction. Buildings in the West District are now significantly protected from further demolition due to the area's designation as a historic district by the New York City Landmarks Preservation Commission. This designation demonstrates preservation policy's unintended built-in embodied carbon consideration as it requires the reuse and maintenance of existing buildings, effectively ensuring that the embodied carbon investment of these buildings is not lost.

However, this local designation does not extend to all of Columbia's properties and itself does not explicitly incorporate the concept of embodied carbon. In areas without this level of protection, such as Manhattanville, where Columbia is deeply invested in changing the urban form, the lack of historic recognition and designation may make historic buildings vulnerable to demolition, disregarding their significant carbon investment. This lack of historic recognition makes it doubly important to think about embodied carbon using other policy tools. Encouraging reuse, while potentially good from an embodied carbon perspective, needs to be further substantiated with data and that also considers operating carbon and deep retrofits.

Construction of Kravis Hall, Manhattanville
Source/Photographer: Nathan Kensinger, 2018

PRESERVATION AND EMBODIED CARBON

Existing embodied carbon databases are largely focused on the replacement values of building materials, meaning their CO_2e is calculated with today's production processes and values, rather than the actual embodied carbon of materials based on their time of production. This presents a considerable challenge for understanding the actual embodied carbon of historic buildings, as the embodied carbon of a brick produced in a Hudson River brickworks around 1900 may greatly differ from that of a contemporary brick produced overseas and shipped to the US. The Buell case study's research into the embodied carbon of timber from 1885 is indicative of the large potential differences in replacement value and historic value.

Experts on embodied carbon are also not well versed in embodied carbon in the context of historic materials. This is due in part to the focus on replacement values, as it is much easier to calculate the embodied carbon of contemporary materials. Yet given the work and interests of preservationists related to the sourcing and manufacture of historic building materials, preservationists have also failed to conduct extensive research into the topic.

The lack of research by preservationists into the topic are limiting the ability to quantify the actual embodied carbon of historic buildings. While studies such as Widder and Meinrenken's "Three Windows" study has provided a strong example of how the embodied carbon of historic materials could be quantified by researching extraction, fabrication, and transportation methods that would have been used at various points in time, there is a lack of widespread studies that have been conducted on the topic.

THE OPERATIONAL CARBON OF HISTORIC BUILDINGS MATTERS

Embodied carbon cannot be separated entirely from operational carbon; both are important. Action must be taken to decrease operating emissions and improve energy efficiency. Historic buildings can no longer rely on their embodied carbon as an excuse to be exempt from meeting energy performance codes and decreasing their emissions. The preservation field has relied on the long-standing rhetoric of "the greenest building is the one already built," and that statement advances the notion that embodied carbon invested in older buildings somehow rationalizes them not changing. Such rhetoric is no longer acceptable.

While embodied carbon is incredibly important, as demonstrated by the research thus far, reducing operating carbon is equally, if not more important, as the research has also shown. As demonstrated by the studio's use of the CARE Tool, doing nothing and preserving buildings as-is, without retrofits, is often the worst thing that can be done with historic buildings from a carbon perspective. Yes, embodied carbon is important and preservation as an enterprise needs to do more to understand it. At the same time, preservationists need to be fully engaged with decreasing operational carbon and improving energy efficiency, which requires historic buildings to be retrofitted, which requires significant change. The status quo and the rhetoric from the 1970s that has persisted needs to be challenged and ultimately changed: the greenest building is the one already built and undergoes a deep retrofit.

Accordingly, preservation needs to get more comfortable with retrofits. The findings of this report point to limits the preservation enterprise exacts upon climate adaptation, which in turn will lead to more demolition. Income-generating National Register buildings may utilize historic tax credits (HTCs), however, HVAC replacements are often not considered qualified expenses in the use HTCs. Additional, the Secretary of the Interior Standards, a primary guidance document for historic preservation, remain relatively inflexible when it comes to disrupting historic materials (Bronin 2020) For example, a retrofit rehabilitation project of the Swift Factory in 2019 that attempted to introduce energy efficiency measures was denied tax credits from the National Park Service for possibly disrupting historic fabric. The developers retrofitting the property initially requested to insulate the interior of the property as well as introduce pre-cast sills as thermal breaks. The proposed insulation did not threaten historic materials and was not visible from the exterior. Nonetheless, the retrofitting measures were rejected and as a result abandoned. Accordingly, the building is lacking in critical energy saving measures (Bronin 2021). In the face of a global climate crisis, the Standards must be challenged. And preservationists must adjust their aesthetic assumptions, and choose to value interventions that reflect resiliency strategies for communities and their generations to come.

Columbia Campus. 2024. Photo by Frederick.

WAYS FORWARD

Acknowledging that the institution of Columbia University and the field of historic preservation are hindered by the lack of embodied carbon research, databases, and policy (as discussed through the key findings), this studio sees both hope and potential for both Columbia University and the study and profession of preservation.

COLUMBIA UNIVERSITY

- **Support retrofits**, a critical partner to Columbia's planned steam loop conversion.
- **Strive for LEED Version 4.1** Operations and Maintenance Certification.
- **Conduct** more in-depth Life Cycles Analyses (LCAs).
- **Adjust Columbia's carbon budget** to account for embodied carbon.
- **Lead** the development and regulation of **building reuse, material reuse, and deconstruction policies** at the institutional level.

HISTORIC PRESERVATION

- **Develop guidelines and databases** for historic embodied carbon quantification.
- **Include material histories** in historic designation nominations.
- **Review** and **update guidelines** and **standards** for energy retrofits.
- **Balance the preservation of historic fabric** with the **prevention of climate collapse** through a decrease in carbon emissions.
- **Reduce operational carbon** and **increase energy efficiency** in historic buildings so that preservation practice remains relevant.

COLUMBIA UNIVERSITY AS AN INSTITUTION

Columbia University needs to invest time and money in retrofitting its historic buildings to avoid fines, meet emission targets, and to create a greener campus. Thus far, the institution has committed to converting the steam loop and electrifying the campus, in parallel to New York State's decarbonization of the grid. Building level retrofits remain a critical aspect of this impactful commitment. These retrofits will require making difficult decisions around a decrease in usable square footage across campus as regarding how to continue typical campus operations during a period of frequent construction, building closures, and general possible disruption to the living and learning environment of Columbia's Morningside Campus.

For those buildings on Columbia's campus that rely on LEED certification at the time of construction or renovation to promote sustainability standards, it is important to underscore that LEED metrics do not necessarily align with the carbon reduction goals of Columbia or NYC. To fully embrace accountability and transform Columbia's building stock into authentic "green" buildings, Columbia University should strive for LEED version 4.1 Operations and Maintenance certification (or LEED O+M). LEED O+M evaluates existing buildings and bases LEED points on reducing operational carbon with ongoing tracking to ensure sustained performance and upkeep of systems over time.

Columbia should also consider that more in-depth life cycle analyses (or LCAs) are needed to understand the tradeoffs between embodied and operating carbon moving forward. The case study calculations, which showed lower carbon impacts for retrofitting existing buildings rather than new construction, establishes a basis for more in depth LCAs. Columbia's anticipated expansion of square footage in Manhattanville coupled with its stringent carbon budget, which does not account for the addition of square footage, poses a challenge. By not accounting for embodied carbon in this situation, there may be incentives to construct new "net zero" buildings due to the lack of recognition of the upfront carbon of these new buildings. Thus, Columbia may take advantage of this possible loophole and create a more intensive carbon impact, especially considering the neighborhood scale at which these institutional changes are taking place.

With limited NYC efforts to implement embodied carbon policy, Columbia has the opportunity to implement policy at an institutional level by requiring building reuse, material reuse, and deconstruction. The LCAs, as mentioned earlier, will provide Columbia the information necessary for these calculations, while policies will create actionable changes in the possibilities for accounting the embodied carbon of building and material reuse. Columbia has the potential to lead the effort in the creation and regulation of institutional embodied carbon policy. While it is a grand task to take on, it is not an impossible one for this campus to achieve. With Columbia University being the largest private landowner in New York City by number of addresses, institutional policy on this scale could have a vital impact on the city's embodied carbon emissions (McKee 2023).

PRESERVATION AS A FIELD

Existing buildings in NYC are going to make up 85 percent of the city's built environment by 2030 year, according to the Greener, Greater Building Plan (New York City Mayor's Office of Long-Term Planning and Sustainability 2014). Therefore, quantifying the value of these existing buildings through embodied carbon calculation and analysis will be essential to understanding what has already been expended. As a discipline, historic preservation has long used rhetoric that recognizes the investment of embodied carbon in existing buildings. However, the field has yet to fully develop the data to back this claim up.

The original intent of this Studio's work was to calculate the historic embodied carbon of the case studies on Columbia's campus. However, the lack of data and standardized guidelines proved this aim to be too difficult given the time constraints of a single semester. No one else is going to be collecting this information for preservationists. If preservationists want historic embodied carbon data, then it needs to be prioritized by the field.

Municipal, state, and national preservation agencies through nomination processes have developed extensive resources on historic design, influential architects and developers, and place-based histories. In recent years, the field has adapted to include a more diverse and inclusive narrative of who is included in these histories. Preservation can adapt again to include material history into nomination reports at the municipal, state, and national level to begin the documentation of material sourcing, transportation, and construction. Precedents, like material passports that document the embodied carbon of building elements, could inform research and guidelines. This information could then aid in the development and regulation of building reuse, material reuse, and deconstruction policies.

The work of this Studio did validate the importance of recognizing the value of embodied carbon in historic buildings. However, the analysis done using the CARE Tool (which was developed in partnership with the National Trust for Historic Preservation) illustrated that both embodied and operational carbon must be considered in the contemporary carbon crisis. It is essential that reducing operational carbon and increasing energy efficiency within historic buildings be prioritized, in addition to embodied carbon research.

Existing, and inevitably, historic buildings will need to undergo retrofits to decrease operational carbon emissions. As stewards for historic buildings, retrofitting and making the existing built environment "greener" is a great solution for limiting upfront carbon emissions of "new construction". However, this may require some leeway on the part of preservationists when it comes to changes to the historic fabric. Designated historic buildings have received liberal energy codes waivers and have not yet been pushed to develop creative solutions to balancing preservation interests with the looming climate crisis. Extensive research and the institutionalization of the reduction of operational carbon is late, compared to other disciplines working in the building industry. Preservationists can decide whether they want to lead these efforts or wait until the law forces compliance, as is currently happening in New York City.

Compromises will be necessary to accommodate for the significant retrofits required to comply with carbon emissions legislation in NYC. However, preservationists can and should have a role in ensuring that these retrofits are done sensitively and effectively. Preservation organizations may benefit from working towards developing new guidelines for historic buildings undergoing major retrofits to balance the need for action in the climate crisis and the protection of historic buildings. As a field, preservationists must challenge status quo and evolve assumptions regarding sustainability and retrofits with new data and knowledge.

APPENDIX A: POLICY AND DATA ANALYSIS

INTERPRETING COLUMBIA'S BENCHMARKING DATA AND ITS RELEVANCE TO LOCAL LAWS

With the passage of Local Law 97 in April of 2019, Columbia began to initiate building-level reporting processes for both direct—e.g. combustion of natural gas or fuel oil—and indirect emissions —associated with purchases of electricity, district steam, district hot water, or district chilled water, (Mayor's Office of Climate and Environmental Justice 2022). Resulting from this passage of law which initiated emissions reporting city-wide, Columbia began to more thoroughly report and record its emissions—as evidenced by internal data provided by Columbia Facilities, and data published by the city as part of Columbia's mandated benchmarking reporting through LL84.

In 2019, the treatment and reporting of building level energy usage and emissions data varies across the studio building set. For buildings within the Columbia Residential Housing Portfolio—within the West District and over 10,000 square feet—Columbia reported data in all fields relating to greenhouse gas emissions. Contrastingly, looking at buildings within the studio set on the Morningside Campus, Columbia publicly reported almost no data to the city. For twenty two of the twenty three buildings on campus within the building set, all emissions and energy usage fields were listed as "not available,"—the notable exception being Hamilton Plaza, who reported data similarly to buildings found in the West District. However, while the building-level data Columbia reported to the city in 2019 was limited, internally, facilities initiated reporting processes documenting chilled water, electricity, and steam usage. Looking at Columbia's most recent benchmarking data from 2022, complete energy usage and emissions data is reported for the entire applicable studio building set.

The reporting mechanism for campus buildings on Columbia's steam loop is complicated by imprecise building-level usage metering. While, as indicated in an interview with Columbia Facilities, each building on campus has a submeter, for Pupin Hall, the site of a central meter on the steam loop, usage seems disproportionately high given building use and potentially indicates a discrepancy in reporting. This discrepancy has resulted in Pupin's designation as the highest emitting building on campus, which will be expanded upon below. This challenge of metering is rooted within the physical development of Columbia's campus, and its reliance on the centralized steam distribution system which complicates dividing specific energy readings from meters in order to effectively report the benchmarking data mandated by Local Law 84.

CALCULATING TARGET EMISSIONS REDUCTIONS

As mandated by city law, all emissions benchmarking data is publicly available through the NYC Open Data Portal. There, annual Energy and Water Data Disclosures for Local Law 84 are published annually. Data is published beginning in 2010 and onwards, with emissions data more sporadically appearing prior to 2019. The operational carbon analysis that underpinned much of this studio's research relied on these public datasets.

Though the benchmarked emissions data found in the annual Energy and Water Data Disclosures is helpful to understand a building's operational emissions, the data does not indicate the degree to which a buildings emissions do or do not comply with the emissions reductions stipulated under Local Law 97.

Within Local Law 97, the city has established municipal target emissions reduction factors based on Energy Star Portfolio Manager (ESPM) property type, which property owners self-select when reporting their benchmarking data, and which influence the emissions factors (New York City 2009a). Buildings can have multiple property types within them, that are then weighted depending on square footage. At Columbia University, the primary property type selected for buildings on the Morningside Heights campus is College/University, yet, as identified in the Pupin Hall case studies, the self-selected ESPM designation can have significant ramifications for energy usage and mandated target emissions reductions based on property type. Municipal target emissions factors are published in Chapter 100, SubChapter C of the Rules of the City of New York, § 103-14 Requirements for Reporting Annual Greenhouse Gas (GHG) Emissions for Covered Buildings.

Once property types were identified for all buildings within the studio building set, a spreadsheet was created with two pages: one with Columbia's most recent benchmarking data from 2022, and one with ESPM Property types and their emissions factor for the compliance periods 2024-2029, 2030-2034, 2035-2039, and 2040-2049. With the assistance of Historic Preservation PhD candidate Anna Gasha, a formula was developed to determine actual emissions factors. The calculation instructions to complete the emissions analysis was as follows:

1. **Insert a new column into page one (benchmarking data) to find the actual emission factors for each property** (New Column 1).
2. Divide the total GHG emissions (Column BW) by the total gross floor area (across all uses): (Column S + Column U) for each row in that column.
3. Create a new column to determine target emission factors for each property (New Column 2)

a.In most cases, look up the ESPM property type on page two to find the corresponding emission factor

b. For properties with multiple use types, take a weighted average based on floor areas for each use:

i.(Column S)/(Column S + Column U) * (target factor from New Sheet 1 for property type in Column R) + (Column U)/(Column S + Column U) * ((target factor from New Sheet 1 for property type in Column T)

ii. Because there appears to be only one property with multiple uses in this data set, using this formula for that one row is fine.

4. **Compare the actual emission factor (New Column 1) to the target emission factor (New Column 2).** Create a new column to indicate, for example, whether the actual emission factor exceeds the target emission factor.

APPENDIX B: CARE TOOL METHODOLOGY

Developed with Architecture 2030 by Larry Strain, Lori Ferriss, and Erin McDade, the CARE (Carbon Avoided Retrofit Estimator) Tool is designed to estimate and compare the carbon impacts and benefits associated with the reuse and upgrade of existing buildings versus replacing them with new construction. Pertinent to the 2024 studio, the tool evaluates embodied carbon and operational carbon across three hypothetical scenarios, "do nothing," "retrofit existing," and "new building." The CARE Tool is an invaluable resource for visualizing tradeoffs between these scenarios and is helpful in assessing the avoided carbon emissions as a result of retrofitting existing buildings. When using the CARE Tool to calculate embodied carbon, each case study input different factors depending on the scale of intervention deemed appropriate in a reuse and replacement scenario. Each building was examined over a time frame of twenty-six years or until 2050, with grid decarbonization for each building set to 2040. The use of the CARE Tool for evaluating operational emissions was consistent in regard to the larger policy framework in which the hypothetical scenarios would take place.

The CARE Tool relies on EUI, or energy use intensity, for estimating operational carbon. EUI indicates the energy efficiency of a building's design and operations and is quantified as energy per square foot per year. It is calculated by dividing the total energy consumed by a building in one year (measured in kBtu or GJ) by the total gross floor area of the building (measured in square feet or square meters). EUI is a valuable performance metric nationally, as it generally reflects the energy efficiency of an existing building, and is dictated on a federal level through the Environmental Protection Agency. Mandatory benchmarking statutes in New York City utilize the EPA's Portfolio Manager to calculate EUI automatically.

However, in New York City the operational energy of existing buildings is regulated through carbon emissions under Local Law 97, and not energy efficiency or EUI. Problematically, EUI does not correlate to emissions reliably. Building on the target emissions reduction factors calculated for the case study buildings, and considering Columbia's existing buildings will have to respond to these set targets and fines under Local Law 97, the retrofit or new building scenarios that the CARE Tool generates must be equal to or less than the cumulative carbon budget from 2024 to 2050. Therefore, this studio developed a system for finding this operational emissions budget. The compliance periods are 2024-2029, 2030-2034, 2035-2039, and 2040-2049. The city provides factors for each compliance period respective to the building's reported property type. The factors become increasingly stringent. To calculate the total carbon budget permissible for each compliance period, target emissions factors for each compliance period were multiplied by the square footage of the property. The values for each compliance period were then totaled to reach each building's net operational emissions budget until 2050. The following example is of the Alumni Center.

	A	B	C	D	E	F	G
1	ALUMNI CENTER						
2	Property Type: College University						
3	NOTE: RED BOX indicates required input						
4					2030-2034 | Property Target Emission Factor **(Depends on property type)**		
5	Start	End	Period	Years	tCO2e/sf	tCo2e/year	tCo2e per interval
6	2024	2029	2024-2029	6	0.00987	535	3210
7	2030	2034	2030-2034	5	0.00210	114	569
8	2035	2040	2035-2040	5	0.00124	67	335
9	2040	2049	2040-249	10	0.00018	10	98
10							
11	Sum			26		**Total Budget**	4212
12							
13							
14	Area						
15	54203	sf					

Carbon Budget Calculator Data Source: Local Law 97 of 2019 Energy Star Portfolio Manager Reference Guide, January 2023. Local Law 84/97 Benchmarking Reporting, NYC Open Data

When the reported EUI for each studio building case was input into CARE, the value was not reflective of the reported greenhouse gas emissions for the same year. Accordingly, CARE's reliance on EUI as a performance indicator was not reflective of the actual scope of retrofit necessary to ensure a reused or new building is in compliance with the local law. Therefore, the team applied the CARE tool so that the EUI input into CARE was reflective of the existing buildings' actual reported emissions. Firstly, the team multiplied the reported greenhouse gas emissions for the most recent benchmarking period (2022) by twenty-six (period to 2050), to come to the total operational carbon emissions for doing nothing. The team then adjusted the CARE Tool-populated EUI until it was approximate to this value. The CARE Tool populated EUI was carried through to the retrofit and replacement scenarios. Then for the "set operational target" for the retrofit and replacement scenarios, a process of guess and check was repeated until the total operational emissions budget for both scenarios was equal to or less than the total budget established earlier.

By employing this method, the team was able to more accurately visualize the scale of intervention necessary to ensure each case study building is in compliance with local policy.

	DO NOTHING	REUSE & ADDITION	NEW BUILDING
Embodied Emissions (Metric Tons CO2e, cradle to gate)	N/A	385	1636
Operational Emissions (Metric Tons CO2e / 26 years)	11181	4183	4183
Total Emissions (Metric Tons CO2e / 26 years)	11181	4568	5820
Total Emissions Intensity ($kgCO_2e/ft^2$ / 26 years)	206	84	107

Example of Carbon Budget input in the Care Tool. Source: Carbon Avoided Retrofit Estimator, Data
Source: Local Law 97 of 2019 Energy Star Portfolio Manager Reference Guide, January 2023. Local Law 84/97 Benchmarking Reporting, NYC Open Data

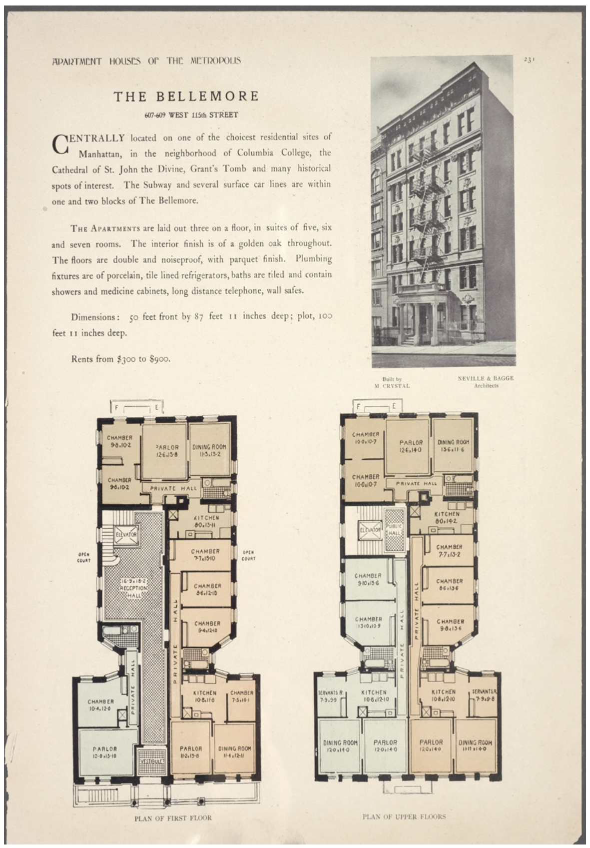
APPENDIX C: EMBODIED CARBON METHODOLOGY FOR SCHAPIRO

The Schapiro Hall case study will be used to illustrate the studio's typical methodology for calculating embodied carbon. This case study uniquely involves both a 1988 dorm building and two early twentieth-century new law tenements, each with different availability of documentation.

CALCULATIONS FOR NEW LAW TENEMENTS

Documentation for Annamere Court and the Bellemore was limited to drawings and textual information from Apartment Houses of the Metropolis (G. C. Hesselgren Publishing Co: 1908).

The floor plans are assumed to be drawn roughly to-scale with variable accuracy in wall thicknesses. The buildings' street frontage was used as a base dimension to which the drawing was scaled and subsequently measured in AutoCAD or Rhinoceros 3D.


APARTMENT HOUSES OF THE METROPOLIS

THE BELLEMORE

607-609 WEST 115th STREET

CENTRALLY located on one of the choicest residential sites of Manhattan, in the neighborhood of Columbia College, the Cathedral of St. John the Divine, Grant's Tomb and many historical spots of interest. The Subway and several surface car lines are within one and two blocks of The Bellemore.

THE APARTMENTS are laid out three on a floor, in suites of five, six and seven rooms. The interior finish is of a golden oak throughout. The floors are double and noiseproof, with parquet finish. Plumbing fixtures are of porcelain, tile lined refrigerators, baths are tiled and contain showers and medicine cabinets, long distance telephone, wall safes.

Dimensions: 50 feet front by 87 feet 11 inches deep; plot, 100 feet 11 inches deep.

Rents from $300 to $900.

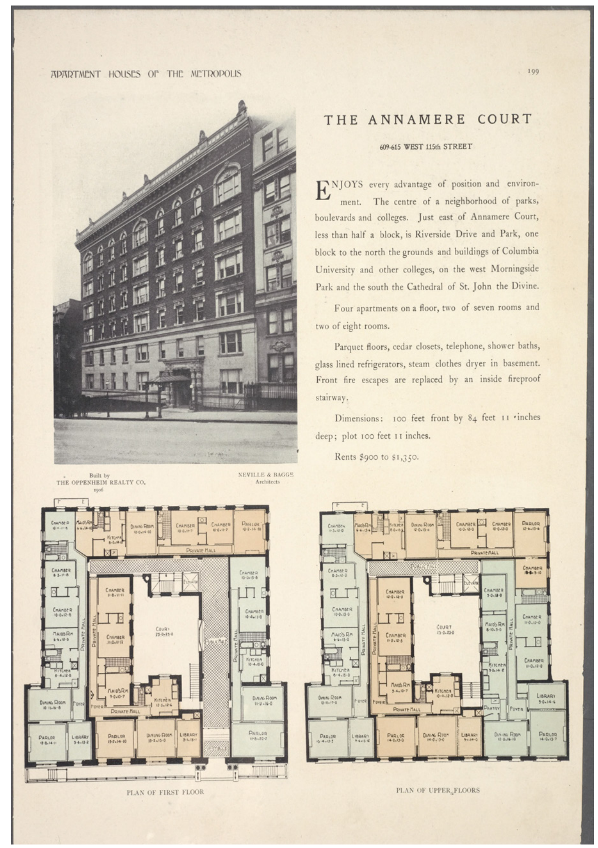
Built by M. CRYSTAL

SEVILLE & BAGGE Architects

PLAN OF FIRST FLOOR

PLAN OF UPPER FLOORS

Annamere Court description and floor plans.
Source: Apartment Houses of the Metropolis.


APARTMENT HOUSES OF THE METROPOLIS

199

THE ANNAMERE COURT

609-615 WEST 115th STREET

ENJOYS every advantage of position and environment. The centre of a neighborhood of parks, boulevards and colleges. Just east of Annamere Court, less than half a block, is Riverside Drive and Park, one block to the north the grounds and buildings of Columbia University and other colleges, on the west Morningside Park and the south the Cathedral of St. John the Divine.

Four apartments on a floor, two of seven rooms and two of eight rooms.

Parquet floors, cedar closets, telephone, shower baths, glass lined refrigerators, steam clothes dryer in basement. Front fire escapes are replaced by an inside fireproof stairway.

Dimensions: 100 feet front by 84 feet 11 inches deep; plot 100 feet 11 inches.

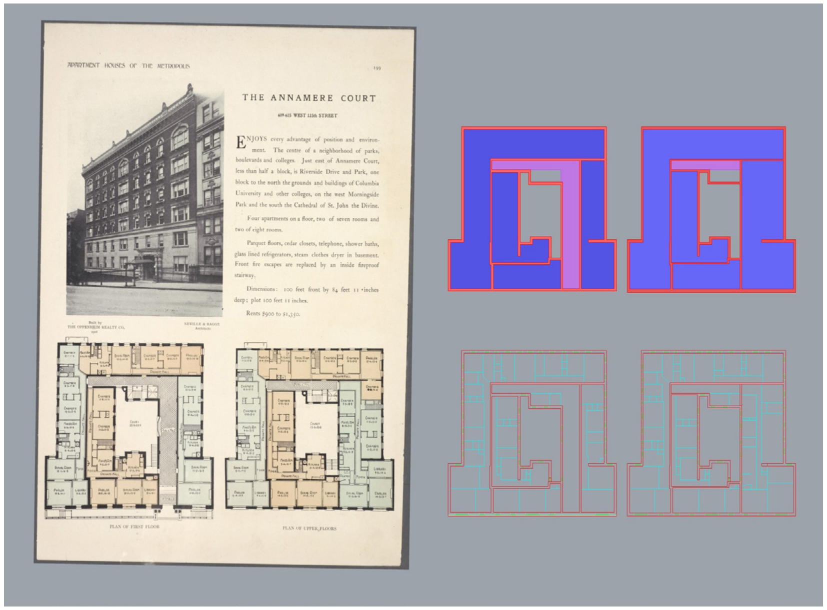
Rents $900 to $1,350.

SEVILLE & BAGGE Architects

PLAN OF FIRST FLOOR

PLAN OF UPPER FLOORS

Annamere Court description and floor plans.
Source: Apartment Houses of the Metropolis.



Measurement of Annamere Court in Rhinoceros 3D.
Source: Schapiro Hall case study group

Assumptions about wall thickness were made based on historical building codes for load-bearing masonry structures. For Annamere Court and the Bellemore, the bottom floor is assumed to be 16 inches thick (four brick wythes) and the upper floors assumed 12 inches thick (three brick wythes). Many similar assumptions were made based on typical rowhouse construction. All dimensional assumptions are listed below:

1. Concrete footings, assumed 1′ deep and 4′ wide
2. All floor and foundation slabs, assumed 4″ thick
3. Floor and roof joists, assumed 3 x 9″ spaced 16″ o.c.
4. Plank subflooring, assumed 3/4″thick
5. Parquet floor, assumed 3/4″thick
6. Ground floor steel beams, assumed W8x20 sections spaced 6′ o.c.
7. Partition walls, assumed constructed of 2 x 4″ wood studs and 1-ply 3/4″ plaster on each side
8. Window height, assumed 6′
9. Floor-to-floor height, assumed 12′
10. Glass thickness, assumed 1/8″
11. Brick and mortar volume, assumed 70 percent and 30 percent respectively of total brickwork volume

Using these assumed dimensions, along with length and width information measured from the floor plans, each building element was inputted into a spreadsheet to calculate total volume. Where applicable, the volume of each material is converted into weight (kg) using density information from Circular Ecology's ICE Material database.

Each building element was then assigned a material, with several assumptions occurring at this stage as well. Material assumptions are listed below:

1. Dimensional lumber and parquet flooring, assumed softwood lumber
2. Concrete, assumed 4000 psi (28/35 MPa)
3. Brick, assumed typical clay masonry
4. Mortar, assumed 1:1:6 cement:lime:sand mix
5. Steel, assumed fabricated hot-rolled structural sections
6. Plywood, assumed softwood lumber plywood

Each material corresponds to a particular embodied carbon factor (ECF). ECFs are typically listed in $kgCO_2e$ per kg of building material, though some materials are calculated using volume (m3) or area (m2) instead. All building case studies used a consistent set of ECFs for identical building materials. The spreadsheet was used to calculate total embodied carbon values (tCO_2e) for each building component and unique material, along with summary statistics, bar graphs, and pie charts.

CALCULATIONS FOR SCHAPIRO HALL

Schapiro Hall, as with most of the studio's case study buildings, had a full set of architectural and structural drawings available for analysis. Little information had to be assumed about component dimensions or details that could not be ascertained from section and detail drawings. The workflow followed similarly to Annamere Court and Bellemore's calculations.

For high-rise buildings like Schapiro Hall, several floor plans are identical, especially among upper stories. As such, calculations often had to be completed for one floor and multiplied to encapsulate the entire building. When floor plans had slight variability in size or layout, students and faculty exercised discretion using a per-square-footage value to extrapolate totals for those floors. At Schapiro, for example, the volume of interior partition elements was calculated for a typical upper floor, and its per-square-footage value used to find the volume for similar floors.

As a non-exhaustive list, these are some of the assumptions made regarding Schapiro Hall:

1. *Piles assumed to reach bedrock, equating to a length of 23'-9" based on the average bedrock depth from nine boring tests*
2. *Hollowcore concrete treated as regular cast-in-place concrete due to a lack of information in carbon databases, with volume modified by 64 percent to account for voids (measured from a structural section drawing)*
3. *CMU and mortar volume calculated based on total CMU wall volume, with CMU accounting for 76.4 percent of the wall and mortar accounting for 23.6 percent (based on typical 3/8" mortar joint)*

For all building case studies, student and faculty discretion was exercised to omit any building components that were expected to yield an insignificant amount of embodied carbon. Components were also omitted if no substantial information was available regarding its volume, weight, and material properties. Omitted materials include fasteners, mechanical and plumbing equipment, and light fixtures, among many others.

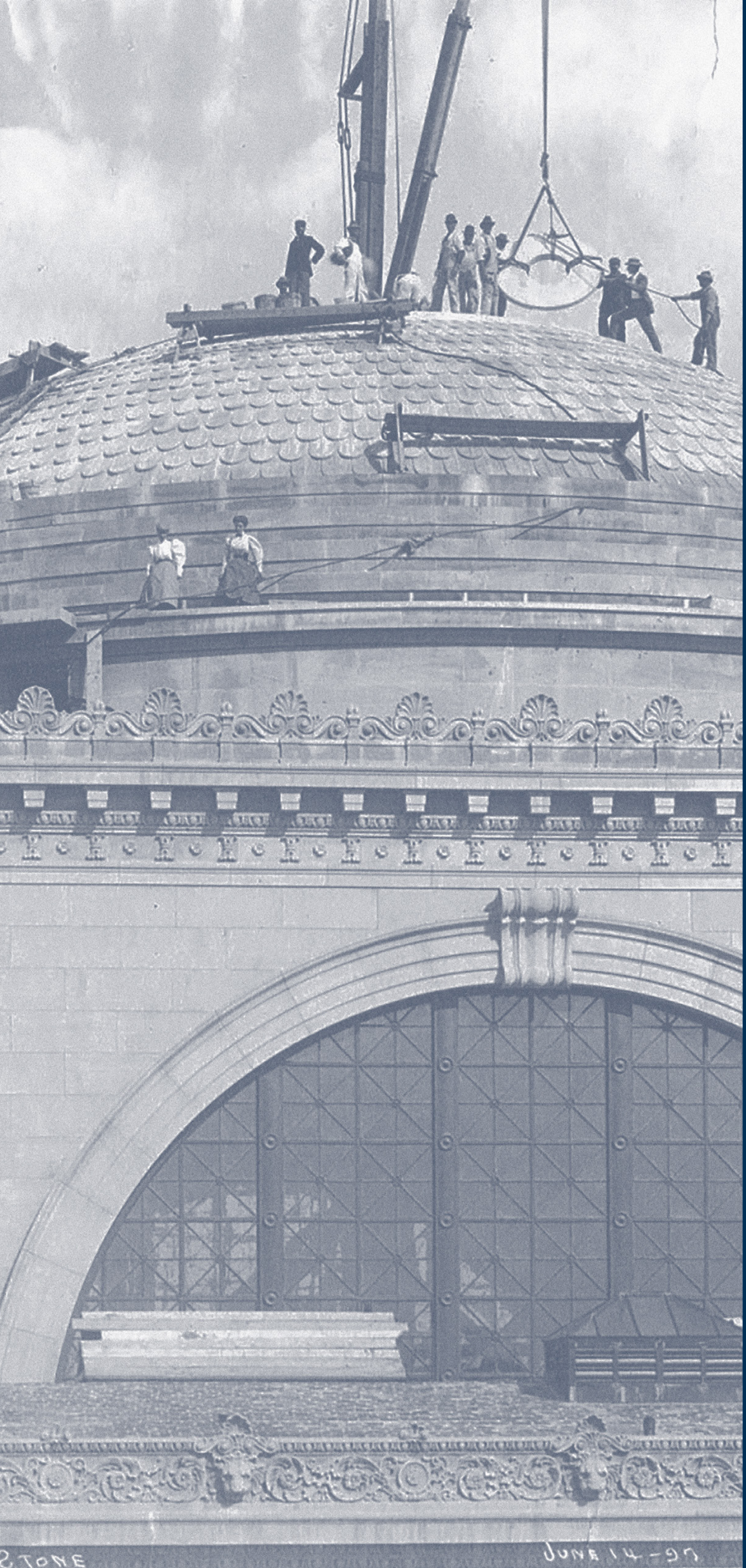
EMBODIED CARBON FACTORS

The studio's primary source for embodied carbon factors is Circular Ecology's ICE Material database due to its inclusion of multiple ECFs per material, each with its associated confidence rating. The studio generally used the ECF with the highest confidence rating for each material. Building Transparency's EC3 database was particularly useful for interior finishes, such as carpet or acoustic ceiling tile, that were not available in the ICE database.

Sequestered carbon was factored at a rate of 1.64 $kgCO_2e$ per kg timber. This number comes from a 2020 report published by the Institution of Structural Engineers (Orr, Gibbons, and Arnold 2020). Aluminum-framed double-glazed windows were calculated using an ECF of 76 $kgCO_2e$ per m2 of window, based on an embodied carbon analysis completed by C.U.in Windows (Hallworth 2023).

A table of ECFs for Annamere Court, the Bellemore, and Schapiro Hall is shown:

Material	Density, kg/m^3	Embodied carbon factor (ECF)	ECF Source
Timber (softwood)	460	0.137 $kgCO_2e/kg$	ICE DB V3.0
Concrete (4000 psi)	2400	0.126 $kgCO_2e/kg$	ICE DB V3.0
Brick (typical clay masonry)	1910	0.195 $kgCO_2e/kg$	ICE DB V3.0
Mortar (1:1:6)	2400	0.14 $kgCO_2e/kg$	ICE DB V3.0
Plaster	100	0.39 $kgCO_2e/kg$	ICE DB V3.0
Steel (hot-rolled structural)	7850	1.22 $kgCO_2e/kg$	ICE DB V3.0
Glass	2500	1.44 $kgCO_2e/kg$	ICE DB V3.0
Limestone	2200	0.0 $kgCO_2e/kg$	ICE DB V3.0
Plywood (softwood lumber)	484	0.45 $kgCO_2e/kg$	ICE DB V3.0
CMU	N/A	545 $kgCO_2e/m^3$	EC3
Gypsum board	N/A	5 $kgCO_2e/m^2$	EC3
Carpet	N/A	20 $kgCO_2e/m^2$	EC3
Sheet vinyl	N/A	2 $kgCO_2e/m^2$	EC3
Ceramic tile	N/A	27.9 $kgCO_2e/m^2$	EC3
Vinyl composite tile	N/A	23.4 $kgCO_2e/m^2$	EC3
Acoustic tile	N/A	14 $kgCO_2e/m^2$	EC3
Aluminum window	N/A	76 $kgCO_2e/m^2$	CUIN Glass
Timber sequestered CO_2	460	1.64 $kgCO_2e/kg$	IStructE



APPENDIX D: HISTORIC CONTEXT ASSESSMENT

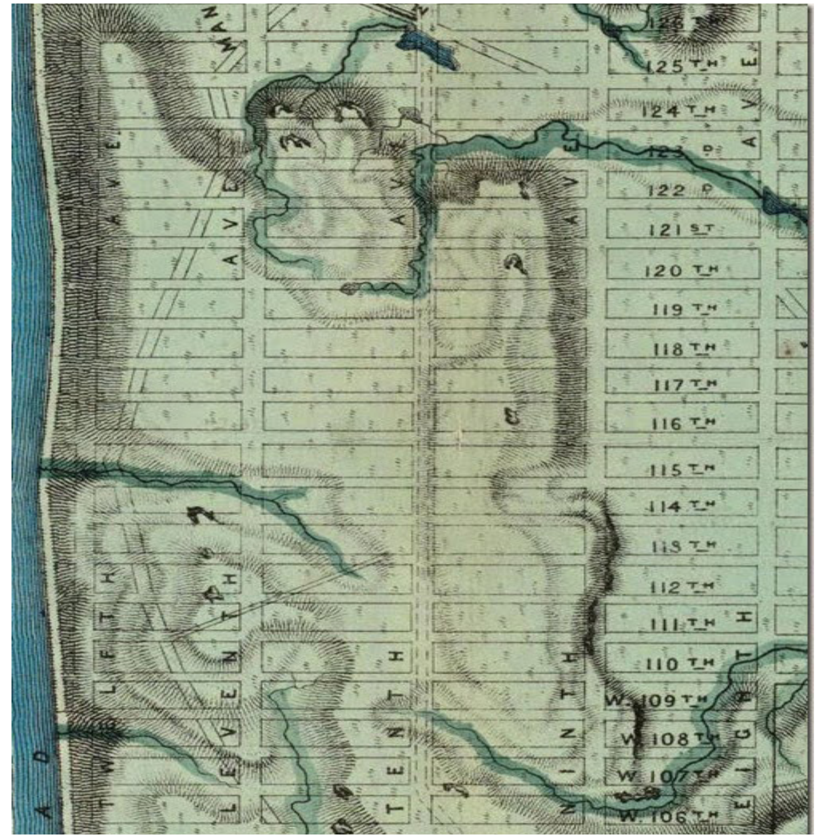
This assessment addressed the larger context of the study area from the perspective of the studio inquiry. As such, it is not a typical historic context assessment, but rather prioritize questions of materials and methods used in the construction and maintenance of the built environment of Morningside.

THE LANDSCAPE AND EARLY DEVELOPMENT

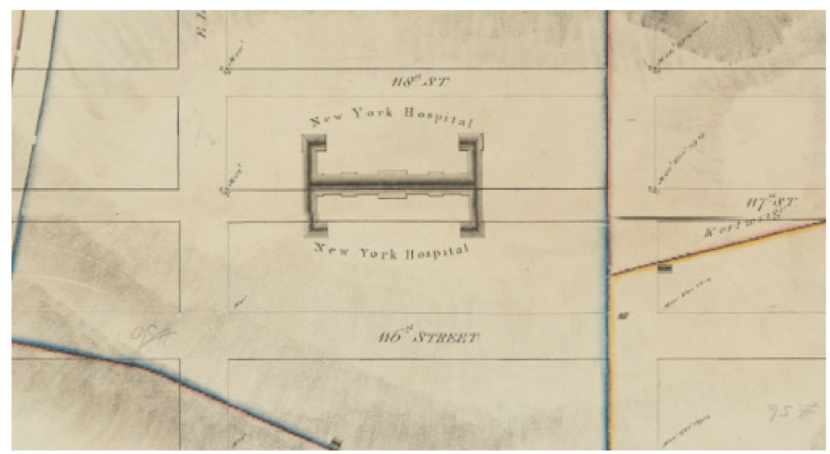
The studio study area, which is part of Morningside Heights today, is part of the ancestral land of the Lenape people. By the seventeenth and eighteenth centuries, with settler colonialism, the area was a quiet and rural land with some cottages, farmhouses, and riverside mansions (Dolkart 1998, 275). The topography and geology of Morningside Heights played a pivotal role in its development and introduced some of the primary structural conditions identified in the study area. The territory is located on a narrow rocky plateau, which is the superstructure of the study area. This plateau extends from 110th Street to the south and drops steeply towards the Manhattan or Manhattanville Valley, beginning at 122 Street with an additional steep drop of about fifteen feet at 119 Street. The plateau is about 2,000 feet wide and bordered by cliffs to the west and east of what is known today as Morningside and Riverside Parks. It is part of the Manhattan Ridge and formed a hard Manhattan schist (Dolkart 1998, 2, 117).

The first institute to settle in Morningside Heights was the Bloomingdale Insane Asylum. Between 1816 and 1820, the Society of the New York Hospital acquired a substantial amount of the Morningside Plateau to move its overcrowded downtown asylum to this quiet countryside area. The area's physical conditions, following its topography and geology, set the borders and locations of the new hospital (Dolkart 1998, 13, 15). The superblock, which combined multiple city blocks, was formed following those plans, breaking the grid laid only a few years earlier. When Columbia University moved to this location, the superblock continued as a principle of its spatial organization.

The first building erected as part of the Bloomingdale Insane Asylum was an imposing 60 foot wide and 211 foot long limestone-clad building. By 1824, there were 120 patients. This is how it appeared on the Randel Farm Maps (1818-1820), which shows it occupied the area from 116th Street to 118th Street which provided a basis for future expansions.



Morningside Heights, Topographic Map.
Source: Library of Congress.



Randal Farm Map of 1818-1820 showing The Bloomingdale Insane Asylum
Source: https://bloomingdalehistory.com/

The Bloomingdale Insane Asylum underwent five expansions within the area now occupied by the Columbia University Morningside campus. Its final view from the street was of a series of wooden-frame, stone, and brick buildings. The timeline of the aforementioned expansions is as follows:

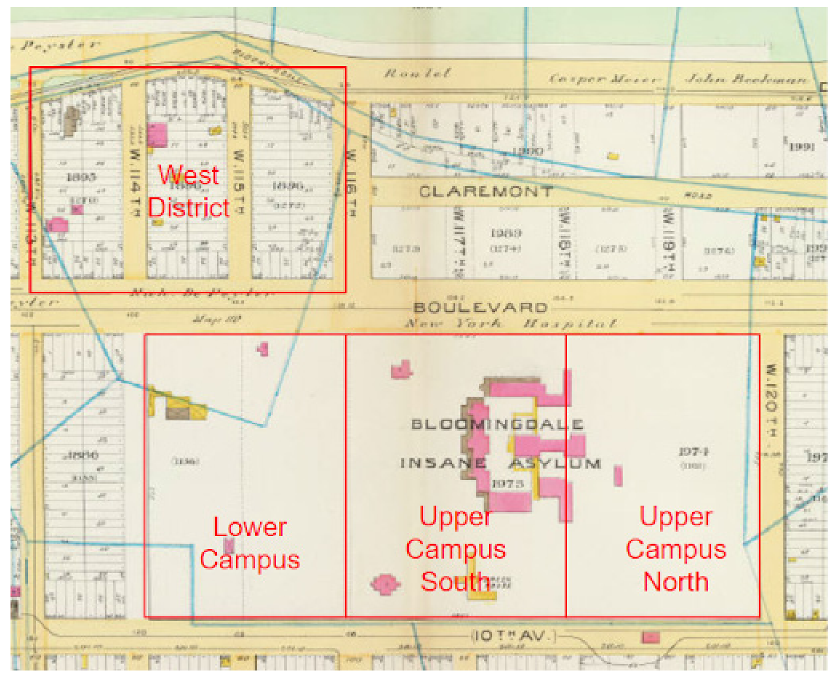
- 1829-1st expansion erected 117 ft. northwest of the main building stories Brick building
- 1834-2nd & 3rd additional buildings-2 stories
- 1862-Connected the buildings into a wing-type design; 4th additional building stories
- 1875-5th additional building-3 stories brick, wood, and glass plant house
- 1880-6th additional building: John C. Green Memorial Building for female patients-Arc: Ralph Townsend (Same as Buell Hall)

In 1892, a pivotal transaction occurred when the Asylum divested its land holdings situated between 116th and 120th Streets, transferring ownership to Columbia University. This transaction marked a significant milestone in Columbia's development, solidifying its physical presence in the area and laying the groundwork for subsequent campus growth. In fact, in the original 1811 Grid Plan of New York City, the area encompassing Bloomingdale kept the conventional block layout characteristic of the urban design scheme. However, Bloomingdale diverged from this standard configuration later, assuming the role of a public space and thereby disrupting the uniformity of the grid, forming a superblock.

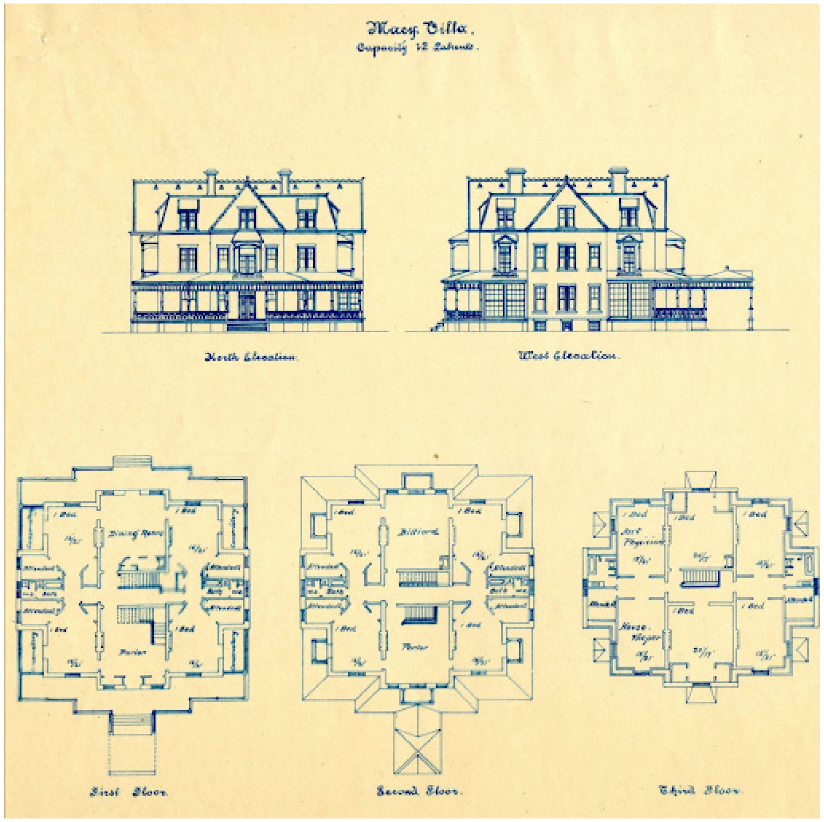
This superblock coincides with the present-day boundaries of Columbia University's campus, thereby establishing a basis for Columbia Morningside height campus.

Buell Hall, originally Macy Villa, is the only building remaining from Bloomingdale. In 1885, William Macy donated funds to construct a special building for Bloomingdale, and Ralph Townsend was hired as the architect. The original plans show a large-sized dining room, a billiards room, and comfortable rooms for about twelve patients.

The 1811 Grid Plan of New York City.
Source: The New York Public Library



Boundary comparison between the 1891 Bloomingdale and current campus
Source: https://bloomingdalehistory.com/



Macy Villa Drawing, Scan. 4982.
Source: Columbia University Archives

After Columbia purchased the property, Buell Hall was renamed "College Hall" since it was the home of the Dean of the College. Before Kent Hall was built, Buell Hall occupied a position directly on 116th Street. However, it was relocated to accommodate the construction of the new building in 1905. During this relocation, the substantial wooden porches that had encircled Buell Hall were dismantled. Buell Hall continued to serve as the administrative hub of the School of General Studies until 1964.

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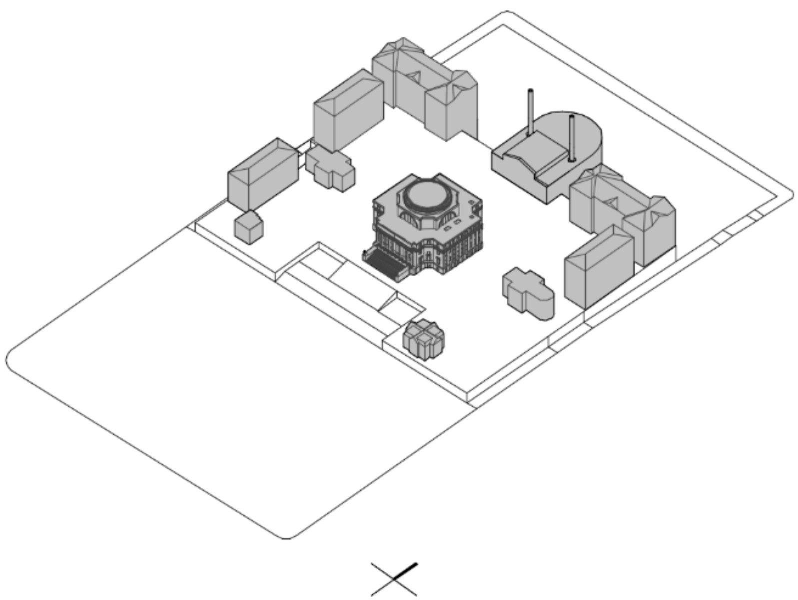
Buell Hall in 1890. /source: Columbia University Archives.

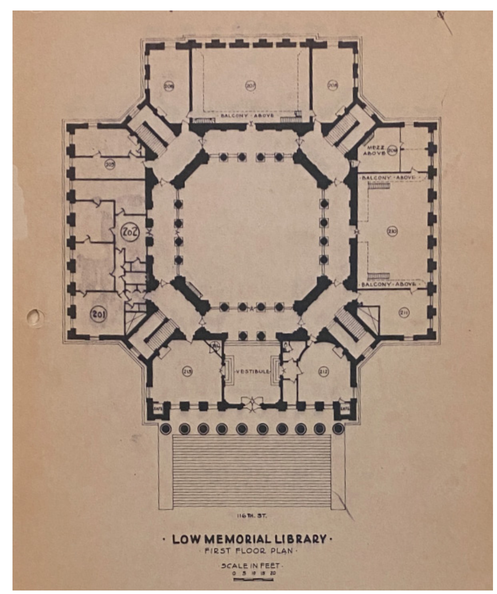
COLUMBIA UNIVERSITY CAMPUS DEVELOPMENT: 1897-1905

The Columbia Campus development between 1897 and 1907 features varying building typologies typical of their time period and representative of the McKim, Mead, and White Columbia plans (Dolkart 1998). It is important to study these typologies as they influence accounting of the embodied carbon it took to construct these buildings. Moreover, studying these typologies allows us to understand and imagine future renovations and retrofits to increase the energy efficiency of these buildings and decrease their operating carbon. The team identified three main building typologies in this first decade (1) Low Library is the only building with masonry bearing walls, tile-arch floors, a masonry dome and interior steel frame (2) Several buildings were constructed with masonry bearing walls, tile arch floors, interior steel frame and pitched copper roofs such as the Fayerweather and the former University Hall. And finally, (3) buildings with masonry bearing walls, masonry floors, and Guastavino tiling such as Earl Hall and St. Paul's Chapel.



Buildings built between 1897 and 1907 at Columbia.
Source: Nicolás Moraga

This section discusses the typologies of Low Memorial Library (1897), the former University Hall (1897), Fayerweather Hall (1897), Schermerhorn Hall (1897), Mathematics Hall (1897), Havemeyer Hall (1897), Earl Hall (1902), and St. Paul's Chapel (1907) .



Low Memorial Library Construction photo (above) & Floor plan (below)
Source: Columbia University Archives

Low Memorial Library was built in 1897, by architects McKim, Mead, and White, marking the beginning of Columbia's campus development. The library was listed as a New York City landmark in 1967. Following the landmark designation, the interior of the library became a NYC landmark for its monumentality and the library became a National Historic Landmark in 1987 (Pitts 1965). Low Library currently houses a visitor center and administrative offices. There are four stories, with a basement level. The main structural elements of the library are masonry bearing walls and masonry dome, terra-cotta tile-arch floors supported on an interior steel frame. Low has some interior metal framing, with its interior dome being constructed of plaster over steel mesh frame.

Built in 1897, University Hall was designed by architect McKim, Mead, and White to house Intercollegiate Athletics and Physical Education as well as the coal powered generator and steam boiler that would lay the foundation for the steam loop that continues to provide heating and cooling to most of the buildings in the study area. The building was designed to be a four story structure, with masonry bearing walls and with interior steel framing and tile arch floors. It only had one story before it burned down in 1914, and the second floor was completed with masonry and concrete roof and the main portion constructed with wooden girders and roof (Buildings and Grounds Collection). University Hall underwent many renovations, additions, and removals over the years, and much of the original structure has been changed.

Fayerweather Hall, Schermerhorn Hall, Mathematics Hall, and Havemeyer Hall are lecture halls that exhibit a similar typology: these four buildings were also built in 1897 following the McKim, Mead, and White campus master plan, utilizing exterior bearing masonry walls made of brick and limestone (Dolkart 1998). Though these lecture halls all look similar, each of their facades are unique in their design, fitting into an overarching style with unique individual elements. The dark, rubbed Harvard brick and limestone elements decorate the exteriors of these halls. Fayerweather, Schermerhorn, Mathematics, and Havemeyer have load-bearing masonry facades that support steel beams carrying the terra cotta tile-arch floors. While no steel columns are embedded in the masonry facades, there are interior structural steel columns that provide additional support for the floor beams, thereby allowing for open and flexible interior lay-outs. The interior partitions were typically made of terracotta covered in plaster. The buildings also have pitched standing-seam copper metal roofs, setting a precedent for later-built university buildings. Overall, these buildings' typologies are typical of late nineteenth century and early twentieth century construction, despite the differences in building design, use, and organization.

Facades of Fayerweather and Schermerhorn Halls.
Source: Library of Congress

Constructed from 1900 to 1902 and donated by William Earl Dodge, Earl Hall was placed to the west of Low Library and planned as an additional location for student activities on the campus. According to Dodge's wishes, Earl was to be a spiritual center for all students that allowed Roman Catholic and Jewish students to hold meetings as freely as Protestants. Designed by McKim, Mead and White, Earl Hall was meant to resemble an Italian Renaissance church and was constructed in two phases. Earl Hall utilizes the same red brick as other campus buildings, in combination with a limestone portico, a long flight of granite stairs, a granite base, a crowned copper dome (housing an assembly hall underneath), masonry bearing walls and floors and a Guastavino tile vault underneath its bronze dome (Dolkart 1998, 158-159). In 2018, Earl Hall was listed on the National Register of Historic Places in recognition of its role as a venue for the meetings and social events of Columbia's Student Homophile League, the first gay student organization in the United States (NYC LGBT Historic Sites Project 2018).

Low Memorial Library Construction & Plan.
Source: Columbia University Archives

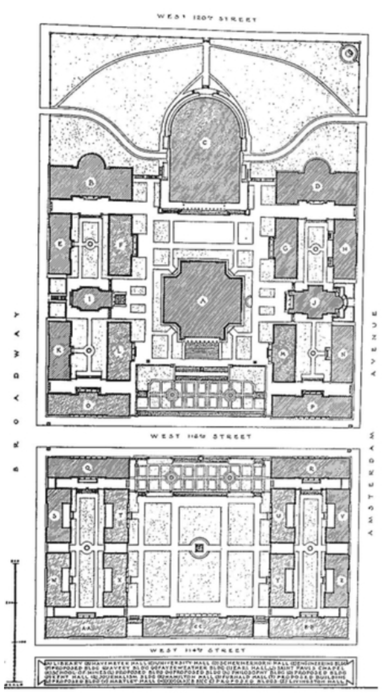
St. Paul's Chapel.
Source: The Craftsman, 1907. Photographer: W.J. Wilson

St. Paul's Chapel, the "twinned" building to Earl Hall was constructed from 1904 to 1907 thanks to the donation of sisters Olivia Egleston Phelps Stokes and Caroline Phelps Stokes. However, the donation for the chapel came with the stipulation that it would be designed by their nephew I.N. Phelps Stokes. Stokes agreed to design the chapel with McKim, Mead and White retained as consulting architects. While one of the first buildings on campus not designed by McKim, Mead and White, Stokes's building nonetheless fits into the guidelines set by their master plan (Dolkart 1998, 173). Designed in the style of an Italian Renaissance church (much like Earl Hall), the chapel utilizes a mix of red brick and limestone on the exterior, like other campus buildings, which is complimented by yellow marble, green ceramic roof tiles, ornamental bronze, and stained glass.

Structurally, St. Paul's Chapel consists of masonry bearing walls, with extensive Guastavino vaulting for its ceilings, floors and dome. The interiors consist of an intricate mix of pink-yellow brick, terra cotta, walnut woodwork done by Florentine craftsmen, and custom bronze chandeliers. Much of the masonry used for the chapel was sourced from the New York City area (Dolkart 1998, 177). St. Paul's Chapel was selected as a New York City Landmark in 1966 for its importance within the architectural history of the city and Columbia's campus (Landmarks Preservation Commission 1966). The chapel also underwent an extensive renovation and restoration of its terra cotta tiles, masonry, stained glass and Guastavino tile from 2017 to 2019, which adds embodied carbon to be accounted for (Design and Construction n.d.).

COLUMBIA UNIVERSITY CAMPUS DEVELOPMENT: 1905-1913

The following stage of campus development was defined by the construction of undergraduate and graduate student dormitories and expanded academic facilities. From 1905 to 1913, eight buildings were developed, seven of which were part of the expansion of McKim, Mead and White's master plan (Dolkart n.d.; Passanti 1977, 75). This era of development began when Columbia acquired the two blocks from West 114th to West 116th Streets between Amsterdam Avenue and Broadway, known as South Field in late 1902 (Dolkart 1998, 165). After the purchase of South Field, McKim, Mead and White were commissioned to add South Field as an expansion of the master plan.



McKim, Mead & White Campus Plan for Columbia including South Field. Published 1915.
Source: (Dolkart 1998, 167)

Building development on the newly acquired real estate began with Hartley and Livingston Halls, completed in 1905, followed by Hamilton Hall in 1907 (Dolkart 1998, 353). Crossing back over College Walk (west 116th Street) to upper campus, Kent, Philosophy and Avery were then completed in 1910, 1911 and 1912 respectively. Pulitzer and Furnald followed and were both finished in 1913 (Dolkart 1998, 354).

DORMITORIES

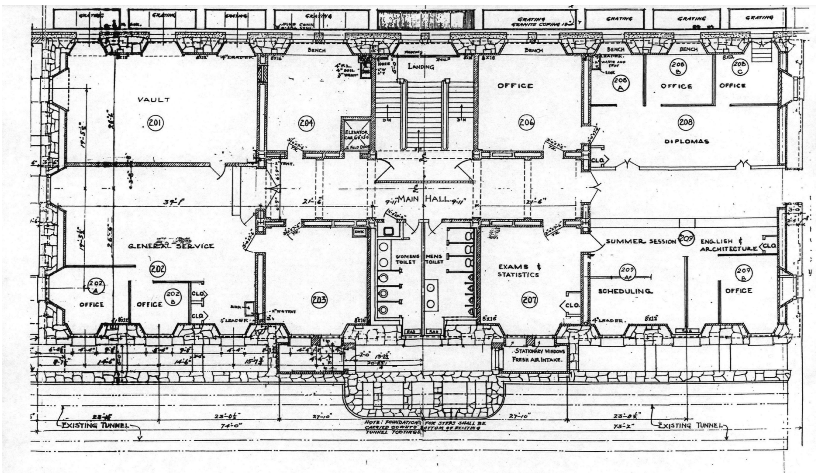
Hartley Hall is a ten story steel-frame building and marks the first on-campus student accommodation. Construction began on October 31, 1904 and the building was completed the following year (Ruskin 2004). Common construction materials include Harvard brick in a flemish bond, an Indiana limestone veneer facade, and a copper roof. Livingston Hall, renamed to Wallach in 1980's, is an identical building and was completed the same year. Hartley and Wallach, the first buildings on South Field and the first dormitories on Columbia's Morningside Heights campus, were experimental for the university when they were completed in 1905. Additional living quarters were put on hold until this new on-campus building residence proved successful. Off-campus housing was generally less costly than Hartley and Livingston dormitories and allowed students greater freedoms. On campus living soon caught on at Columbia, leading to the construction of a third dorm, Furnald Hall, in 1913 (Dolkart 1998, 170). Furnald Hall copies the U-shaped design typical of lower campus dormitories as originally planned by Charles McKim.

ACADEMIC BUILDINGS

The building technology for both the dormitories (Hartley, Wallach, Furnald) and academic buildings (Hamilton, Kent, Philosophy, Avery and Pulitzer) completed between 1905-1913, follow a similar typology. They are steel frames with masonry facades. They also have limestone trim, which is clearly illustrated in a drawing of Kent Hall. As was mentioned previously, several of the academic buildings completed during this time further developed the second half of McKim's master plan on South Field. All continued the design aesthetic and geometric proportions starting with Fayerweather, Schemerhorn, Mathematics, and Havermeyer. Hamilton, Kent, Philosophy, Avery and Pulitzer stay consistent with Harvard brick facades, limestone trim, and copper roofing. Each is similar in typology, though none identical in finish. Lewisohn Hall, designed by Arnold Brunner, rather than McKim, Mead, and White, is designated a National Chemical Landmark. All of these academic buildings feature fireproof flooring, terra cotta partitions, copper roofing, and rubble stone foundations.

Construction of Hamilton Hall
Source: University Archives

Kent Hall
Source: MCNY, 1910



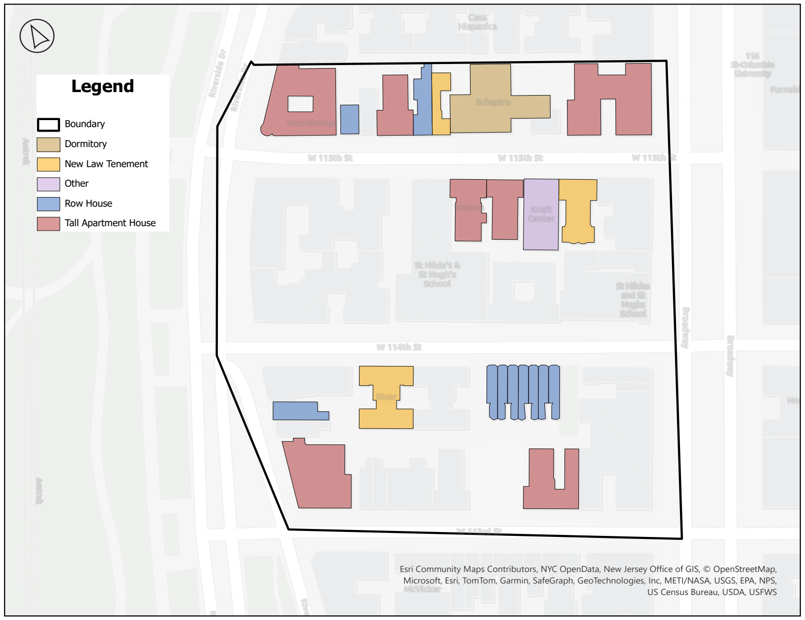
Philosophy Hall 2nd floor plan (1910).
Source: Columbia University Planning, Design & Construction Office.

Philosophy Hall, a National Historic Landmark (Criterion A/B), is an Italian Renaissance Revival building that has a concrete and granite foundation, a steel frame and concrete floor system, brick and limestone walls (pilasters, courses, sills, lintel), and a copper metal roof (Colburn 2002, 3-4). The added flexibility of existing classrooms and offices, separated by plaster-clad thin terra-cotta partition walls, that permitted alterations as needed "The removal of internal walls separating Rooms 201 and 202 alter the original configuration of those laboratory spaces, but the ease with which they could be reconfigured reveals the modesty of even those modifications'' (Colburn 2002, 5-6).

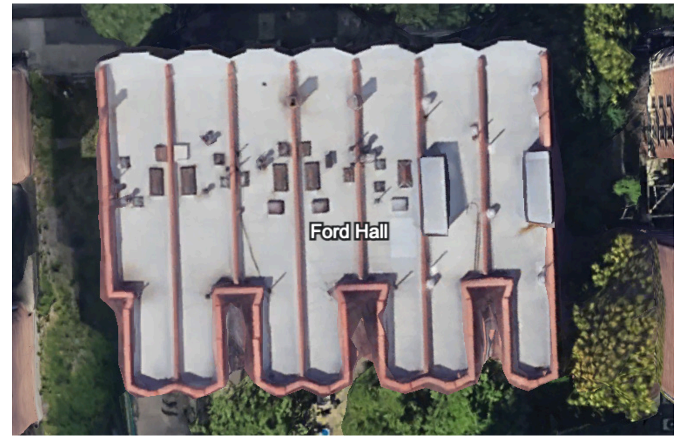
WEST DISTRICT (RESIDENTIAL DEVELOPMENT NEAR CAMPUS): 1893-1925

The neighborhood around Columbia's campus began to evolve residentially following the expansion of the subway to Morningside Heights, transforming it into a quiet, suburb-like area where residents commuted downtown for work. The area that the studio refers to as the West District developed between approximately 1885-1925. Historic residential building typologies within these blocks include rowhouses and New Law tenements. Ten row houses owned by Columbia are covered by the study area, as well as ten New Law Tenements. Three of the New Law Tenements are six or seven stories, and seven of them are above seven stories, up to fourteen stories (the taller are referred to as "apartment houses"). Developers purchased lots and constructed housing prior to and following the completion of the new subway expansion in 1904, as seen by the construction years in the following table.

- **10 Rowhouses**
  - 604-616 W. 114th St (eight rowhouses): **1896**
  - 635 W. 115th St: **1893**
  - 415 Riverside Dr: **1898**
  - 627 W. 115th St: **1903**
- **3 New Law Tenements**
  - 617 W. 115th St: **1909**
  - River Hall: **1910**
  - 604 W. 115th St: **1925**
- **7 Apartment Houses over 7 stories**
  - 605 W. 115th St: **1895**
  - Woodbridge Hall: **1902**
  - Watson Hall: **1906**
  - 629 W. 115th St: **1910**
  - 410 Riverside Dr: **1910**
  - Regnor Court, 610 W. 115th St: **1912**



West District Typology Map.
Source: Map Studio Team.

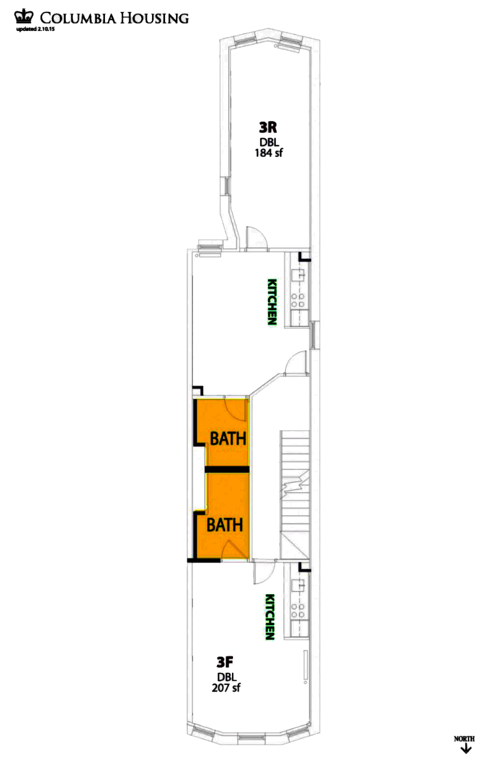


Aerial view of Rowhouses present within the studio boundary area.
Source: Google maps.

ROWHOUSES

Starting in the nineteenth century in New York City, row houses (also known as brownstones) were commonly built in development groupings, where one developer would construct multiple adjacent to one another. They typically served as housing on upper-middle class streets, as each was a single family home with an entrance up from the street level. The row houses in the studio study area, constructed in the late nineteenth and early twentieth century, tend to have 4 stories but maybe a floor or two taller. They have masonry load-bearing walls with wood floors and partitions and are considered “non-fireproof” construction. Row Houses in this neighborhood are heated and cooled on a building-by-building basis. Some continue to use steam heating and pair cross-ventilation cooling with windows AC units, whereas others have undergone improvements to more modern systems.

Of the ten rowhouses in the studio building set:
Seven were built together by developer Frank A. Lang at 604 to 616 W. 114th St in 1895. Since Columbia’s acquisition of the rowhouses between 1957 to 1969, they have been renovated to a new floor plan to accommodate student housing.



Rowhouse Floor Plan.
Source: Columbia Housing.

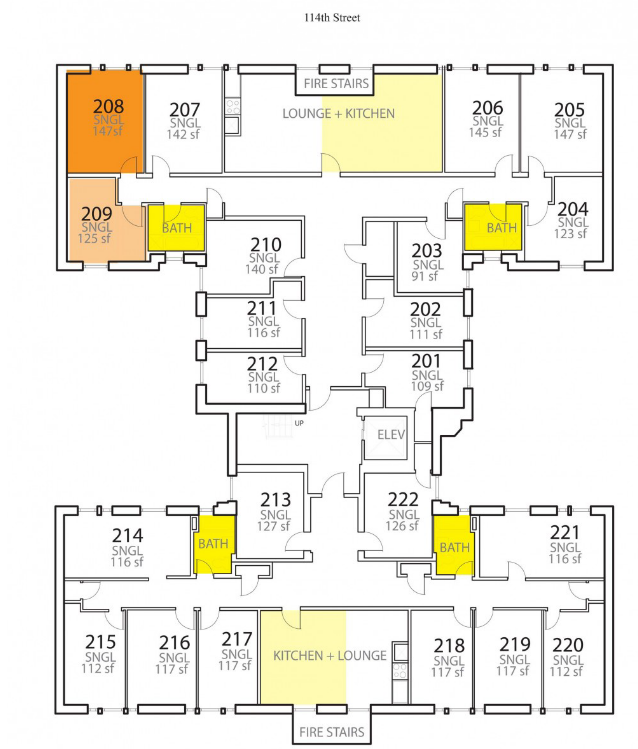
627 West 115th St was constructed in 1903 by Little & O'Connor and was acquired in 1976. It is distinctive through its mansard-style roof with dormer windows and currently houses Columbia undergraduates.

635 West 115th St was constructed in 1893 by Henry Otis Chapman and was acquired in 1956. A green roof was added in 2007.

415 Riverside Drive was constructed in 1898 by George F. Pelham and was acquired in 1968. Done in the Renaissance Revival style, the building now functions as staff and faculty housing.

New Law Tenements

All apartment buildings built following the 1901 Tenement House Act are considered to be New Law tenements. However, for the purpose of establishing a useful construction typology for carbon analysis, the team defined "New Law tenements" to be those apartments that are of non-fireproof construction and six (or sometimes seven) stories and lower. Apartments taller than six stories in the study, which the team called "apartment houses," have significantly different construction materials, systems, and assemblies. In addition, buildings taller than six stories are subject to New York City's Facade Inspection & Safety Program, which contributes to recurrent embodied carbon values.



River Hall Second Floor Plan.
Source: Columbia Housing.

River Hall and Revere Hall Aerial View.
Source: Google Maps

New Law tenements are characterized by H-shaped floor plans, operable windows in every habitable room, and substantial light courts. There are three of these buildings in the study:

617 W 115th St is a six-story New Law tenement constructed in 1909. Acquired in 1964, the building currently houses Columbia graduate students. It was described in a Columbia Spectator article to be one of many Columbia-acquired buildings that had been "known to police as centers of neighborhood crime [. . . housing] drug addicts, prostitutes, or degenerates" (Drosnin 1965).

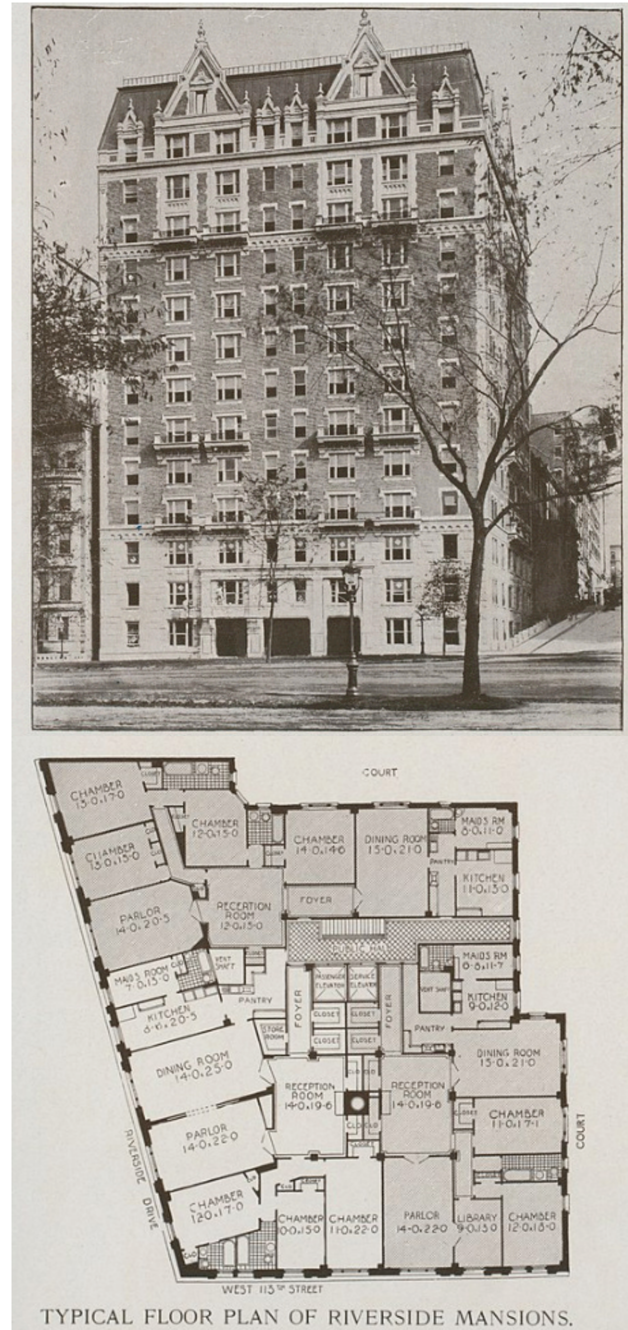
River Hall is a six-story New Law tenement constructed in 1910. It contains 127 single rooms housing underclassmen undergraduates. A renovation was completed on this building in January of 2002 (Fuma 2021). The building next door, Revere Hall, has an identical exterior but maintains an original lobby.

604 W 115th St is a seven-story New Law tenement constructed in 1925. It currently functions as Columbia housing with 28 units. According to a Columbia Spectator article, two years after its acquisition in 1964, it was stated that "no relocation of tenants is planned in the near future" (Columbia Spectator 1966).

New Law Tenements are typically constructed of load-bearing masonry exterior walls. Their floors and partitions are largely wood-framed, similar to row houses. However, unlike most row houses, New Law Tenements may have terracotta partition walls and concrete floors in public hallway areas, providing partial fireproofing. Due to their classification as non-fireproof construction, New Law tenements are required to have regularly maintained exterior fire escapes.

APARTMENT HOUSES

Within the study area, there are seven apartment houses between seven and fourteen stories, dating between 1895 and 1912. Illustrative of the potential of steel frame structures to enable greater building heights, these apartments represent the early development of multiple dwelling unit structures in the city–a new building typology designed to serve middle and upper-middle-class New Yorkers, stemming from the 1901 Tenement House Act (Fons 2016). Unlike non-fireproof structures below six stories, the apartment houses highlighted in this section have markedly different structural systems. The earliest building in the study, 605 West 113th Street–dating to 1895, most likely has a cage frame structural system with cast iron columns. The seven other apartment houses, built after 1900, rely on structural steel frames. The floor systems within tall apartment houses are often reinforced concrete or draped mesh, depending on the construction period, with partitions made of terracotta.



Rendering and Floor Plan of Typical Riverside Apartment houses.
Source: Avery Library

Four of the seven apartment houses found in the study are designated as contributing structures to the Morningside Heights Historic District. The complete list of apartment houses in the study area is as follows:

605 W 113th Street is an eight-story apartment house built in 1911. Acquired by Columbia in 1965, the building hosts 25 residential units reserved for faculty and staff eligible for residential housing. DOB filings indicate its address as 605-607, and it appears that the building's entrance portico originally housed two entrances. The building was converted into a single property after Columbia's acquisition in 1965, per its 1977 certificate of occupancy (NYC Department of Buildings n.d.).

Regnor Court (601 W 115th) is a twelve-story apartment house built in 1912 and acquired by Columbia in 1967. The building is infamous for the death of a Barnard student in 1979 due to a falling piece of its terracotta ornament (Geberer 2015). This incident was the impetus for Local Law 10, which developed into Local Law 11 and the Facade Inspection & Safety Program (FISP). As a result of this tragic event, Columbia University stripped the exterior facades of Regnor Court of nearly all protruding ornaments. It currently operates as Columbia graduate student and faculty housing.

610 West 115th is a nine-story apartment house built in 1910 and acquired by Columbia in 1969. Designed by Schwartz and Gross, the building is listed as a contributing structure to the Morningside Heights Historic District (listed as 608 West 115th) for its Renaissance Revival style, prominently featuring a two-story limestone entrance, bracketed cornice, and molded stone sill (Percival 2017). Today, the building houses students, postdocs, faculty, and staff eligible for residential housing.

Watson Hall, or 612-614 West 115th, is an eight-story Beaux-Arts apartment house designed by Neville and Bagge and built-in 1905. The building is primarily composed of brick and limestone and features terracotta ornamentation, and is a contributing structure to the Morningside Heights Historic District. While its date of acquisition is unclear, in 1991 Columbia entered into a declaration of zoning restriction with St. Hilda's School, where the school conveyed to Columbia the property's right, title, and interest (NYC Department of Buildings n.d.). It is home to Columbia's Administrative Information Systems and the School of the Arts today.

629 W 115th Street, historically referred to as the "Waramaug," is an eight-story apartment house designed by William L. Rouse and built-in 1910. Acquired by Columbia in 1964, it currently serves as Columbia graduate student and faculty housing. It appears to have had a cornice that has been completely removed, though it is listed as a contributing structure to the Morningside Heights Historic District.

410 Riverside Drive is a fourteen-story apartment house designed by Neville and Bagge and built-in 1910. Originally known as the Riverside Mansions, the building is listed as a contributing structure to the Morningside Heights Historic District. The building was acquired by Columbia in 1968 and today hosts 57 units and houses postdocs, faculty, and staff.

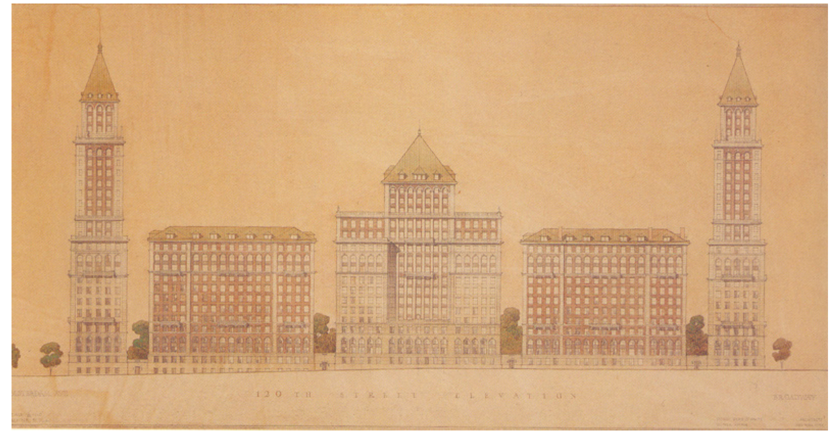
Woodbridge Hall (431 Riverside Drive) is a seven-story Beaux Arts apartment house designed by George Keister and built-in 1902. It is primarily composed of brick, limestone, and terracotta; among other notable alterations, all its windows have been replaced. It is a contributing building to the Morningside Heights Historic District. The date of Columbia's acquisition of the building is unknown and the building does not appear in Columbia's 1986 property inventory. Today, it serves as a residence hall for seniors enrolled at the university, with 81 residential units.

COLUMBIA UNIVERSITY VERTICAL DEVELOPMENT & CLASSROOM EXPANSION IN 1924-1934

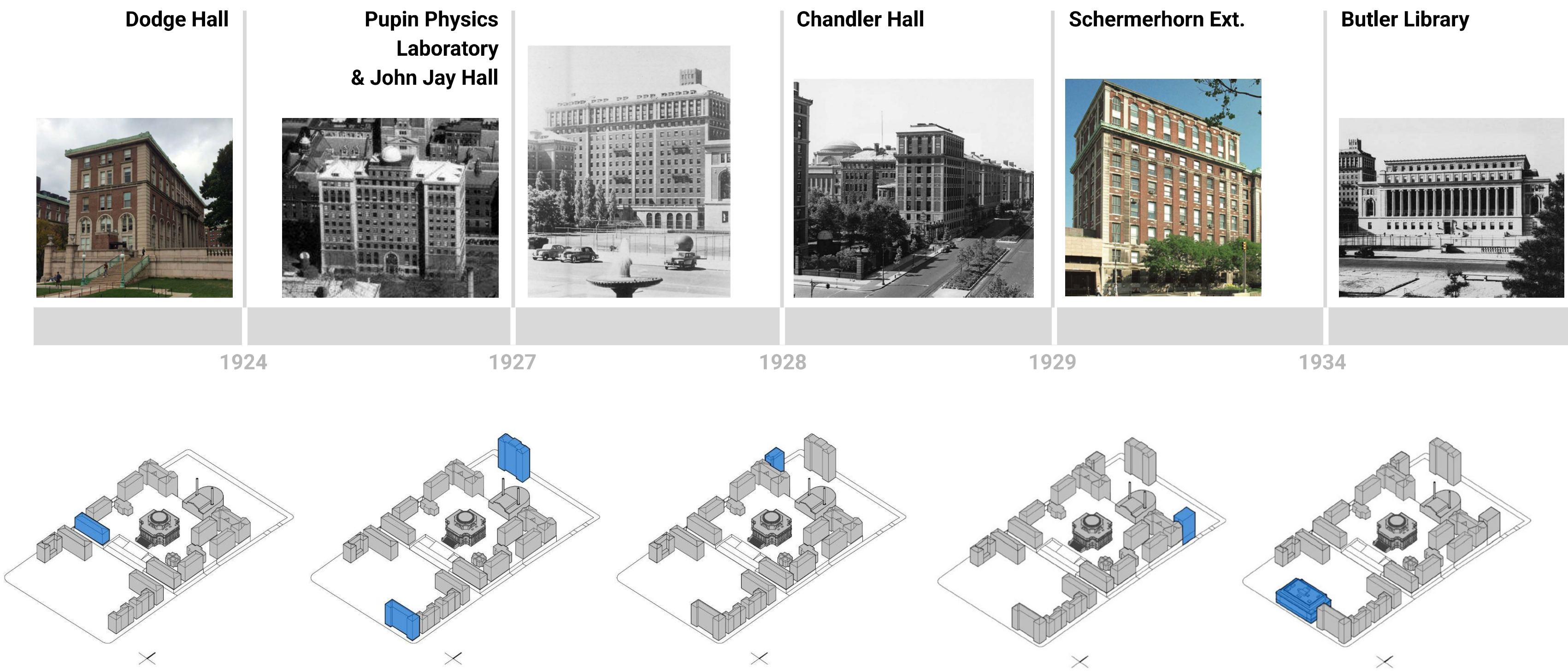
After 1912, no new construction was begun for a decade in the Columbia Morningside Heights campus because of the rapid increase in classroom and dormitory space between 1904 and 1912. However, in 1923, Columbia demolished its Men's Faculty Club building and built a Business School building that is to date known as the Dodge Hall.

Laboratory and John Jay Dining Hall, with Pupin standing as one of the "slender skyscraper towers" scheme designed by McKim, Mead & White. The Green/Grove was a potential site at the north end of the campus for larger and taller new buildings since this area, incorporating approximately one square block, was still undeveloped in the early 1920s. After this intervention, the remainder of the Green/Grove remained undeveloped for several more decades.

The development during these decades was followed by the improvement of science facilities with the completion of Chandler Hall in 1928 and Schermerhorn Extension in 1929. The momentum continued with the completion of South Hall Library, designed by architect James Gamble Rogers. Later in 1946, South Hall Library was renamed Butler Library after president Butler's retirement.



The Slender Skyscraper Towers Scheme by McKim, Mead & White
Source: Courtesy of McKim, Mead & White - WikiCU



1924-1934 Buildings Timeline
Source: Nicolás Moraga

BUILDING TYPOLOGY

Integrating the new scale and density required for laboratory and residential buildings with the architectural heritage of McKim, Mead & White's earlier designs and the existing compositional of the campus mega-block, engendered significant changes in the aesthetic composition of Morningside Campus, especially with the addition of the significantly taller Pupin and John Jay Halls and culminating in the design of Butler Library by architect James Gamble Rogers, closing off the city views to the south of campus in contrast to the intention of the Mckim Mead & White master plan.

CONSTRUCTION TYPE

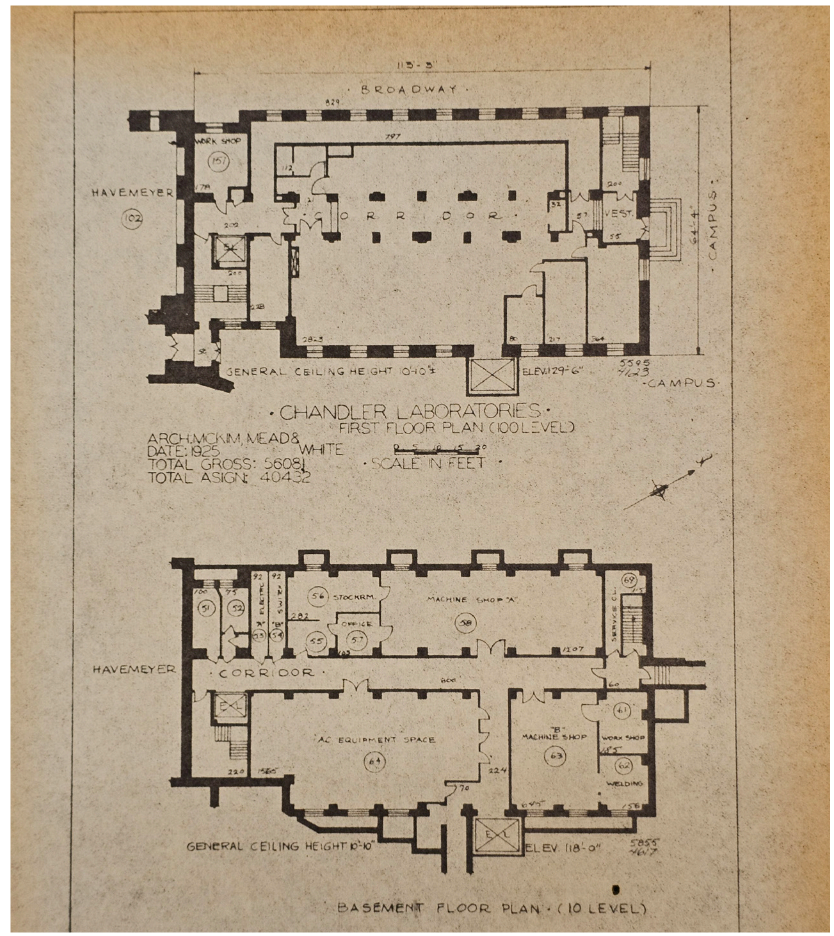
In this phase of Columbia's development, As the building footprint got bigger and the floor levels higher, buildings started to be built with steel frame structures with curtain walls. This introduced a new building typology to Columbia allowing for taller buildings with larger windows. This created significantly more floor area that was better ventilated and illuminated than earlier buildings on campus.

Buildings built in this period also began using heavy machinery during construction. Tractor cranes and bulldozers were used for the digging and removal of materials as well as during the laying of foundations. Another change that can be observed is the transition to a more extensive use of reinforced concrete. This was used for the footings of the steel frame but also in the construction of stem walls and ground floors. However, most importantly in regards to the quantity of material used, buildings started using draped mesh concrete floors and hollow concrete blocks for fireproofing the structural steel and either hollow concrete or gypsum blocks for interior partitions. Exterior cladding maintained the materiality of the earlier Mckim Mead & White buildings continuing to use brick, limestone, copper roofing and brass detailing.

For the proposals of both Chandler and Schermerhorn Extension the new constructions trace their architectural origins with granite bases, and brick facades with limestone trim, but had built up higher floors for a vertical expression instead of a horizontal difference. McKim's brick walls punctured with oversized double-hung windows were also replaced by Kendall's spaced brick piers and a setback honeycomb of standard sash windows. With the advancement of steel frame construction and sash windows, the vertical expansion also fulfills the campus's growing needs for laboratory and classroom spaces.

CHANDLER

The Chandler building used an advanced steel frame structure but applied limestone and brick facade on the exterior so they are architecturally similar to Havemeyer, matching the original McKim, Mead & White. In the building's plan, the contrast between the thick load-bearing walls of Havemeyer and the steel columns in Chandler reveals the change in construction technology between 1924 to 1934.



Chandler Hall Plan
Source: Courtesy of HP Studio-II, Spring 2024

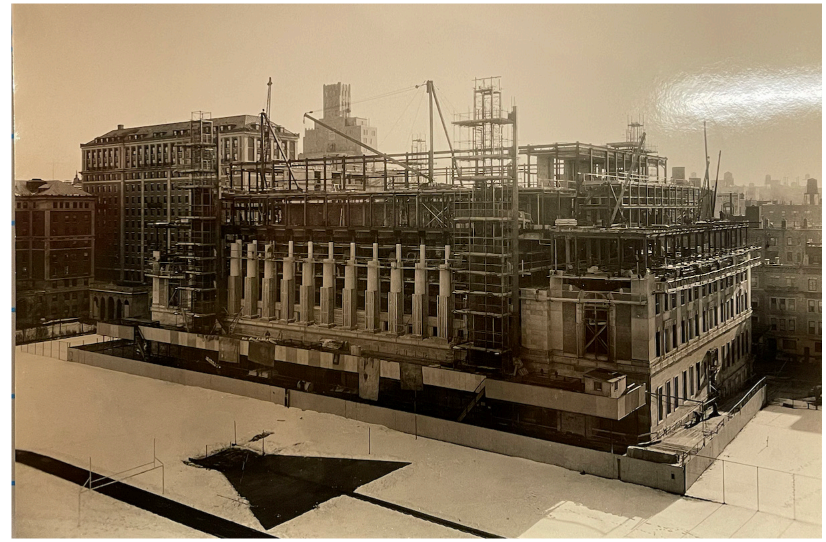
SCHERMERHORN EXTENSION

The Schermerhorn Extension also utilizes the steel-frame construction with bricks and limestone tracing the McKim's original Schermerhorn design. However, since there is a steeper grade on Amsterdam Avenue, Kendall was able to design a taller building compared to Chandler Laboratories. Another difference was that Kendall brought back the moldings of the original Schermerhorn and he laid it out through all three exposed facades of the extension building, while Chandler had been reduced to a shallow and flat facade design. Kendall was authorized to incorporate more ornament and more three-dimensional stone trim in Schermerhorn Extension than Chandler.

Schermerhorn Extension
Source: Courtesy of HP Studio-II, Spring 2024

BUTLER LIBRARY

Butler Library is a steel frame building with brick and limestone cladding on the facade. Such construction facilitates a central interior court where the book stack holds 2.9 million volumes of Columbia's book collection on fifteen tiers. The cladding of limestone and brick possess proportionally more limestone at the center to echo the Low Library, while at its extremities brick dominated to blend in with McKim's Dormitories, such as the John Jay Hall.



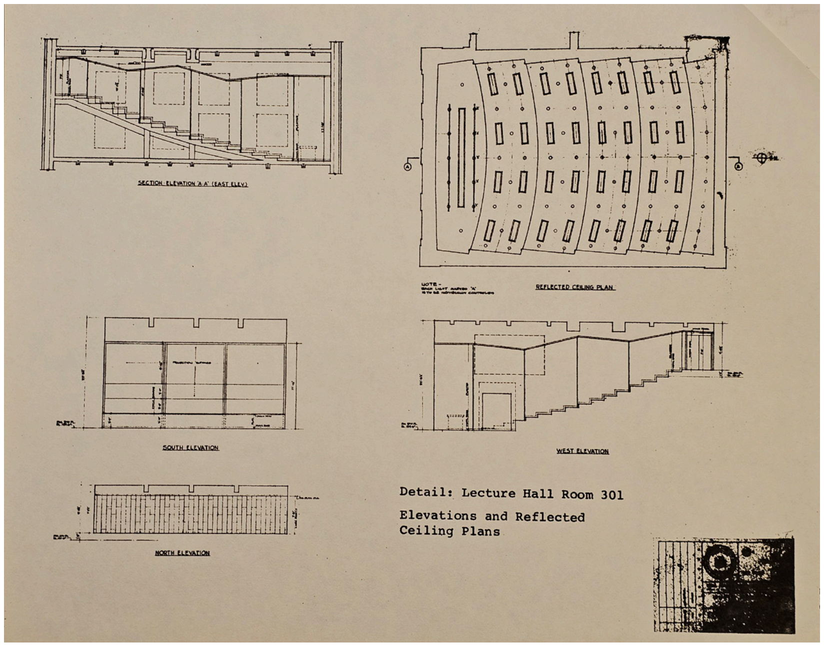
Butler Construction
Source: Courtesy of HP Studio-II, Spring 2024

JOHN JAY HALL

In response to a lack of affordable housing options around campus, John Jay Hall was constructed and has a total of fifteen stories doubling the height of previous dormitory construction. The steel frame construction enabled a total area of 148,292 square feet of John Jay Hall, accommodating primarily single rooms along narrow corridors.

PUPIN HALL

Pupin Hall utilized a steel frame system and curtain wall construction. The building has angle braces at the corners, and the allowance is made for a live floor load of 120 pounds per square foot on the first seven floors and 70 pounds per square foot for floors above. Aligning with the city's building code, beams and girders are fireproofed with cinder concrete and the floor slabs are made of 4-inch cinder concrete reinforced with heavy woven mesh. Last but not least, the columns are fireproofed with hollow tiles, responding to the laboratory's requirements.



Pupin Hall Detailed Section
Source: Courtesy of HP Studio-II, Spring 2024

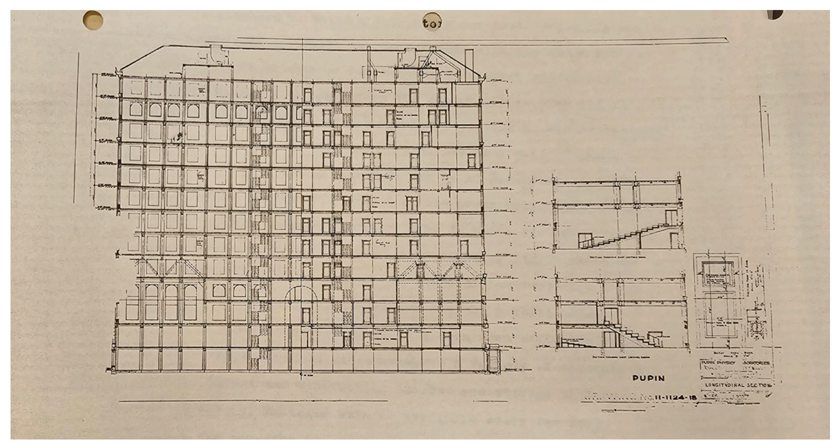
MECHANICAL SYSTEM

The design of University buildings between 1924 and 1934 optimized for both laboratory and dormitory functions by embedding all mechanical and plumbing systems in the envelope and flooring of the building allowing for easy reconfiguration of the interior partitions during future renovations.

PUPIN AS EMBLEMATIC EXAMPLE

For Pupin Hall, among the most notable features of the building are the extensive networks of service pipes and electrical wiring that serve every room. Each space is equipped with water access, a drainage system, and a sink where necessary, alongside compressed air supplied at two different pressures. Heavy-duty electrical conductors provide direct current to each room for both power and laboratory applications. Additionally, each laboratory room includes six conductors with a 30-ampere capacity, connected to switches and binding posts. These are linked to strategically placed distribution boards throughout the building, enabling the connection of rooms to various types of electrical currents as needed.

The building's laboratory electrical systems are meticulously organized through conduits embedded in the concrete of the envelope and flooring, ensuring they remain entirely separate from the lighting, elevator, and other machinery systems. The infrastructure includes over four miles of heavy copper cables designed to handle up to 175 amperes, alongside more than fifty miles of thirty-ampere conductors. This is in addition to the six miles of smaller wires dedicated to the lighting circuits, underscoring the building's comprehensive and sophisticated utility framework.



Pupin Hall Section
Source: Courtesy of HP Studio-II, Spring 2024

RENOVATION AND ALTERATION

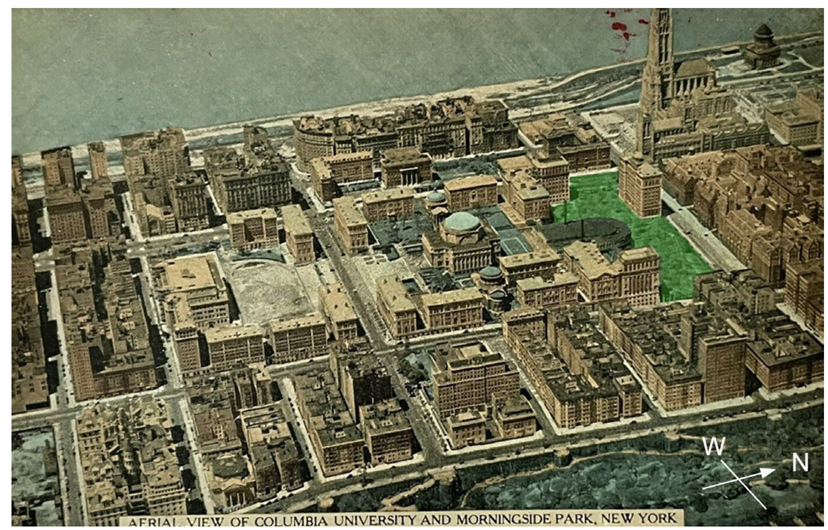
All of the above buildings have undergone alterations and renovations, some were driven by mandated building codes and others were implemented in order to keep up with the changing user needs. One example of such regulation-driven alterations to all campus buildings was the American Disabilities Act (ADA), passed by Congress in 1990. This law has an immediate effect on the building's appearance and spatial narration from both exterior and interior perspectives. Plaza and building entrances were renovated to incorporate ADA-compliant ramps and posts with push buttons were installed at the front; the restroom layout was altered to accommodate at least one ADA-compliant restroom on each floor.

Interior Renovation of 4th Floor Reading Room.
Source: Bernstein Assoc./University Archives, 1998.

The northern entry plaza of Butler Library was reconstructed in response to the ADA requirement featuring new granite stairs and ramps. According to the 1995 Butler Renovation plan, asbestos was removed from all the sub-basement areas, a new ventilation system was installed in a wooden structure rising sixteen feet above ground level. On the north side: a new lounge, coffee bar, expanded AcIS lab, collaborative classroom, and a new undergraduate reading room were added. New heating, air conditioning, and the connection to the new chilled water system, fire protection, and suppression systems were also added. This required the modernization of all mechanical and electrical systems and new lighting fixtures were installed throughout the building with Motion sensors with additional new switches.

CAMPUS DEVELOPMENT AFTER 1960: THE CONSOLIDATION OF THE NORTH CAMPUS SUPERSTRUCTURE.

The development of Columbia's Morningside Campus during the second half of the twentieth century continued in the upper north area facing 120th street, at the rear side of the University Hall. This landscaped terrain known as "The Green" or "The Grove" was originally planned for future constructions. When funding for further development was not found, the area was transformed into a park setting, designed with input from Frederick Law Olmstead. Paved roads led vehicles from Broadway and Amsterdam Avenue to lateral entrances of University Hall, where academic lectures and scientific meetings were open to the public (Bergdoll 1997, 62).

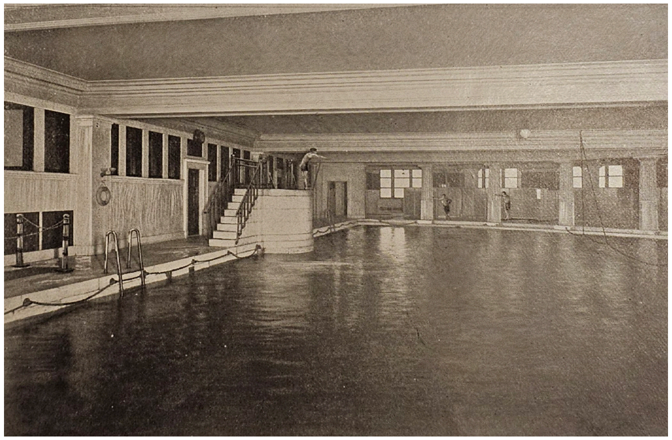


Aerial view of Columbia University and Morningside Park, New York. Circa 1940.
Source: Ebay.

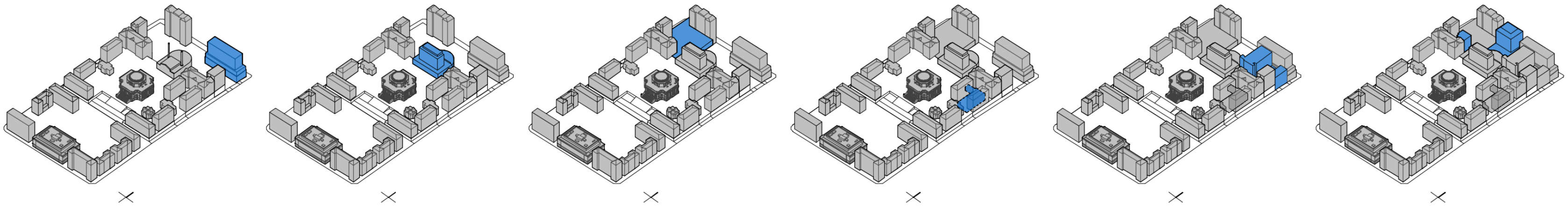
One of the main issues to consider in the development of the northern part of the campus is the morphological condition of the terrain. The topography from the center of the campus to the north maintains a prolonged slope, creating a significant difference in level from the central part of the campus to 120th Street. According to the original plan, the campus area surrounding University Hall, Low Library, and other Academic Buildings was constructed on a platform 40 feet above the street level, creating a continuous walkable area between buildings (Bergdoll 1997, 206). This platform ended at the rear of University Hall and the Havemeyer and Schermerhorn Halls, with a rusticated retaining wall and stairs connecting the upper and lower levels. Later buildings have leveled these differences in elevation to create a continuous platform at the campus level. Accordingly, on the street level, different entrances convey separate uses and connect facilities to service spaces.

Over time, the addition of different free-standing buildings completed the physical shape of the upper north campus, which extended below the underground campus level creating a continuous superstructure that contains the central steam plant and connects other mechanical facilities across Columbia's upper-campus buildings. For over three decades, no major building construction occurred in the upper north campus area besides Pupin Hall. Built in 1927, Pupin was considered the first high rise building on the Morningside campus, along with John Jay Hall, constructed in the same year to the south. The development of the North campus continued in the 1960s, with the construction of the Seeley Mudd Hall in 1961 (Applied Science and Applied Mathematics) at the east corner facing 120th Street and Amsterdam Avenue.

The Grove.
Source: University Hall. Office of Superintendent records. Box 2. Columbia University Archives.



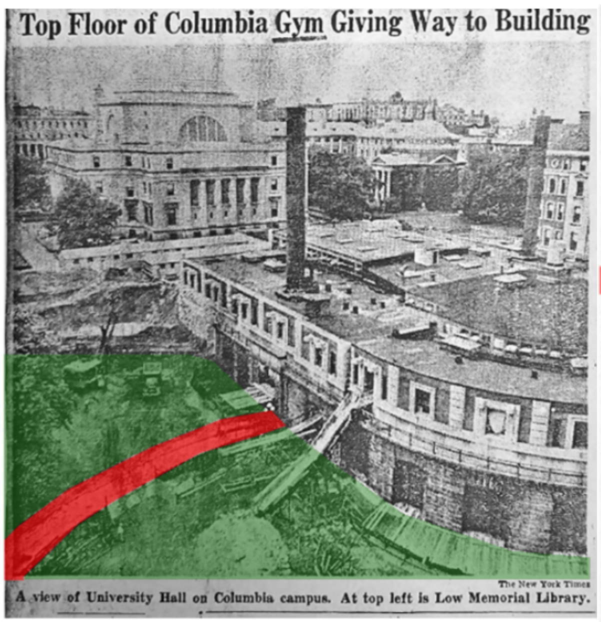
Gymnasium
Source: University Hall. Office of Superintendent records. Box 2. Columbia University Archives.

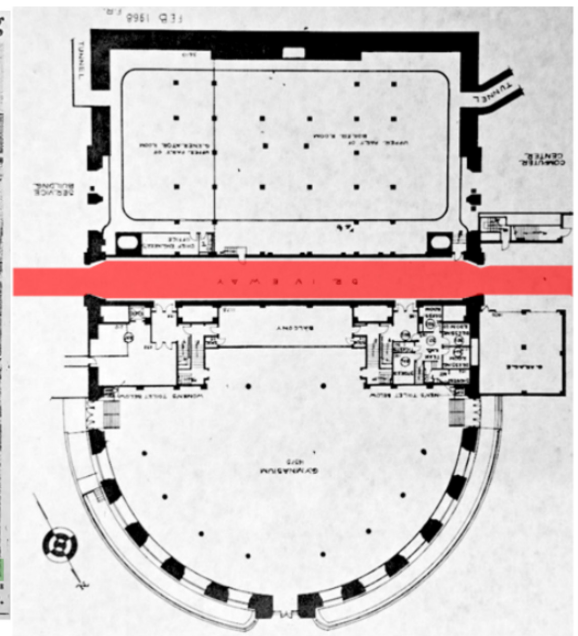


Physical development of the North Campus Area from the 1960s. From Left to right: Mudd Building (1961) Uris Hall (1964) Dodge Gym (1974) Avery Extension (1977) Fairchild Center (1978) and Schapiro CEPSR (1991). Source: Nicolás Moraga

The next substantial building to be erected in this area was Uris Hall, which housed the new Business School building in 1964. At that time, University Hall was the site of the original power plant for the University, among other uses such as a gym and a dining hall. Nevertheless, the top floors of University Hall were never completed, and a fire destroyed part of the non-permanent facilities on the top floors of the building, according to a 1953 Columbia Spectator article. The top floors of the University Hall building were razed for the construction of Uris atop which reused the previous building as a structural base. These foundations were retained because of the function of the powerhouse and the presence of the steam loop which connected this building to the other facilities on the campus. A corridor conveyed coal to the powerhouse and connected to Amsterdam and Broadway Avenue. These lower levels were therefore sustained because of their importance to the mechanical function of the campus.

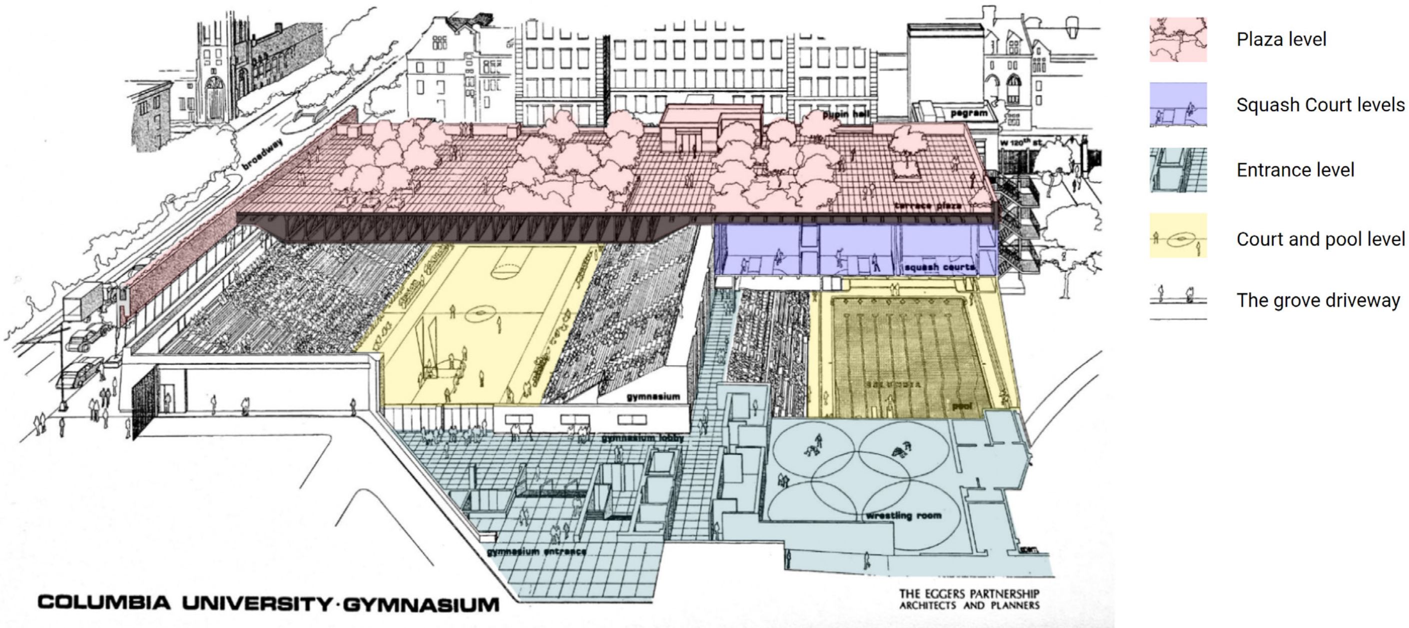
This connecting tunnel and the infrastructure for energy production within the foundations of University Hall informed the development of the later superstructure. The continuous superstructure of layered and interconnected ancillary, academic, and recreational spaces are all founded within this network of energy distribution. At the lowest level of the campus, the distribution network extends through the tunnel system to the rest of the Columbia campus through the basements. Since the mid-century, this loop has been modified and repurposed for other uses, such as hot water, chilled water, and electricity.





Driveway (the grove road)   Remaining landscape area

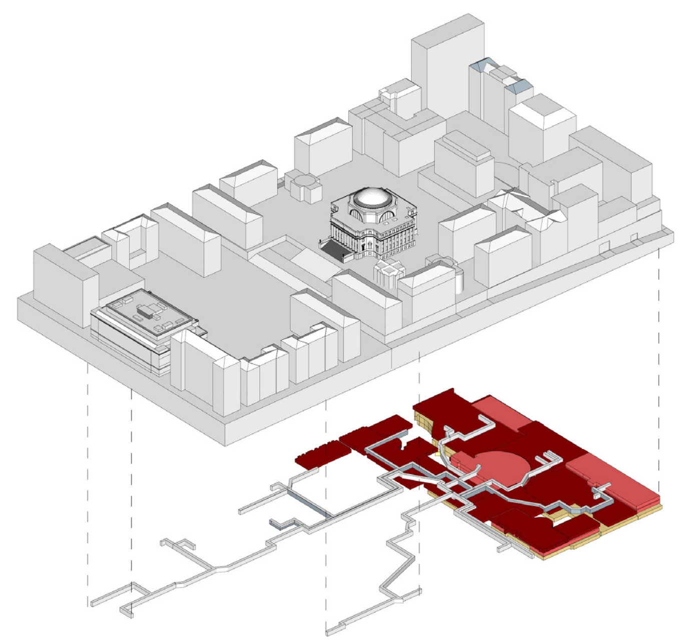
Graphic example of distribution network under University Hall and the Grove. This route is still used until today for facilities purposes.
Left: Image from New York Time Article, 1952. Center: University Hall Underground level floorplan (Columbia University Archives) highlighted in blue is the coal tunnel and the yellow area shows the boiler rooms. Right: Caption of a postcard from the 1960s. Source: Ebay.



Perspective section of the Grove, highlighting in different colors the sports spaces under the public plaza (red) All this structure could be considered a part of a"superstructure" or a continuous sequence of facilities connected by mechanical uses.
Source: Egger Partnership Architects and Planners. Columbia University Archives.

During the 1990s, the north campus's continuous platform level was completed with the construction of the Schapiro Center for Engineering and Physical Science Research building (CEPSR) in 1995. The first four underground levels at this building were considered to incorporate new complementary power facilities to provide steam and chilled water for the Air conditioner system on the campus. The construction of the Havenmeyer extension and the Northwest Corner Building designed by Raphael Moneo in 2010, puts an end to the physical development of the North Campus.

The historic development of the North Campus area could be summarized as the physical result of the evolution of the infrastructural spaces, based on the iteration of different power supplies and the function of mechanical systems that allow the daily use of all buildings on the campus. The presence of these systems and their networks, under and above campus level, still determined the use of the space and also the actions over buildings around the campus.

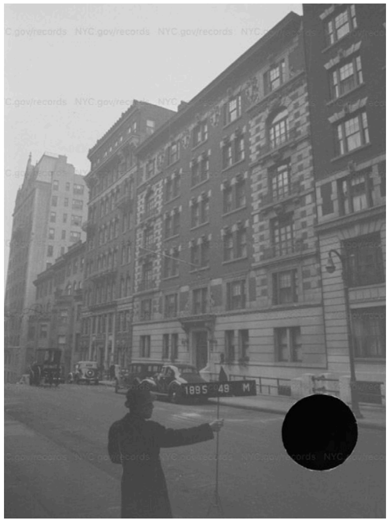


Axonometric view of the Columbia Morningside Campus and the underground levels part of the superstructure, connected by the tunnel network used by the steam and chilled water loop. Source: Nicolás Moraga, based on Columbia University Facilities Documentations.

ACQUISITION, DEMOLITION, RENOVATION: 1950S

In tandem with the university's expansion, it also began demolishing and renovating its new real estate holdings with the embodied carbon implications this entails. In 1956 a wave of property acquisition by the University in the West District began culminating in 1991. These acquisitions totaled 24 buildings, five of which were demolished by new law tenements.

"Sunnycrest" located at 611 West 113 Street was demolished in 1965 per DOB records. Although it is unclear when Columbia acquired this property, it remains empty today as a Columbia University Parking lot. It is unclear if Columbia originally intended to construct anything on this property or not.



Sunnycrest.
Source: NYC Tax Photo 1940.

Rockland Hall.
Source: NYC Tax Photo 1940.

Empty Parking Lot.
Source: NYC Tax Photo 1980.

Empty Lot. Source:
NYC Tax Photo 1980.

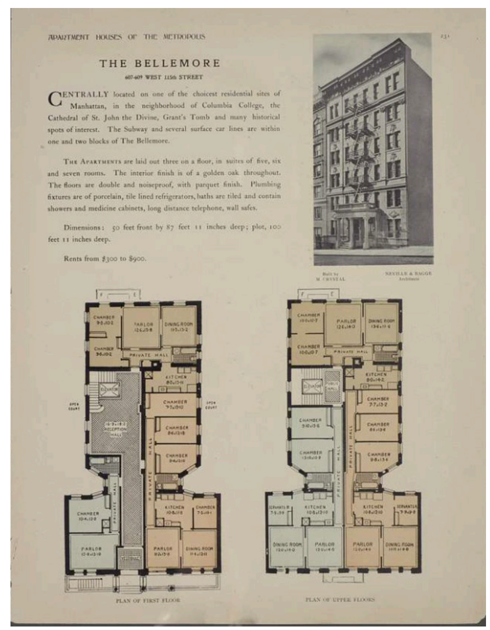
"Rockland Hall" located at 618 West 114 Street was acquired by Columbia on June 23, 1965 according to a 1968 letter by the Columbia University's Office of Public Information (Buildings and Grounds Collection). Although there are no property records found at the DOB, according to the Columbia University Office of Public Information from 1968: "The six-story building, along with several adjacent properties, was purchased so that it could be razed and the site used for the construction of a new building for the University's School of Social Work". However, this project never materialized on this lot, it remains empty today, and under Columbia's ownership.

Image of Wharfedale in 1940 before demolition.
Source: NYC Tax Photo 1940.

An image of 606 W 115th St after the demolition of the Wharfedale.
Source: NYC Tax Photo 1980.

Kraft Center.
Source: Columbia Operations Website

"Wharfedale" located at 606 West 115 Street was demolished in 1966, one year after Columbia's 1965 acquisition according to Columbia University's 1986 apartment inventory (Buildings and Grounds Collection). The Kraft Center was built in its place in 1999 and remains there today. The Kraft Center serves as Columbia's Center for Jewish Student Life and is home to a wide range of cultural, social, religious, and educational activities (Columbia Operations n.d.).



APARTMENT HOUSES OF THE METROPOLIS

THE BELLEMORE

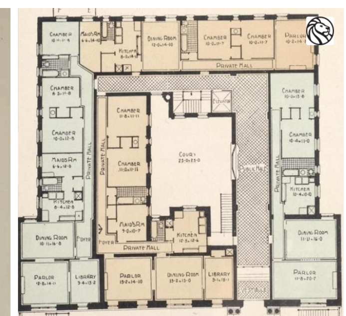
607-609 WEST 115th STREET

CENTRALLY located on one of the choicest residential sites of Manhattan, in the neighborhood of Columbia College, the Cathedral of St. John the Divine, Grant's Tomb and many historical spots of interest. The Subway and several surface car lines are within one and two blocks of The Bellemore.

THE APARTMENTS are laid out three on a floor, in suites of five, six and seven rooms. The interior finish is of a golden oak throughout. The floors are double and noiseproof, with parquet finish. Plumbing fixtures are of porcelain, tile lined refrigerators, baths are tiled and contain showers and medicine cabinets, long distance telephone, wall safes.

Dimensions: 50 feet front by 87 feet 11 inches deep; plot, 100 feet 11 inches deep.

Rents from $300 to $900.



Apartment buildings.
Source: Various

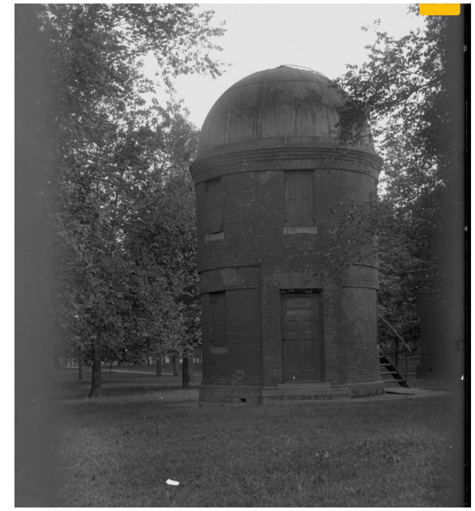
Adjacent apartment buildings at 605 and 609 West 115 Street, named "The Bellemore" and "Annamere Court" were acquired by Columbia in 1966 according to Columbia University's 1986 apartment inventory (Buildings and Grounds Collection). According to the DOB, both buildings were demolished in 1977 and remained empty until 1987. The lots were eventually combined and Columbia built residence hall Schapiro which opened in 1988 and remains there today.

Schapiro.
Source: NYC Tax Photo 1980.

The Bellememore.
Source: NYC Tax Photo 1940.

Annamere Court.
Source: NYC Tax Photo 1940.

Wilde Observatory.
Source: NYHS.



Other buildings that were demolished after 1950 within the main campus area include the Wilde Observatory which was built in 1906 and was later replaced by the Rutherford Observatory in the Pupin Laboratory, and a small cottage was removed from the southwest corner from campus (Columbia University 1907, 80). Those were the last buildings to be demolished within the perimeter of the main campus and their removal created both a visual and typological impact on campus. The buildings were removed in a critical period as the construction of superstructures was on the rise, making their demolition an invitation for the appearance of a different building typology on campus.

The organization known as Morningside Heights, Inc. had a large impact on the redevelopment of the Morningside area throughout the late 1900s, much of which lies beyond the immediate study. Though its activities started in 1947, it was not until the 1963 Morningside General Renewal Plan did the organization recorded its influence on Columbia's West District. The Renewal Plan called for the acquisition and renovation of apartment buildings that had been converted into single-room occupancy, including Albert Hall and the Alumni Center.

There is some evidence that the NYC Department of Housing Preservation and Development had planned to erect mixed-income housing in the area, including on the lot that would eventually become Schapiro Hall. Columbia objected to this proposal, claiming that it already had plans underway to make the neighborhood "better."

Columbia Campus. 2024. Photo by Frederick.

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