Building Circularity

Pathways and Barriers to Carbon Emission and Waste Reduction In NYC's Built Environment

For The Earth, who's sacred nature has radicalized me since childhood.

To my Mom and Dad, Diane and Adam, who have always supported me and instilled within me a lifelong pursuit of knowledge.

To Ot, who I could never have done this without,

And to Goose, the worlds greatest dog.

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Abstract

New York City faces a significant challenge in reducing embodied carbon from its construction and demolition (C&D) sector. Unlike operational emissions, embodied carbon is embedded across material sourcing, manufacturing, construction, and end-of-life processes, making it more difficult to regulate and reduce. Addressing it requires not just incremental improvements, but coordinated changes across design, procurement, waste management, and the data systems used to track materials over time. While the city has made meaningful commitments to climate action, existing policies lack a system-wide, scalable, and economically viable strategy for reducing embodied carbon. This research examines how circular construction can serve as that strategy. It evaluates the implementation, expansion, and market implications of circular policies as a pathway for reducing embodied carbon at scale. Using a mixed-methods approach, the study maps the current policy and market landscape in New York City to identify where barriers, gaps, and opportunities exist. Through policy analysis, semi-structured interviews, LCA-informed OLS analysis, and policy informed scenario-based econometric modeling, the research demonstrates that the primary constraint to scaling circularity is not technical feasibility, but coordination, cost structures, and market signals. It identifies where circular strategies offer the greatest environmental and economic impact and outlines a planning framework for accelerating low-carbon, material-efficient, and equitable construction practices in New York City.

Executive Summary

New York City has made real progress in addressing operational emissions, but embodied carbon in the construction and demolition (C&D) sector remains largely unregulated. This gap is significant, as material production, use, and disposal continue to drive a substantial share of the city's emissions. This study explores how circular construction can address that gap, not as a niche sustainability strategy, but as a system-level shift in how materials are used and reused across the built environment.

What emerges is not a lack of technical solutions, but a lack of alignment. Existing policies, including New York State's Buy Clean framework and New York City's Executive Order 23, begin to address embodied carbon through procurement and lifecycle assessment, but they operate at different scales and do not yet form a cohesive system. At the same time, industry perspectives make clear that while awareness of embodied carbon is growing, project decisions are still shaped by cost, timelines, and risk. Circular strategies and material choice are often considered early, but frequently fall away as projects move forward, constrained by fragmented supply chains and the absence of reliable markets.

The quantitative results reinforce this dynamic. Structural systems, particularly those dominated by concrete and steel, remain the primary drivers of embodied carbon, especially as buildings increase in size. This suggests that reducing emissions is not simply a matter of choosing different materials, but of extending material lifecycles through reuse and recovery. In other words, the problem is not only what we build with, but how long those materials stay in circulation. Economic analysis shows that this transition is not only possible, but financially viable. Scaling circular construction would require meaningful public investment, estimated at approximately $1.7 billion annually under a high-adoption scenario. However, this investment functions less as a cost than as a catalyst, with projected returns between $2 and $8 billion per year through job creation, market development, and reduced material demand.

This study finds that Circular construction is the mechanism with which lower embodied carbon is achievable, but it is constrained by systemic barriers rather than technological limitations. Moving forward will require shifting from project-level optimization to system-level coordination, supported by integrated policy, targeted investment, and the use of public procurement to create stable and lasting market demand.

II. Setting the Scene

Structure

This thesis is organized to move from context to implementation. It begins by situating embodied carbon and construction waste within broader climate and urban systems, and introduces circularity as a framework for addressing both. It then reviews relevant literature on circular construction, material flows, and building systems to establish the technical and conceptual foundation for the study. The empirical chapters follow, combining policy analysis, interviews, and quantitative modeling to assess how circular strategies are currently applied in New York City and where key barriers remain. These findings are then used to evaluate the potential for scaling circular construction through scenario analysis. The final chapters translate these insights into planning implications, policy recommendations, and a framework for implementation.

Introduction

The Day the World Stops Shopping by J. B. MacKinnon examines the persistence of overconsumption and its relationship to rising global carbon emissions. Across sectors and countries, economic growth continues to drive increased demand for carbon. While emissions per unit may decline as materials and production processes become more efficient, these gains are offset by rising levels of consumption. Products are replaced rather than reused or remade, waste continues to accumulate, and overall emissions continue to increase.

This dynamic makes clear that efficiency alone is not enough. Consumptive demand continues to outpace operational improvements, limiting their impact at the system level. Addressing this challenge requires more than incremental change. Economic stagnation is not a viable solution. What is needed instead is a structural transformation in how materials are produced, used, and recirculated. What is proposed in this study is a first step in what would be a long journey to full economic circularity. Construction and demolition may provide an optimal entry point into a circular economic model that can combat the massive challenge of human created waste and consumptive driven emissions and the resulting climate crisis.

Context

Climate change poses one of the most significant and complex challenges facing humanity today. A warming planet is already reshaping ecosystems, threatening species, and placing increasing pressure on the systems that support human life (IPCC, 2022). Addressing it will require a substantial reduction in the drivers of emissions and a transformation of the systems that produce them. Climate change is not only an existential challenge however, it is increasingly becoming evident that it is also a massive organizational challenge (IPCC, 2022). One rooted deeply in the need for human coordination and cooperation.

Effectively achieving decarbonization and sustainability depends on coordination across every level of government, society, ecosystem, and urban environment (Intergovernmental Panel on Climate Change [IPCC], 2022). This reality produces both despair and hope among activists, citizens, and policymakers. Failure to collaborate and synchronize across national and international levels could spell cascading consequences, as emphasized by the Paris Agreement's call for unified global climate action (UNFCCC, 2015). Yet even as large bureaucratic institutions falter under polarization and neoliberal capture, more adaptable and agile actors, like cities, are emerging with the power to make profound impacts (Barber, 2013). This shift brings the potential for significant and needed change much closer to everyday people, creating a viable channel for a sustainable future.

In other words, the United States federal government is falling short of the pace required to cut emissions and exercise global climate leadership. Weighed down by bureaucracy, political gridlock, misinformation, corporate influence, and powerful lobbyists, the nation-state is failing to meet the moment (Byrne et al., 2022, Barber, 2013). The Trump administration's second term has significantly altered federal climate policy, including revoking the EPA's 2009 endangerment finding. The finding was the legal basis for regulating greenhouse gas emissions under the Clean Air Act. Trump's administration continues to roll back key environmental regulations, actions that are now the subject of ongoing legal challenges (Sabin Center for Climate Change Law, 2025, World Resources Institute, 2026). At the same time, the EPA has moved to weaken or repeal emissions standards for power plants and vehicles, steps that would increase fossil-fuel use and slow the transition to cleaner energy and transportation systems (Carbon Direct, 2025; Freshfields, 2025). These rollbacks are paired with a broad deregulatory agenda across air, water, and pollution rules, signaling a federal shift away from climate mitigation at the exact moment when stronger action is needed (Politico, 2025).

In contrast, cities, more permeable, grounded, and responsive to the public, have a crucial role to play in making meaningful progress (Barber, 2013). Many cities have held firm in their commitments, positioning themselves as key players in achieving decarbonization and climate justice (Global Covenant of Mayors for Climate & Energy, 2025). Even as the federal government retreats from climate regulation, cities have continued to pursue their own decarbonization pathways by adopting local climate action plans, setting emissions-reduction targets, and expanding policies on clean energy, building performance, and transportation (C2ES, 2024; Climate Advisers, 2024). Coalitions like America Is All In have also allowed cities, states, and counties to remain aligned with the goals of the Paris Agreement, working to fill the vacuum left by federal rollbacks and signaling that subnational actors intend to carry climate leadership forward regardless of shifts in Washington (America Is All In, 2024). This decentralized momentum shows that climate progress in the United States increasingly depends on the choices made in municipal governments, where policy can move faster, align more directly with community needs, and remain insulated from the ideological swings of national politics.

New York City, as a large and highly influential metropolitan environment, functions as a real-world testing ground for climate policy and innovation, where new technologies and strategies can be piloted and scaled in live urban conditions (New York City Economic Development Corporation, 2023, Global Covenant of Mayors for Climate & Energy, 2025). Scholars and global climate networks alike argue that cities such as New York drive climate governance and experimentation in ways that often surpass national action (Rosenzweig et al., 2010; Barber, 2013; C40 Cities, 2020). To meet this responsibility, New York must address two intertwined challenges: a massive and rapidly growing waste stream, and a built environment responsible for staggering levels of embodied carbon emissions. Together, these crises reveal a critical opportunity. One where circularity, adaptive reuse, and material efficiency can turn waste into value and carbon-intensive practices into pathways for resilience. This project responds to that opportunity. It examines the gaps in New York's current plans and explores how circularity, digital information systems, material science, engineering, incentives, and policy can be woven together to create a more regenerative, low-carbon, and economically resilient built environment for the city.

Background

The Embodied Carbon Problem

The built environment contributes to New York City's carbon footprint in two interconnected ways. The first is operational carbon, which includes the energy used to heat, cool, and power buildings throughout their life. For many existing buildings, especially those constructed under older performance standards, these operational emissions still dominate the overall carbon profile. But as building efficiency improves as a result of regulation like Local Law 97 and operational demands shrink, the remaining sources of emissions become a remaining limitation to achieving net zero. A growing proportion of NYC's climate impact comes not from running buildings, but from making them. In many new or high-performance projects, embodied emissions can account for 20 to 50 percent of a building's total life-cycle footprint, sometimes even more (UKGBC, 2023; Circular Ecology, 2024; IESVE, 2024). In other words, as cities succeed at driving down operational energy use, embodied carbon becomes the harder, more structural challenge left to solve.

This reality is especially important in New York City, where buildings define the emissions landscape. The sector is responsible for just over two-thirds of total greenhouse gas emissions within the city, largely driven by space heating, cooling, and lighting (NYC Department of Buildings, 2024; Urban Green Council, 2024; NYCEDC, 2025). Because buildings dominate the city's emissions profile, the combined weight of operational and embodied carbon ultimately determines whether New York can meet its commitment to reduce emissions 80 percent below 2005 levels by 2050 (City of New York, 2015; NYC Mayor's Office of Climate & Environmental

Justice, 2024). As operational emissions decline through policies such as building electrification and efficiency improvements, embodied carbon represents an increasingly significant share of total building-related emissions.

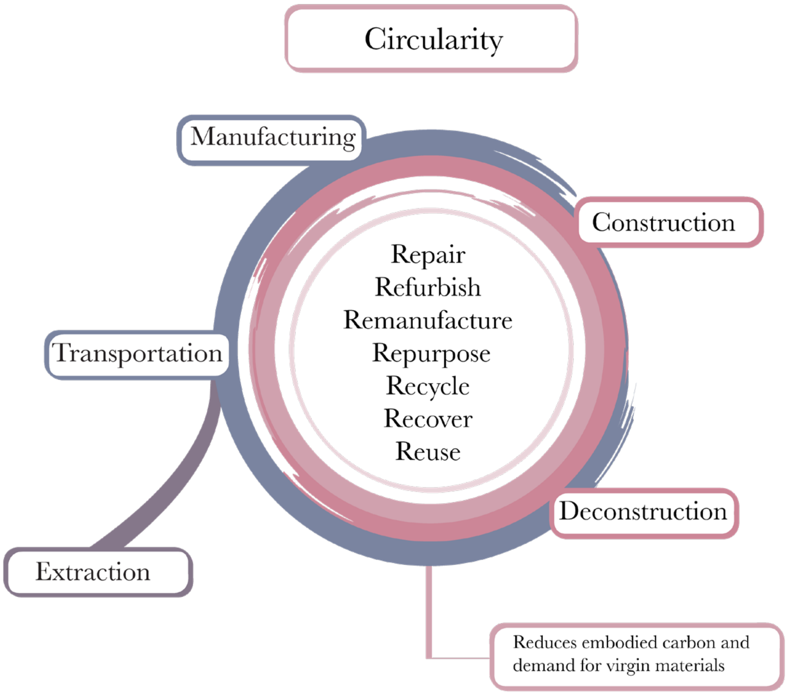
Cutting embodied carbon through circularity is therefore not a secondary environmental goal, but a key opportunity to reshape how climate solutions are understood and implemented. Rather than relying primarily on downstream policies such as cap-and-trade systems, circular approaches shift attention upstream to the beginning of the material lifecycle, where carbon consumption is first embedded. In this way, addressing embodied carbon is not just complementary to existing strategies, but essential to them. Ensuring that embodied carbon is a central component of the city's climate trajectory is therefore critical.

Concrete, steel, glass, and other construction materials carry enormous carbon footprints through their extraction, processing, manufacturing, and transport (EESI, 2021; U.S. Department of Energy, 2023). Industry guidance shows that these material stages account for roughly 70 percent of embodied carbon in the built environment, with the remainder coming from on-site construction, installation, and end-of-life activities (American Council of Engineering Companies of New York, 2023; NYCEDC, 2025). This means the construction and demolition sector is not only a major source of emissions, but also one of the most promising sites for meaningful carbon reduction. If the city wants to cut emissions at the scale required, the way it builds, renovates, and dismantles buildings will need to adapt and evolve.

The Waste Problem

Understanding construction and demolition waste in New York City requires moving past the idea that waste is simply a byproduct of building activity. The global literature shows that most embodied emissions are generated long before materials reach a job site, which means that when C&D waste is created, the city is not just dealing with disposal. It is losing the carbon, energy, and ecological resources that are embedded in those materials from the moment they were extracted, processed, and transported (Myint and Shafique, 2024; De Wolf et al., 2017). Countries like the Netherlands and cities across Europe are already seeing how rising material consumption undermines climate goals. Waste represents a lost resource and a renewed demand for high carbon virgin materials that restarts the entire emissions cycle (PBL, 2025).

Research on urban metabolism takes this even further. Cities sit on enormous stocks of materials such as steel, timber, brick, and stone that could be harvested and reused if proper systems were in place (Jawanrudi et al., 2021). Without those systems, demolition destroys materials that could have circulated through multiple building cycles. This pattern is especially clear in New York City, where high development pressure and fast construction timelines often make full demolition the easiest choice. The city produces millions of tons of C&D debris each year, although even the basic numbers are inconsistent. The New York City Economic Development Corporation estimates that C&D activity produces about 7,500 tons of garbage per day, equating to 2.7 million tons per year. The Department of Sanitation reports a much larger figure: roughly thirteen million tons of total waste annually, about half of which, or 6.5 million tons per year, is tied to C&D activity (NYCEDC, 2024; DSNY, 2024). Other studies point out that even these numbers are incomplete because the city has no unified system for tracking material flows, which means that large portions of the waste stream go unmeasured (Ezrapour et al., 2024). What we do know is that most of these materials are sent to landfills or downcycled, even when they still hold significant structural or architectural value. Much of the old-growth timber, steel, brick, and stone inside New York's existing buildings is recoverable with selective deconstruction, yet most of it is destroyed during conventional demolition practices.



Why Circularity?

Given the scale of both the waste and embodied-carbon challenges outlined above, New York City needs a strategy that does more than manage waste at the end of a building's life. It requires an approach that reduces material demand altogether (Dutch Ministry of Infrastructure and the Environment, 2016; MacKinnon, 2021). Circularity offers exactly this kind of structural solution. Instead of treating materials as disposable, circular systems keep resources in use for as long as possible through reuse, repair, repurposing, and high-value material recirculation. This shift is central to climate action. Global research shows that reducing consumption of virgin materials is one of the most effective pathways for cutting life-cycle emissions, especially because 60 to 80 percent of embodied carbon occurs before a material ever reaches a job site (Myint & Shafique, 2024).

For New York, circularity directly addresses the failures of the current linear system. The city can turn its enormous C&D waste stream into a resource by harvesting the materials already embedded in buildings rather than destroying them through mechanical demolition. Reusing existing materials avoids the high-carbon extraction and manufacturing processes associated with virgin production (De Wolf et al., 2017), reduces long-distance transport emissions, and preserves the carbon already stored in materials like wood (Souaid et al., 2024). It also brings material flows back within the city's boundaries, shortening supply chains and increasing resilience in the face of global disruptions (PBL, 2025).

Circularity also produces a set of economic and social co-benefits that strengthen its policy relevance. Reuse and deconstruction industries create local jobs that cannot be outsourced, supporting new roles in material salvage, processing, certification, warehousing, and resale (Falk & McKeever, 2004). As salvage markets grow and materials circulate through multiple cycles, cities that implement circularity at scale see reduced project costs through avoided disposal fees and lower reliance on volatile global commodity markets (Ellen MacArthur Foundation, 2020).

III. Methodology

Research Goal

To identify the primary barriers to circularity and reducing embodied carbon in New York City's construction and demolition sector, and to evaluate the most feasible and impactful policy solutions, while clarifying the evolving role of planners within this increasingly multidisciplinary urban context.

Research Questions

1. Mapping the Current Landscape

RQ1: What policies, programs, and regulatory frameworks currently shape embodied carbon and circular construction practices in New York City?

2. Identifying Gaps and Barriers

RQ2: What structural, regulatory, economic, and logistical barriers limit the adoption and scaling of circular construction and adaptive reuse in New York City?

3. Understanding Current Practice

RQ3: To what extent are circular strategies—such as adaptive reuse, deconstruction, and material salvage—being implemented in NYC construction projects today?

4. Evaluating Systems and Outcomes

RQ4: How are decisions around material use, demolition, and reuse currently made in practice, and to what extent are circular strategies being implemented across projects?

5. Quantitative Assessment

RQ5: How do building characteristics and material decisions, particularly structural system, height, and material specification, shape embodied carbon outcomes, and what does this reveal about the most effective points of intervention for reducing emissions in urban construction?

RQ6: To what extent can policy interventions, particularly public procurement and targeted incentives, shift market conditions to scale circular construction and reduce embodied carbon in New York City?

Analytical Framework

This project uses a few simple but connected ways of looking at New York City's construction and demolition sector. The first is circularity itself. Circular economy thinking shows up here as a practical question rather than a buzzword: are materials kept in use, reused at a high value, and designed to move through multiple building cycles, or are they treated as disposable? This frame guides how I read policies, industry practices, and proposed solutions. It helps identify where materials are being lost, where carbon emissions are being wasted, where reuse is possible, and where interventions could meaningfully cut embodied carbon. The project also uses an institutional and governance lens. Circularity depends on how agencies, developers, contractors, haulers, and reuse actors are organized, what rules they work under, and where incentives or frictions show up in everyday practice. This frame shapes how I interpret interviews, policy documents, and program designs by asking who has the power or responsibility to act, who stands to benefit, who is responsible for coordination, and where that coordination is missing.

The framework also draws on concepts from urban metabolism and material stock thinking, but these are used primarily to inform how the problem is understood rather than as a primary analytical method. Buildings are treated as temporary assemblies of materials that move through stages of extraction, construction, use, and eventual dismantling, which helps contextualize the relationship between waste, reuse potential, and embodied carbon. Within this research, this perspective supports the interpretation of interview findings and policy analysis by highlighting how design and demolition decisions influence whether materials remain in circulation or are lost as waste. Rather than directly modeling material flows, this lens provides a conceptual foundation for understanding why material management, tracking systems, and design choices are critical to enabling circular construction.

A final part of the framework focuses on economic feasibility. Circularity will only take hold in New York if it works financially for the people who build, demolish, and manage projects. This means paying close attention to costs, savings, and the possible revenue streams tied to reuse, resale, and avoided disposal. By looking at economic data, market prices, and the structure of the city's development industry, this lens helps identify where circularity creates financial opportunity, where it adds cost, and where policy or market shifts could change those outcomes. This perspective grounds the analysis in the realities of New York's building economy and helps evaluate whether proposed circular strategies are workable, not just ideal in theory.

Research Methods

In urban planning, mixed-methods work lets us use the power of data without losing the context in which that data is collected, shaped, and shared. When data are paired with lived experience and on-the-ground knowledge, planning gains the ability to answer questions in ways that are more precise and more grounded in real conditions. What works in the Netherlands may not work in New York State. What succeeds in Amsterdam may fall apart in Brooklyn. What solves a problem in Brooklyn may not make sense on the Upper West Side. Much like modular design or adaptive reuse, planning models need to be adjusted to fit the places where they are used. There is no one-size-fits-all approach and planning must be informed by place (Jacobs, 1961). Similarly, data are only useful when tied to the people whose lives it reflects, and expert knowledge is strongest when supported by clear evidence. For these reasons, this project uses a mixed-methods approach.

Because this project asks how circularity can realistically take shape within New York City's construction and demolition sector, the research design needs to capture the measurable patterns of material flows, the regulatory landscape, and the expertise of those leading the way in the field. Qualitative insights reveal how efforts to reduce embodied carbon are currently being implemented, why certain practices persist, how institutions are working to shift them, and what barriers limit the widespread adoption of circular construction. Meanwhile, quantitative analysis identifies which materials are most emissions-efficient, demonstrates how material and strcutural choices influence outcomes, and estimates the level of investment needed to incentivize and regulate industry practices. Bringing these forms of knowledge together creates a fuller picture of how circularity might work in practice, not only in theory. This combination of methods provides the structure needed to study a complex and uneven transition,

one that spans policy, market behavior, and everyday decision making across New York City's built environment.

Generative AI tools (OpenAI ChatGPT) were used to support code development, data visualization, and editorial refinement. All analytical decisions, model construction, and interpretations were conducted and verified by me, the author.

Research Focus and Explanation

New York City is the chosen site of this research for several reasons. The city has a mix of political commitment, economic stability, and cultural influence that makes it a national testing ground for new ideas in climate planning and urban policy (City of New York, 2019; Urban Green Council, 2024). New York has already adopted climate laws such as Local Law 97 and Executive Order 23, which show not only willingness but active effort to reduce emissions and move toward circular practices. New York's sustained climate planning efforts and its demonstrated ability to carry out complex, multi-agency initiatives make it an ideal setting for testing new policy and design models (NYC Mayor's Office of Climate & Environmental Justice, 2024; City of New York, 2023).

Economically, New York attracts people from across the country and around the world who want to live, work, and visit here. This creates a strong and relatively stable tax base (NYC Comptroller, 2023; NYC Department of City Planning, 2023). While taxes may influence some decisions, the cultural and economic draw of New York often outweighs concerns about cost

(Florida, 2017; Glaeser, 2011).. The city's limited land supply also creates constant demand for development, a pattern documented across several decades of redevelopment cycles (NYU Furman Center, 2022). This steady demand supports stable returns for builders and developers, which is important for the transition to circularity. Circular construction will only scale if environmental goals align with financial incentives. New York's market conditions, political environment, and institutional capacity make it a better test case than many other American cities.

The construction and demolition sector was chosen because it occupies a part of the economy where material flows are concentrated and easier to track. Unlike consumer markets, where millions of individual choices shape demand, this sector involves a smaller and more organized group of actors (McKinsey Global Institute, 2017). Developers know where their materials come from, how they move through supply chains, where they are installed, and how they are handled when a building reaches the end of its life (McKinsey Global Institute, 2017; De Wolf et al., 2017). Demolition teams know which materials can be salvaged and who will collect them (Jawanrudi et al., 2021). Because decisions in this sector are made by a limited set of participants, system-wide changes are not only more realistic but also may provide an ideal entry point for circular practices in the current linear model within the United States(McKinsey Global Institute, 2017). This is an area where circular practices can increase efficiency, create value from recovered materials, and help developers meet the requirements of Local Law 97. For these reasons, the construction and demolition sector in New York City provides a practical and meaningful setting for studying circularity.

These features make New York City a critical case for understanding how circular construction might be implemented in the United States. It is large enough, regulated enough, and economically complex enough to reveal the pressures and trade-offs that any circular system must confront. At the same time, the city's policy environment, existing climate commitments, and active real estate market create conditions where new practices can be tested, evaluated, and scaled. Studying New York therefore provides insight not only into the barriers that shape circularity today, but also into the kinds of governance structures, financial tools, and industry relationships that would be needed for a broader transition. By focusing on the construction and demolition sector within this particular urban context, the research is able to examine circularity within a system that is both highly carbon-intensive and tightly shaped by local policy, market incentives, and institutional capacity. This specific combination allows the findings from New York to speak to larger questions about how circularity could take shape in other American cities with different political, economic, and spatial realities.

Research Design

Figure 1.1 outlines the logic of the research design and demonstrates how each method contributes to understanding how New York City can reduce embodied carbon by scaling circularity within the construction and demolition (C&D) sector. The project follows a layered, mixed-methods approach that integrates qualitative and quantitative analysis. It begins by establishing the global and local context through literature and policy review, and then builds into three primary analytical components: semi-structured interviews and a cross-case synthesis matrix, embodied carbon estimation using life cycle assessment (LCA) principles combined with both ordinary least squares (OLS) and machine learning modeling, and scenario-based modeling of policy and market interventions. Each method addresses a different dimension of the research question, and together they form the basis for a grounded and implementable planning framework.

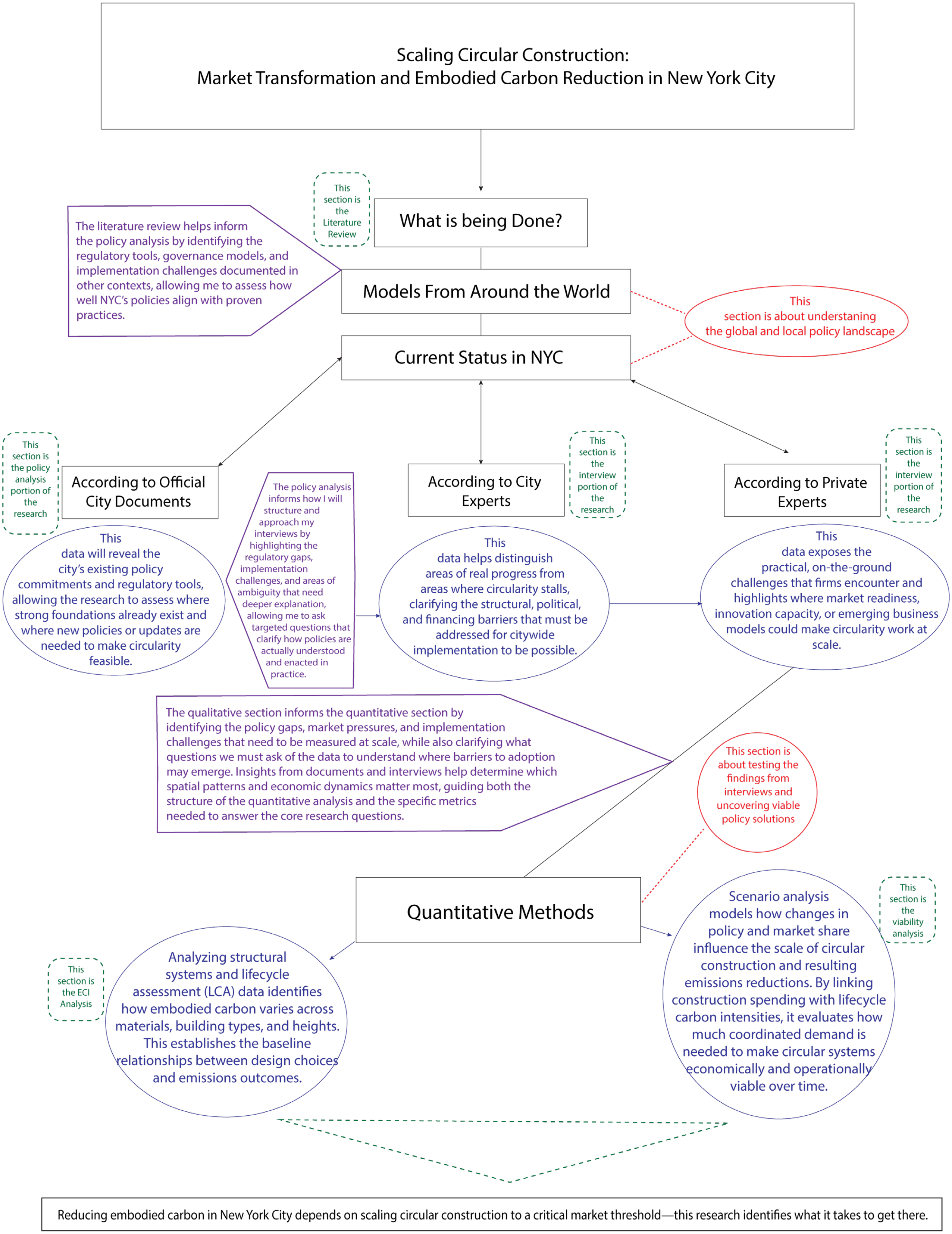
The first stage of the research consists of a targeted literature review focused on circular economy strategies, embodied carbon in the built environment, and material flow systems. This includes work on building information modeling (BIM), material passports, and advances in material science. Rather than serving as a general overview, this review is used to establish the technical and conceptual boundaries of circular construction, identify gaps in current research, and clarify how technological feasibility intersects with policy ambition. This foundation informs both the policy analysis and the design of the empirical methods that follow.

The second stage analyzes the existing policy and regulatory landscape in New York City. This includes key legislation, procurement frameworks, and planning tools that influence embodied carbon and material flows. The purpose of this analysis is to identify where current policies enable or constrain circular practices, and to map the institutional structure within which implementation occurs. These findings directly informed the design of the interview process by highlighting areas of uncertainty, fragmentation, and potential leverage within the system.

The qualitative core of the research consists of semi-structured interviews with stakeholders across the public and private sectors of New York City's C&D ecosystem. Participants include individuals working within city agencies, low-carbon material supply chains, and engineering roles focused on circular and low-carbon construction, as well as professionals whose work interfaces with design and construction processes through material provision and technical expertise. These interviews are not intended to represent the full spectrum of actors within the sector, but rather to capture a range of perspectives on the barriers, opportunities, and conditions shaping the adoption of circular construction practices.

These interviews were designed to capture how policies are interpreted and implemented in practice, how decisions around demolition, reuse, and material sourcing are made, and what barriers exist to circular strategic adoption. To synthesize findings across interviews, responses were organized into a structured analytical matrix. This matrix categorizes insights across key themes, including regulatory constraints, economic barriers, data limitations, and opportunities for intervention. This approach allows for systematic comparison across stakeholder groups and helps identify recurring patterns, points of alignment, and areas of divergence between policy intent and industry practice.

The quantitative component of the research is used to ground and validate the patterns identified in the interviews, particularly around how material choices translate into carbon outcomes. Using LCA-informed assumptions about material emissions factors, a combination of ordinary least squares (OLS) and machine learning modeling is used to estimate how variations in material selection and levels



Scaling Circular Construction:
Market Transformation and Embodied Carbon Reduction in New York City

What is being Done?

This section is the Literature Review

Models From Around the World

The literature review helps inform the policy analysis by identifying the regulatory tools, governance models, and implementation challenges documented in other contexts, allowing me to assess how well NYC's policies align with proven practices.

This section is about understanding the global and local policy landscape

Current Status in NYC

According to Official City Documents

This section is the policy analysis portion of the research

This data will reveal the city's existing policy commitments and regulatory tools, allowing the research to assess where strong foundations already exist and where new policies or updates are needed to make circularity feasible.

The policy analysis informs how I will structure and approach my interviews by highlighting the regulatory gaps, implementation challenges, and areas of ambiguity that need deeper explanation, allowing me to ask targeted questions that clarify how policies are actually understood and enacted in practice.

According to City Experts

This section is the interview portion of the research

This data helps distinguish areas of real progress from areas where circularity stalls, clarifying the structural, political, and financing barriers that must be addressed for citywide implementation to be possible.

According to Private Experts

This section is the interview portion of the research

This data exposes the practical, on-the-ground challenges that firms encounter and highlights where market readiness, innovation capacity, or emerging business models could make circularity work at scale.

The qualitative section informs the quantitative section by identifying the policy gaps, market pressures, and implementation challenges that need to be measured at scale, while also clarifying what questions we must ask of the data to understand where barriers to adoption may emerge. Insights from documents and interviews help determine which spatial patterns and economic dynamics matter most, guiding both the structure of the quantitative analysis and the specific metrics needed to answer the core research questions.

This section is about testing the findings from interviews and uncovering viable policy solutions

Quantitative Methods

This section is the ECI Analysis

Analyzing structural systems and lifecycle assessment (LCA) data identifies how embodied carbon varies across materials, building types, and heights. This establishes the baseline relationships between design choices and emissions outcomes.

This section is the viability analysis

Scenario analysis models how changes in policy and market share influence the scale of circular construction and resulting emissions reductions. By linking construction spending with lifecycle carbon intensities, it evaluates how much coordinated demand is needed to make circular systems economically and operationally viable over time.

Reducing embodied carbon in New York City depends on scaling circular construction to a critical market threshold—this research identifies what it takes to get there.

Figure 1.1

of circularity affect embodied carbon at the project and city scale. OLS is used to identify interpretable relationships between variables, while machine learning methods capture more complex, non-linear patterns and assess the relative importance of different factors. Rather than serving as a precise predictive tool, this analysis is used to demonstrate two key points: first, that material choices do have measurable and meaningful impacts on emissions, and second, that there is significant variation across systems, indicating that lower-carbon pathways are both possible and already partially available.

These findings reinforce the central insight from the interviews that cost and project priorities, rather than technical feasibility, are the primary drivers of decision-making among developers, engineers, and contractors. While different materials and construction approaches carry different carbon impacts, they are not consistently selected because they are not consistently accessible or economically competitive. The quantitative analysis therefore establishes the technical feasibility of reducing embodied carbon, while the interviews explain why those reductions are not currently realized in practice. This combined understanding provides the foundation for the scenario analysis, which explores how policy and market interventions can shift these decision-making conditions and make lower-carbon choices more accessible at scale.

The scenario analysis is conducted to evaluate different policy and market pathways for scaling circularity. These scenarios vary key parameters such as public procurement coverage, market adoption rates, and policy intervention levels. The scenario model is used to project potential emissions reductions, material diversion from landfill, and broader system impacts over time. This allows the research to move beyond static analysis and assess how different planning strategies influence long-term outcomes.

Together, these methods form an integrated framework that connects policy, practice, and measurable impact. The qualitative findings identify where and why circular construction is currently constrained, while the quantitative analysis demonstrates what is possible under different conditions of scale and coordination. By combining these approaches, the research is able to move from diagnosis to strategy, providing a clear foundation for the planning implications and recommendations that follow.

IV. Literature Review

International Context: Why Circularity Matters for Climate Goals

Circular construction is not a one-size-fits-all model; its implementation varies significantly across institutional, regulatory, and geographic contexts. At its core, circularity offers a pathway to reduce material demand, extend product lifespans, eliminate unnecessary waste, and shift the built environment away from a linear "take, make, dispose" model toward systems that prioritize reuse, repair, refurbishment, and material recirculation (Ellen MacArthur Foundation, 2013; European Commission, 2020). The adoption of these practices is increasingly recognized as central to reducing carbon emissions across sectors, particularly in the built environment, where material production and construction processes account for a significant share of global emissions (United Nations Environment Programme, 2020; Ellen MacArthur Foundation, 2019).

Examining leading examples from cities such as London, Copenhagen, and Brussels, as well as countries like Australia and Japan, provides critical insight into how different governance structures and market conditions shape the adoption of circular practices. These cases function as real-world test beds, illustrating a range of approaches—from regulatory mandates to procurement strategies and market-building initiatives—that operationalize circularity at scale. Drawing from these examples allows this research to identify transferable mechanisms while avoiding context-specific limitations, ultimately informing the development of a more effective and locally appropriate circular construction framework for New York City.

At the city scale, European municipalities have translated circular economy goals into operational practices within the construction sector through targeted programs and institutional support. In Copenhagen, the municipality has embedded circularity into its procurement and construction processes through tools such as a municipal circular economy handbook, which is incorporated into public project contracts and includes material-specific requirements, pre-demolition resource mapping, and source separation practices to enable the reuse of building components (City of Copenhagen, 2018; Nordic Council of Ministers, 2023).These requirements support practices such as selective demolition—where buildings are carefully dismantled to preserve reusable materials—and are increasingly linked to emerging material exchange platforms and "material banks" that facilitate the circulation of salvaged components across projects (Nordic Council of Ministers, 2023).

In Brussels, circular construction has been advanced through ecosystem-building initiatives such as the Be Circular program, which supports reuse-oriented businesses, alongside organizations like Rotor Deconstruction that dismantle buildings prior to demolition, recover materials, and reintroduce them into the market as usable construction components (Brussels Environment, 2016; Rotor Deconstruction, 2020). By organizing the recovery, storage, and resale of salvaged elements—including doors, fixtures, and architectural materials—Rotor

Deconstruction creates a functional supply chain for reclaimed materials, addressing key barriers related to availability, logistics, and market access that often constrain reuse in construction (Rotor Deconstruction, 2020). Together, these approaches illustrate how cities can move beyond policy commitments to actively support the markets, processes, and infrastructure required for large-scale material reuse.

Developers in London are required to demonstrate how their projects align with circular economy principles through the submission of a Circular Economy Statement, which is mandated for all referable planning applications under the London Plan (Greater London Authority [GLA], 2022a). In parallel, applicants must complete a Whole Life Carbon Assessment in accordance with Policy SI2, using a standardized GLA reporting template that ensures consistent quantification of lifecycle emissions across projects (GLA, 2022b). These documents are expected as part of the formal planning submission process and are often incorporated into local authority validation requirements, meaning that applications may be deemed incomplete without them (GLA, 2022a; City of Westminster, 2023). These requirements compel developers to quantify material flows, assess lifecycle carbon impacts, and demonstrate how design strategies—such as reuse, adaptability, and waste reduction—are integrated into the project from the outset. Collectively, these cases demonstrate how different policy tools—procurement, deconstruction systems, and planning requirements—can be used to shape circular construction practices.

Other regions reinforce the importance of consistent policy frameworks and data systems. Australia's long-term investment in material flow accounting highlights how tracking material inputs, stocks, and waste streams can inform policy and reveal structural dependence on virgin materials (Australian Bureau of Statistics, 2020; CSIRO, 2022). Japan offers a complementary example through its Construction Material Recycling Law, which mandates the separation and recovery of key materials such as concrete, asphalt, and wood. This policy has produced recovery rates above 90 percent for certain materials and demonstrates how clear regulatory expectations and enforcement can normalize material recovery practices at scale (MLIT, 2021). These international examples highlight how progress is already being made to reduce embodied carbon, and how international states and cities are working to end linear practices in the name of delivering a more sustainable future.

The Dutch Model and NYC Implementation

The Dutch model offers one of the most practical and developed examples of circular implementation. Nationally, the Netherlands has committed to a fully circular economy by 2050, outlining a coordinated approach across government, industry, and institutions to keep materials in use and reduce dependence on disposal (Government of the Netherlands, 2016). Amsterdam translates this national vision into city-level implementation, making it a particularly relevant case for New York.

A central feature of the Dutch approach is the prioritization of material value through the "R-ladder," a framework that ranks circular strategies according to their ability to preserve material integrity and reduce environmental impact. At the top of the hierarchy are strategies such as refuse and reduce, which aim to eliminate unnecessary material use altogether, followed by reuse and repair, which extend the lifespan of products while maintaining their highest value. Lower on the ladder are refurbishment and remanufacturing, which retain partial value through transformation, and finally recycling, which is treated as a last resort due to its associated energy use and loss of material quality. This hierarchy reflects a broader shift away from waste management toward value retention, emphasizing the need to minimize primary raw material use and maximize reuse across value chains (Government of the Netherlands, 2016).

Amsterdam operationalizes these principles through public procurement, embedding circular criteria into construction tenders that promote material efficiency, reuse, and lower-carbon design strategies (Dutch Ministry of Infrastructure and the Environment, 2016; Ellen MacArthur Foundation, 2019, 2020). This approach aligns with national policy goals to reduce reliance on primary raw materials and restructure production and consumption systems around reuse and material efficiency (Government of the Netherlands, 2016). In parallel, the Dutch approach emphasizes the importance of data and monitoring systems to track material flows and support more efficient resource use across the economy (Government of the Netherlands, 2016).

Importantly, the Dutch strategy recognizes that the transition to a circular economy is not only technical but cultural. The national program highlights that achieving circularity requires technological, social, and system innovations, as well as shifts in behavior among producers, consumers, and institutions (Government of the Netherlands, 2016). Barriers such as entrenched linear consumption patterns, lack of coordination

across supply chains, and limited awareness of circular business models must be addressed to enable widespread adoption. As a result, the transition depends not only on policy and infrastructure, but on broader cultural change in how materials are valued, used, and recirculated within the economy (Government of the Netherlands, 2016).

While the Dutch circular economy strategy is designed to transform the entire national economy, its application within the construction and demolition (C&D) sector provides one of the most concrete and instructive examples of how these principles are operationalized in practice. In this sector, life cycle assessment (LCA) is institutionalized through a standardized national methodology and the Milieuprestatie Gebouwen (MPG), which requires developers to quantify the environmental impacts of building materials across the full life cycle using data from the Dutch National Environmental Database (Stichting NMD, 2022; Rijksoverheid, 2016). This effectively embeds material impact assessment into both design and permitting processes, ensuring that embodied carbon and resource use are considered alongside cost and performance (Rijksoverheid, 2016). However, it is important to recognize that this system functions as part of a broader, economy-wide transition framework aimed at reducing primary raw material use and promoting circularity across multiple sectors . Within the C&D context, the Dutch approach demonstrates how LCA can move beyond voluntary analysis to become a standardized and enforceable tool for guiding material choices, while also highlighting the limits of sector-specific interventions in achieving full circularity without parallel changes in supply chains, markets, and consumption patterns (Potting et al., 2017; Rijksoverheid, 2016).

Beyond environmental goals, the Dutch strategy frames circularity as an economic and resilience strategy. Reducing reliance on imported raw materials lowers exposure to supply disruptions and price volatility while supporting the growth of domestic reuse and remanufacturing industries (TNO, 2013; Government of the Netherlands, 2016). Construction and demolition are central to this transition, as they account for a significant share of material use, energy consumption, and emissions. At the same time, the Dutch case reveals the limits of circularity in practice. Despite high reported recovery rates, much of the material is still downcycled rather than reused at high value. Barriers such as buildings not designed for disassembly, regulatory constraints, and inconsistent secondary markets continue to limit full circularity. These challenges underscore a key insight: circular systems require not only strong policy signals, but also coordinated design practices, data systems, and market infrastructure.

Lessons From Other Regions

These international examples reveal that successful circular construction systems are not driven by a single policy or intervention, but by the alignment of regulatory frameworks, market infrastructure, and cultural change. London demonstrates the importance of embedding circularity directly into the planning system through mandatory reporting and lifecycle assessment, ensuring that material and carbon considerations shape development decisions from the outset. Copenhagen illustrates how public procurement can be used to operationalize circular practices within municipal projects, while Brussels highlights the critical role of intermediary organizations and reuse markets in addressing logistical and supply chain barriers. At the national scale, Japan shows how clear regulatory mandates can normalize material recovery, and Australia underscores the importance of material flow data in informing policy and identifying systemic inefficiencies. The Netherlands and Amsterdam bring these approaches together, combining policy, procurement, data systems, and cultural transformation into a coordinated strategy that prioritizes value retention over waste management.

The international cases reviewed suggest that circular construction is not achieved through a single intervention, but through the alignment of policy, market infrastructure, and cultural change. However, the extent to which these components can be translated into the New York City context remains uncertain. While regulatory tools, procurement strategies, and reuse markets have each demonstrated effectiveness in different settings, it is unclear how these mechanisms interact within a dense, highly regulated, and market-driven urban environment like New York. This raises a central question for this research: what combination of policy instruments, market structures, and institutional practices is required to enable circular construction in New York City? More specifically, how can regulatory frameworks generate sufficient demand for reused and low-carbon materials, how can markets and supply chains support their availability and reliability, and what cultural or behavioral shifts are necessary among developers, designers, and policymakers to move away from linear construction practices? Rather than assuming that any single model can be directly replicated, this research investigates how these components can be adapted, integrated, and scaled within the specific economic, regulatory, and material conditions of New York City. In doing so, it seeks to identify not only what works in theory, but what is feasible in practice.

Tracking, Digitalization, and Data Infrastructure

Operationalizing circularity and reducing embodied carbon depends on reliable, consistent, and transparent data. Both require the ability to identify what materials exist, how much carbon they contain, where they are located, and whether they can be reused (Costa, F. et al., 2025; Ezrapour, S. et al., 2024; Circular Ecology, 2024; Carbon Leadership Forum, 2021, 2023). Yet the construction sector remains highly under-digitized, with fragmented systems that do not communicate across design, procurement, construction, demolition, and reuse phases (McKinsey Global Institute, 2017; De Wolf et al., 2017). Without shared data infrastructure, materials cannot be recovered at scale, embodied carbon cannot be measured consistently, and policy interventions cannot be verified. For New York City, where millions of tons of materials move through the construction system each year, this represents a major structural constraint. A circular system cannot function without standardized data that is accessible across actors and project phases.

Life Cycle Assessments

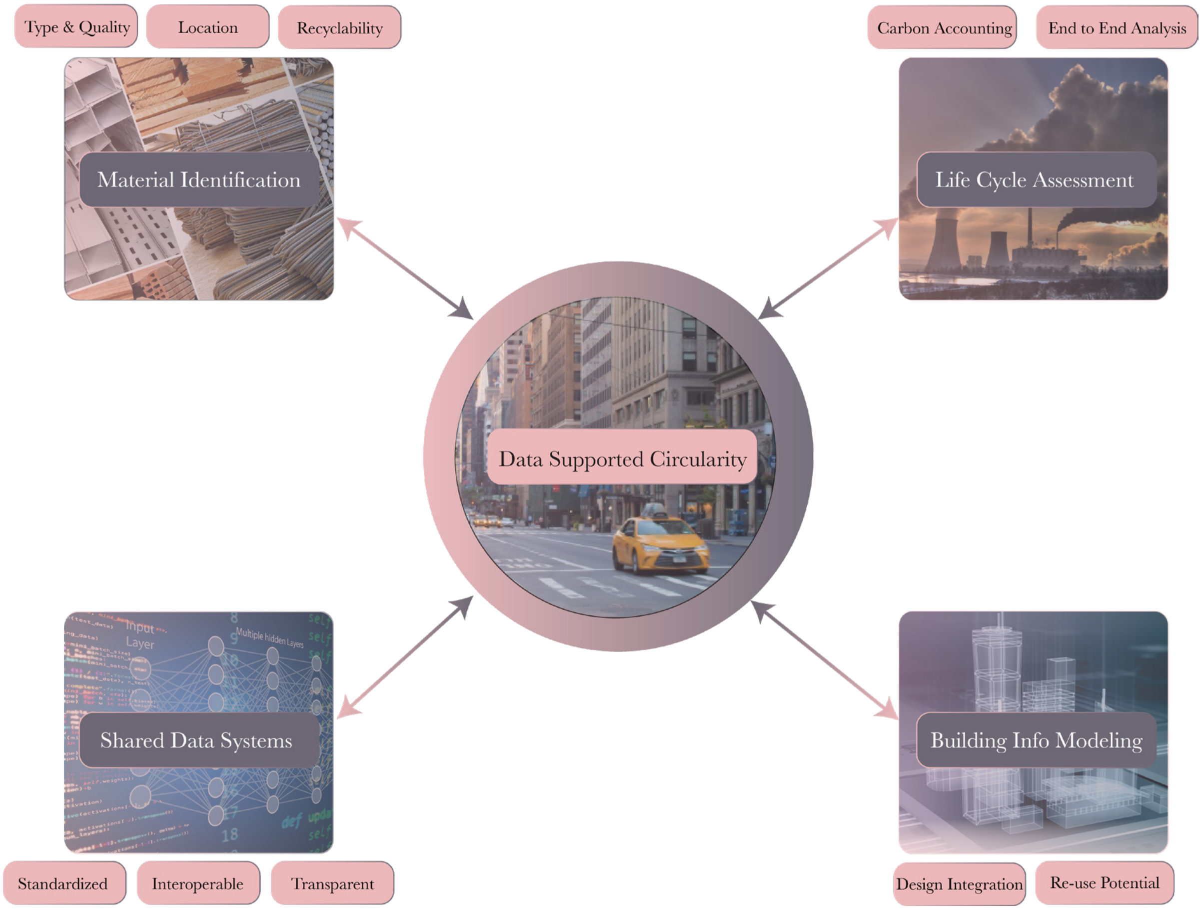
A central challenge in embodied carbon accounting is the lack of consistency in life cycle assessment (LCA) methodologies. Practitioners use different system boundaries, assumptions, and data sources, making results difficult to compare across projects (De Wolf et al., 2017). Many life-cycle assessments exclude or inconsistently account for stages such as transportation, construction, and end-of-life impacts, leading to incomplete estimates. At the same time, embodied carbon is not fixed for any given material, but varies based on production location, energy sources, and supply chain conditions (Environmental Protection Agency, 2022; De Wolf, C. et al., 2017; Carbon Leadership Forum, 2021, 2023; Circular Ecology, 2024). Identical materials can differ significantly in carbon intensity depending on where and when they are produced (Zhang et al., 2024). As a result, transparency and consistent reporting must be established not only within the city's construction system, but across the broader supply chains that extend beyond local, state, and national boundaries.

Existing research shows that LCA results are often difficult to compare due to inconsistent methodologies, fragmented datasets, and a lack of harmonized reporting frameworks (Soust-Verdaguer et al., 2017; Pomponi & Moncaster, 2017). In addition, incomplete system boundaries and missing data can lead to underestimation of total lifecycle impacts, particularly when upstream and downstream processes are excluded (National Institute of Standards and Technology [NIST], 2022). Variability in production conditions—including geographic location, energy sources, and timing—further contributes to differences in embodied carbon outcomes for otherwise similar materials (Zhang et al., 2024). Addressing these challenges requires not only standardized methodologies, but also robust verification mechanisms and shared data systems capable of producing comparable, reliable, and actionable embodied carbon assessments.

Building Information Management Systems

Digital tools offer pathways to address these challenges, particularly at the design stage. Building Information Modeling (BIM), when integrated with lifecycle assessment, allows teams to evaluate embodied carbon early in the design process, when decisions about structure and materials are most impactful (Myint, 2018; De Wolf et al., 2017). This shifts carbon accounting from a retrospective exercise to a design parameter, enabling comparison across material and structural options before construction begins (Dewagoda et al., 2024). Material passports extend this capability by providing structured information on material composition, performance, and reuse potential across a building's lifecycle (Costa et al., 2025). Modular and parametric design approaches further support circularity by standardizing components and enabling future disassembly and reuse. These tools demonstrate that the technical capacity to track and reduce embodied carbon already exists.

Despite these advances, the literature consistently shows that the primary barrier is not a lack of tools, but a lack of integration (Ezrapour, S. et al., 2024; Markou, E. et al., 2025; Costa, F. et al., 2025; Myint, S. E., 2018). Digital systems, including BIM platforms, material databases, tracking systems, and certification tools, often operate in isolation, using incompatible formats and standards (Markou et al., 2025). This fragmentation leads to a loss of material information across project phases,



particularly at the point of demolition and reuse, where circular systems depend most on accurate data. As a result, materials that could be recovered are instead treated as waste. For New York City, this highlights a central challenge: circular construction requires coordinated data infrastructure, not just new technologies. Standardization, interoperability, and institutional alignment are necessary to ensure that material information can move across actors and phases of the building lifecycle. Without this level of integration, digital tools remain limited in their ability to support circular material flows.

Design and Structural System Choice for Circular Construction

Circularity begins with design. The way buildings are assembled determines whether materials can be recovered or whether they become waste. When components are fused, cast in place, or embedded within composite systems, they are effectively locked into a single and linear lifecycle (Ottenhaus, L., 2022; Dunant, C. F. et al., 2018; Pomponi, F. & Moncaster, A., 2017). When connections are reversible and assemblies are standardized, materials can move through multiple building cycles (Ottenhaus, 2022; Sakthibala et al., 2020). Research consistently shows that construction and demolition waste is largely shaped by design decisions rather than being an unavoidable byproduct of building activity (Dunant, C. F. et al., 2018; Ottenhaus, L., 2022; Ezrapour, S. et al., 2024; Circular Ecology, 2024). Non-standard components, inaccessible connections, and proprietary systems make material recovery impractical, often turning renovation into demolition. In contrast, design strategies that prioritize modularity, accessibility, and standardization enable reuse and reduce waste (Dunant, C. F. et al., 2018; Ottenhaus, L., 2022; Dewagoda, K. et al., 2024).

Structural systems play a decisive role in determining both embodied carbon and reuse potential because they govern the quantity, type, and configuration of materials within a building. Research shows that structural elements account for the majority of a building's embodied carbon, meaning that early-stage decisions about structural form and material efficiency have the greatest potential to reduce overall emissions (Arup, 2023). Strategies such as minimizing material quantities, optimizing structural form, and selecting lower-carbon materials directly reduce embodied impacts by lowering both the volume of material used and the carbon intensity per unit of material (Arup, 2023).

Simultaneously, the way structural systems are assembled determines whether these materials can be recovered in the future (Ottenhaus, L., 2022; Dunant, C. F. et al., 2018; Pomponi, F. & Moncaster, A., 2017). Systems that rely on monolithic construction or chemically bonded materials—such as cast-in-place concrete—tend to prevent separation and reuse, while systems that use discrete elements and mechanical connections enable disassembly and reuse of structural components across multiple lifecycles (Vale, 2017). In addition, the carbon intensity of structural materials varies significantly depending on production processes, supply chains, and material composition, meaning that identical structural systems can have substantially different environmental impacts depending on how and where materials are sourced (Vale, 2017). Together, these factors position structural design as a primary mechanism through which both embodied carbon reductions and circular material flows can be achieved. This relationship will be further tested through empirical analysis using an ordinary least squares (OLS) regression applied to life cycle assessment (LCA) data.

Materials: Strategies, Carbon Intensity, Reuse Potential, and Engineering Constraints

Material choice is central to embodied carbon. Before a building is ever occupied, a large share of its lifecycle emissions is already determined through decisions about structure, framing systems, cladding, and finishes (Myint & Shafique, 2024). Unlike operational emissions, which can be reduced over time, embodied carbon is largely fixed at the point of material production. For a city like New York, which relies heavily on imported, energy-intensive materials, these upstream emissions are particularly significant. As a result, reducing embodied carbon requires more than substituting individual materials. It requires rethinking how materials are selected, used, and managed across the building lifecycle.

While earlier sections have highlighted the challenges associated with inconsistent lifecycle assessment methods and fragmented data systems, these limitations directly affect how materials are selected in practice. In New York City, designers and developers are often required to make low-carbon material decisions without access to fully comparable or complete information. As a result, reducing embodied carbon requires not only better materials, but a shift in how materials are evaluated, selected, and managed across the building lifecycle.

Concrete remains the dominant source of embodied carbon in most buildings due to the energy-intensive nature of cement production. Research identifies several strategies for reducing its impact, including clinker substitution, improved mix design, and structural optimization (ARUP, 2021; Scrivener et al., 2018). However, adoption remains uneven, largely due to a lack of standardization and consistent procurement signals. In New York, where high-rise construction relies heavily on reinforced concrete, this represents a significant opportunity for emissions reduction. At the same time, concrete presents challenges for circularity. Reinforced systems are difficult to disassemble, and demolition typically results in downcycled aggregate rather than reusable components. These constraints highlight the importance of both material substitution and design strategies that reduce material use or enable future recovery.

New York's existing building stock contains large quantities of reusable materials, including structural steel, heavy timber, masonry, and architectural components. However, much of this material is lost during demolition due to time constraints, limited deconstruction practices, and a lack of storage and resale infrastructure. The literature on urban material banks emphasizes that cities should treat buildings as long-term resource reservoirs rather than waste streams (Jawanrudi et al., 2021). Reusing these materials reduces the need for new extraction, preserves embedded carbon, and supports the development of secondary markets. Without systems to recover and redistribute these materials, significant environmental and economic value is lost.

Research shows that many low-carbon materials are technically viable but require different design approaches and regulatory support. Engineered timber and other alternative materials can meet structural demands but depend on updated building codes, testing standards, and design workflows (Ottenhaus, 2022; Manandhar et al., 2019). Across studies, the primary barriers to adoption are not technical but institutional, including regulatory constraints, fragmented supply chains, and limited market demand. This reinforces a central theme of the literature: advancing low-carbon construction depends as much on policy, coordination, and market conditions as it does on material innovation.

Materials, Reuse, and Circular Potential

Biobased materials offer a unique opportunity to reduce emissions while introducing regenerative processes into the construction system. Timber and other renewable materials store carbon during growth and retain it throughout their use, meaning their climate impact depends on how they are sourced, used, and reused across building cycles (Manandhar et al., 2019; Vale, 2017). For a city like New York, which relies heavily on carbon-intensive imported materials, these materials provide a pathway to reduce embodied emissions while diversifying the city's material base.

The benefits of these materials are significantly amplified through reuse. Reclaimed timber avoids emissions associated with extraction, processing, and transport while extending the duration of carbon storage. Research shows that when materials are reused across multiple lifecycles, both carbon storage and

avoided emissions compound over time (Souaid et al., 2024; Falk & McKeever, 2004). This principle is captured in the concept of cascading utilization, where materials are kept in high-value use for as long as possible before being downcycled or discarded.

For New York, this has immediate relevance. The city discards large volumes of structurally viable materials during demolition, including high-quality timber, steel, and masonry. Without systems for deconstruction, storage, and redistribution, this material is lost. Treating the built environment as a material reservoir rather than a waste stream would reduce emissions, extend material lifespans, and support the development of secondary markets.

At the same time, the literature makes clear that material substitution alone is not sufficient. While low-carbon and renewable materials are technically viable, their adoption depends on regulatory alignment, market demand, and supply chain coordination. Without these conditions, material innovation remains limited in scale.

Carbon Impacts and Research Gap

The literature provides strong evidence that circular material strategies can significantly reduce embodied carbon. Life cycle assessment studies show that substituting reused or recycled materials for newly manufactured products can substantially lower emissions by avoiding extraction, production, and disposal processes (Papadaki et al., 2022). At the material level, reuse offers particularly high potential. Reusing structural steel, for example, avoids the energy-intensive remelting process required for recycling and can significantly reduce embodied emissions (Dunant et al., 2018). At the building scale, research shows that a small number of material categories—primarily concrete, steel, and wood—account for the majority of embodied carbon, making them key targets for intervention (Benke et al., 2025). Strategies that reduce material demand, extend material lifespans, or substitute lower-carbon alternatives therefore represent some of the most effective pathways for emissions reduction.

However, these benefits are not realized at scale. The literature consistently highlights that the primary barriers are not technical, but structural. Weak data systems, fragmented supply chains, limited reuse markets, and inconsistent policy frameworks prevent circular strategies from moving beyond isolated applications. This gap is particularly pronounced in New York City. While international examples demonstrate the potential of circular construction, there is limited understanding of how these strategies can function within New York's regulatory environment, development patterns, and construction systems. This thesis addresses that gap by combining qualitative and quantitative analysis to identify where circularity can realistically take hold and what changes are required to support it. In doing so, it moves from general theory to a place-specific understanding of how circular construction can be implemented at scale.

V. Policy Review

New York's progress in tackling climate change and its transition away from carbon intensive practices spans a wide range of policy. A framework for circular practices, lower-carbon material selection, and reducing an exponentially growing waste stream is beginning to emerge across multiple policy instruments, rather than being driven by any single intervention.

Circularity, and by extension embodied carbon reduction, sits at the intersection of three overlapping policy domains:

(1) climate mitigation mandates,

(2) solid waste and materials management reform, and

(3) economic development strategy.

While these policies do not explicitly establish circular economy targets, they collectively signal a shift toward outcomes aligned with circularity.

New York State

Solid Waste Management Plan and Extended Producer Responsibility

The 2023 New York State Solid Waste Management Plan establishes a formal transition toward a system more equipped to close the loop on the current linear model. The Plan, though not specific to the construction and demolition (C&D) industry and not explicitly naming circularity as its goal, sets a long-term vision of reducing landfilling and combustion by 85 percent by 2050 and frames materials management as a climate strategy aligned with the Climate Leadership and Community Protection Act (CLCPA) (New York State Department of Environmental Conservation [NYSDEC], 2023). The Plan emphasizes reuse, repair, remanufacturing, and market development, and calls for legislative action.

The State Plan identifies extended producer responsibility (EPR) as a key policy mechanism within this framework. Under EPR, producers are required to finance and manage the end-of-life collection and processing of covered products, typically through Producer Responsibility Organizations (PROs). EPR is an important step toward establishing a circular system because it internalizes environmental costs by holding producers accountable for the full lifecycle of their products, from design through disposal, which in turn incentivizes more sustainable production and waste management practices (Tong et al., 2024). It also shifts responsibility for waste away from governments and consumers and back onto producers, where decisions about materials and design are made (Tong et al., 2024). Currently, New York State requirements apply only to a limited set of product categories and are not directly related to core C&D materials. The State Plan also does not regulate building design or material specification, instead focusing primarily on end-of-life waste management.

Environmental Product Declarations are central to this framework, providing standardized, third-party verified lifecycle assessment data for construction materials. By introducing comparability across products with similar structural performance, EPDs enable procurement decisions based on carbon intensity rather than cost alone. For circular construction, this data is critical: determining whether reuse, recycling, or material substitution reduces emissions depends on consistent lifecycle accounting. However, uneven EPD coverage across material categories introduces uncertainty into benchmarking and limits their immediate regulatory application (Carbon Leadership Forum, 2023).

Embodied Carbon Approach

New York State's approach to embodied carbon exists within the broader framework of the Climate Leadership and Community Protection Act (CLCPA). Enacted in 2019, the CLCPA mandates an 85 percent reduction in statewide greenhouse gas emissions by 2050 and establishes legally binding decarbonization targets across all sectors of the economy (New York State Climate Leadership and Community Protection Act, 2019). The statute does not distinguish between operational and embodied emissions, nor does it prescribe how reductions within the building and construction sector must occur. As a result, while the law creates a binding obligation to reduce economy-wide emissions, it leaves unresolved the regulatory treatment of emissions embedded in construction materials such as concrete, steel, aluminum, and insulation.

To date, most implementation under the CLCPA has focused on operational energy performance, leaving embodied carbon comparatively under-addressed in statute and regulation (New York State Climate Action Council, 2022). This emphasis reflects a broader reliance on downstream decarbonization strategies, which primarily target energy consumption and emissions after they occur, rather than upstream interventions that shape material production, design, and lifecycle management. As a result, emissions associated with material extraction, manufacturing, and disposal remain largely outside the scope of enforceable policy, reinforcing a regulatory gap between economy-wide climate targets and the systems through which those emissions are generated.

In addition, downstream approaches tend to concentrate costs at the point of energy consumption, placing responsibility on building owners and occupants after emissions have already been embedded in the system. In contrast, upstream interventions distribute responsibility across producers, supply chains, and early-stage design decisions, allowing emissions to be addressed closer to their source. More importantly, they create the potential to reduce total carbon consumption by reshaping how materials are produced and used, rather than simply managing emissions after they have already occurred.

It is important to note as well that recent political debate surrounding the implementation of the CLCPA further underscores the fragility of this approach. Proposals from the administration of Kathy Hochul to delay or modify elements of

the law, particularly in response to projected energy cost increases and affordability concerns, have raised questions about the State's ability to meet its long-term decarbonization targets (Politico, 2026; The City, 2026; New York State Focus, 2026; City & State, 2026).

While these debates are primarily centered on the cost and pace of electrification and energy system transformation, emerging analysis suggests that climate policy does not inherently increase household costs. Research indicates that well-designed policies, such as cap-and-invest systems, can offset or even exceed cost increases through mechanisms like revenue redistribution and lower long-term operating costs associated with electrification (Resources for the Future, 2025). However, these outcomes depend on complex policy design, sustained public investment, and widespread adoption of new technologies. In contrast, upstream interventions in material systems, such as circular construction, material reuse, and low-carbon procurement, offer pathways to emissions reduction that do not rely on consumer behavior or energy system transformation, thereby reducing both political and economic risk in achieving long-term climate targets.

Recognizing the gap in addressing material-based emissions, New York State convened an Embodied Carbon Working Group in 2025 to develop near-term policy recommendations aimed at integrating embodied carbon into the State's climate strategy. Rather than immediately imposing carbon intensity limits, the Working Group prioritized the development of measurement and disclosure infrastructure as a prerequisite to regulation (New York State Embodied Carbon Working Group, 2025). The report calls for requiring embodied carbon reporting in state-funded construction projects, expanding and standardizing Environmental Product Declaration (EPD) use, establishing baseline benchmarks for high-impact materials, and aligning procurement practices with lower-carbon alternatives (New York State Embodied Carbon Working Group, 2025).

This sequencing reflects a deliberate strategy. It focuses on establishing consistent data and methodologies before imposing enforceable limits. Importantly, while the Working Group advances harmonized reporting and disclosure, it does not mandate specific lifecycle assessment tools, system boundaries, databases, or carbon intensity thresholds. This falls short of establishing fully integrated data systems and cross-agency coordination needed to support enforceable standards. As a result, New York remains in a measurement-building phase rather than a fully standardized regulatory phase (New York State Embodied Carbon Working Group, 2025).

New York State's Executive Order 22 (EO 22) introduces embodied carbon into public procurement by requiring state agencies to measure and disclose the lifecycle emissions associated with key construction materials in major capital projects. Rather than setting immediate limits, EO 22 focuses on building the data infrastructure necessary for future regulation. Design teams must calculate project-level embodied carbon using life cycle assessment (LCA), and contractors are required to submit Environmental Product Declarations (EPDs) to quantify material-level impacts (New York State Office of General Services [NYS OGS], 2025). The policy targets high-impact materials such as concrete, steel, asphalt, and glass, and applies to projects over $1 million, effectively embedding carbon accounting into the procurement process at scale (NYS OGS, 2025). However, EO 22 does not explicitly incorporate circular construction strategies, such as material reuse or design for disassembly, as mechanisms for reducing embodied carbon.

Procurement and Market Shaping

New York State has proposed the Sustainable Building Materials Act, which represents a potential next phase in this policy trajectory. The legislation seeks to reduce greenhouse gas emissions associated with construction materials by aligning state purchasing power with lower-carbon production and supporting manufacturers in developing Environmental Product Declarations (EPDs) and lifecycle transparency. The bill identifies public procurement and financial incentives as key mechanisms for accelerating market adoption while supporting in-state industry development (New York State Senate [NYS Senate], 2025). While still emerging, the proposal signals a shift beyond disclosure toward more performance-oriented policy. By coupling procurement reform with economic incentives for low-carbon material production, the Act begins to formalize a "Buy Clean"–style framework in New York. If enacted, it would mark a transition from reporting embodied carbon to conditioning market access on carbon performance.

From Measurement to Market Intervention

Together, EO 22 and the proposed Sustainable Building Materials Act illustrate an emerging policy trajectory in New York that moves from measurement toward market intervention. EO 22 However, establishes the foundation by requiring lifecycle carbon accounting and material-level disclosure, making embodied carbon visible within public procurement processes. The Sustainable Building Materials Act builds on this by introducing financial incentives and procurement alignment mechanisms that begin to reward lower-carbon material production. However, both policies remain focused on material substitution rather than material circulation. Importantly, they prioritize reducing the carbon intensity of new materials but do not yet address how existing materials can be retained, reused, or recirculated within the built environment. The state level waste management plan sets the stage for this to become possible. That said, a significant opportunity remains unaddressed: reducing embodied carbon not only through cleaner production, but through extending material lifecycles and minimizing the need for new material extraction altogether. This gap highlights the need for policy frameworks that treat buildings as material systems and integrate circular construction strategies, such as adaptive reuse, deconstruction, and material recovery, into climate-oriented procurement and planning.

New York State's embodied carbon policy landscape remains in an infrastructural phase. As a result, the regulatory framework remains incomplete, and the extent to which the State's climate commitments extend to material systems in the built environment or circularity as a whole will depend on its ability to transition from measurement to performance-based regulation.

New York City

Embodied Carbon

Shifting to this research's primary study area, New York City's embodied carbon policy operates primarily through procurement rather than comprehensive building code reform. This means that rather than imposing enforceable, system-wide requirements on all construction, the City relies on its role as a purchaser to influence carbon outcomes, leaving privately funded projects largely unaffected. EO 23 applies selectively to City-funded capital projects, primarily those involving building construction and major renovations, meaning that even within public spending, its coverage is partial and excludes significant portions of infrastructure investment. This positions public procurement as a mechanism for influencing material specifications and supply chains (City of New York, 2023). The Order requires agencies to measure and report embodied carbon in key construction materials and to consider lower-carbon alternatives where feasible (City of New York, 2023). The mechanism is straightforward: the City, as purchaser, sets material performance expectations for its own projects. However, the policy does not mandate specific material substitutions, for example low carbon concrete or steel, or enforce emissions limits, meaning its impact depends largely on how project teams respond to these requirements rather than on binding performance standards.

In practice, EO 23 functions by embedding disclosure and material specifications into capital project procurement. It establishes enforceable reporting requirements for materials such as concrete and structural steel, including the submission of product-specific Environmental Product Declarations (EPDs) to the Building Transparency database (City of New York, 2022). By requiring both measurement and documentation, the policy increases transparency in material sourcing and begins to shape supplier behavior, without mandating material substitution toward lower-carbon alternatives or introducing formal changes to zoning, permitting, or the building code. Although EO 23 requires project-level analysis and comparison of embodied carbon outcomes, these requirements are implemented through procurement rather than binding performance standards. As a result, the policy's reach is inherently limited to the scale of public capital investment. Therefore, the degree of the policy's impact is dependent on how much of the construction market comprises public procurement projects that fall within EO 23's requirements.

Circularity

In parallel with its embodied carbon initiatives, New York City has begun to advance circular construction through economic development and planning frameworks rather than binding regulation. In 2024, the New York City Economic Development Corporation (NYCEDC) released the Circular Design & Construction Guidelines alongside the Green Economy Action Plan, positioning material reuse, deconstruction, and low-carbon construction as emerging sectors within the city's broader climate and economic strategy (NYCEDC, 2024a; NYCEDC, 2024b).

The Circular Design & Construction Guidelines provide project-level recommendations for incorporating circular practices into development, including pre-demolition material audits, selective deconstruction, and design-for-disassembly strategies. While not codified into law, these guidelines are designed to influence projects developed on public land or through public-private partnerships. Because NYCEDC controls long-term ground leases and Requests for Proposals (RFP) processes, it can require or incentivize circular design practices within these agreements, using development authority as a lever to shape both markets and urban material flows. When circular requirements are embedded into RFPs or ground leases, they become contractually binding for those projects. This governance approach operates at the predevelopment and negotiation stage, conditioning participation in publicly controlled projects on alignment with circular principles.

The Green Economy Action Plan complements this approach by framing circular construction as a driver of workforce development, local supply chain expansion, and industrial growth, linking material recovery and reuse to job creation and economic resilience. The Plan projects that New York City's green economy could grow to nearly 400,000 jobs and $89 billion in annual economic output by 2040, with the buildings and construction sector already comprising roughly half of this activity (New York City Economic Development Corporation [NYCEDC], 2024). Much of this growth is expected to come from the transformation of existing construction occupations, supported by investments in workforce training, apprenticeship programs, and new industrial infrastructure (NYCEDC, 2024). In parallel, the City is investing in innovation ecosystems and supply chain development to support emerging climate industries, including construction materials and building technologies, through initiatives such as the Harbor Climate Collaborative and the Climate Innovation Hub (NYCEDC, 2024). Together, these efforts position circular construction not only as an environmental strategy, but as a mechanism for economic development, job creation, and long-term market formation.

However, while these frameworks identify material recovery and reuse as economic opportunities, they do not yet establish the market infrastructure or regulatory requirements necessary to scale these activities across the construction sector. Rather than mandating sector-wide change, current approaches rely on project-specific implementation, leaving circular construction uneven and dependent on individual development contexts.

The policy landscape reflects a coordinated but ultimately indirect strategy. State and city climate mandates, including the Climate Leadership and Community Protection Act (CLCPA) and New York City's Climate Mobilization Act (particularly Local Law 97), establish legally binding emissions reduction targets and define the broader decarbonization trajectory. State waste policy articulates a circular vision and legislative pathway, including mechanisms such as extended producer responsibility. At the same time, city-level procurement and development agencies operationalize embodied carbon and circularity through project-based interventions, using public capital and land-use authority to influence design and material selection. These policies begin to define the contours of a circular construction system. However, they remain fragmented across scales and functions, and do not yet constitute a comprehensive regulatory framework. Most notably, there is no integrated approach that links material production, building design, digital data systems, and end-of-life recovery within a single governance structure. As a result, circular construction remains dependent on indirect incentives and project-specific implementation, rather than being embedded as a consistent requirement across the broader construction market, particularly within private development.

Digital Governance In New York

New York City has formalized the use of Building Information Modeling (BIM) through the New York City Department of Design and Construction (DDC) BIM Guidelines, first issued in 2012 as part of its public capital project delivery framework (NYC Department of Design and Construction [DDC], 2012). These guidelines apply specifically to City-managed capital projects delivered by DDC, rather than to all construction activity within New York City. Within this scope, BIM is required on public building projects and embedded directly into procurement and project delivery. In practice, this means that teams are required to develop coordinated digital models across all phases of a city managed project. The guidelines set clear standards for how these models are built and managed, including defined Levels of Development (LOD 100–500), the use of classification systems such as Uniformat and OmniClass, and coordinated multi-disciplinary modeling processes (DDC, 2012).

Uniformat and OmniClass organize building elements at both the system and component level, allowing materials and assemblies to be categorized consistently within BIM models. Coordinated modeling means that architects, engineers, and contractors are working within a shared digital environment rather than in separate drawings. Together, this produces a structured and interoperable dataset that describes building components across the project lifecycle. BIM models are also required as formal deliverables at key project milestones and must be submitted as detailed as-built "record models" at project completion to support long-term asset management (DDC, 2012).

This regulatory framework is significant because it requires the creation of structured, digital representations of buildings across their lifecycle, including detailed information on building systems, quantities, and spatial organization. In doing so, it establishes a technical foundation for tracking materials, integrating lifecycle data, and supporting embodied carbon analysis. However, while the guidelines ensure the production of standardized digital models, they do not require the integration of embodied carbon metrics, material reuse classifications, or lifecycle tracking systems, limiting their role in enabling circular construction at scale. In practice, this means that New York City mandates the creation of structured digital building data within a subset of publicly managed projects, while the broader construction sector remains far more fragmented.

From a circular construction perspective, this represents a significant institutional foundation within publicly managed projects. Circularity depends on identifying materials, quantifying them accurately, and maintaining that information across a building's lifecycle (De Wolf et al., 2017; McKinsey Global Institute, 2017). BIM platforms are capable of embedding Environmental Product Declaration (EPD) data, linking building elements to verified emission factors, and automating quantity takeoffs for life-cycle assessment (Myint, 2018; Dewagoda et al., 2024). In this sense, the city's BIM mandate already provides much of the technical architecture needed to support embodied carbon accounting and material tracking within project workflows.

However, this infrastructure currently operates at the project level and is not structured to function as a continuous, system-wide data platform. Once delivered, BIM models primarily function as archived records rather than as living, continuously updated datasets. They are not integrated into public material inventories, carbon reporting platforms, or deconstruction planning tools, nor are they designed to update as materials are replaced or removed over time. This reflects a broader disconnect identified in the literature: interoperable material passports, dynamic datasets, and lifecycle tracking systems are widely recognized as essential to circular construction (Costa et al., 2025; Markou et al., 2025), yet remain largely absent in practice.

As a result, New York's BIM regulations ensure the existence of detailed digital building models without requiring that those models function as material traceability systems. The regulatory infrastructure for digital modeling exists, but it is not designed to operate beyond individual projects or across the broader construction market. What is missing is a mandate to embed carbon data, reuse classifications, and disassembly information directly into BIM objects in a way that is standardized, updatable, and accessible across actors. Without this level of integration, data remain fragmented, limiting market-wide visibility and constraining the development of secondary material markets (McKinsey Global Institute, 2017; De Wolf et al., 2017). In this configuration, BIM operates primarily as a coordination and design tool rather than as a persistent, interoperable platform for material governance.

Material Specific Regulations In New York

Embodied carbon governance in New York operates differently depending on the material in question, with distinct regulatory approaches shaping how materials are measured, specified, and deployed in practice (New York State Office of General Services [OGS], 2023; Mayor's Office of Climate and Environmental Justice [MOCEJ], 2024; New York City Building Code, 2022). The following sections examine how these frameworks apply to key construction materials, highlighting how procurement standards, lifecycle modeling requirements, and building code constraints interact at the material level.

Concrete: Procurement-Based Carbon Limits

Under the New York State Buy Clean Concrete Guidelines, embodied carbon is addressed through public procurement by establishing maximum allowable Global Warming Potential (GWP) thresholds for concrete used in state-funded projects (New York State Office of General Services [OGS], 2023). Implemented through State Finance Law §136-d, the policy requires contractors, beginning January 1, 2025, to submit third-party verified Environmental Product Declarations (EPDs) for concrete mixes and demonstrate that emissions fall below state-defined thresholds. These thresholds are structured by compressive strength, recognizing that higher-strength concrete typically requires greater cement content and therefore results in higher embodied carbon.

By tying carbon limits to strength categories, the policy functions as a procurement-based screen that constrains the carbon intensity of materials without prescribing specific mix designs.

Specified compressive strength (f'c in PSI)	NYS Buy Clean Concrete GWP Limits (in kilograms of carbon dioxide equivalent per cubic yard - kg-CO2e/y3)	NYS Buy Clean Concrete GWP Limits (in kilograms of carbon dioxide equivalent per cubic meter - kg-CO2e/m3)
0 - 2500	275	360
2501 - 3000	360	471
4001 - 5000	434	568
5001 - 6000	458	599
6001 - 8000	541	707

This preserves flexibility in how contractors meet the requirements while still pushing the market toward lower-carbon production. This approach is significant because it shifts embodied carbon from a largely voluntary consideration to a binding constraint within state-funded procurement. By aligning carbon limits with existing engineering and procurement practices, the policy enables emissions reductions without fundamentally altering how materials are specified, while leveraging public purchasing power to influence supply chains.

However, because these limits apply only to the carbon intensity of new materials and are limited to life cycle stages A1–A3, raw material extraction, transport to manufacturing, and production, they do not account for construction, use-phase, or end-of-life impacts (OGS, 2023). As a result, the policy does not address material

demand, reuse, or broader lifecycle strategies, functioning primarily as a cap on upstream emissions rather than a full lifecycle accountability framework.

Unlike New York State, which regulates the carbon intensity of concrete through procurement thresholds, New York City does not currently maintain a material-specific policy governing embodied carbon in concrete. While embodied carbon is addressed at the project level through broader lifecycle modeling requirements, there are no binding citywide standards that set maximum allowable emissions for specific material categories. In practice, this means that material-level carbon intensity is regulated upstream through state procurement, while decisions around material use, system selection, and overall carbon outcomes remain project-dependent at the city level. As a result, embodied carbon governance operates across two distinct but only partially aligned scales: state-level material regulation and city-level project evaluation.

Wood: Code Constraints and Carbon Accounting

While concrete is regulated by the State through carbon-focused procurement policy, wood is governed primarily through structural and fire safety provisions in the New York City Building Code (New York City Building Code, 2022, Chapter 23). Chapter 23 of the code establishes allowable construction types, height and area limitations, fire-resistance requirements, and detailing standards for wood and mass timber systems, determining where timber can be deployed structurally and under what conditions within New York City.

Recent updates aligned with the 2022 code cycle expand allowances for certain mass timber construction types under specified fire-resistance and encapsulation requirements (New York City Building Code, 2022, Chapter 23). However, timber use remains contingent on occupancy classifications, structural span requirements, and building height limits, constraining where and how it can be applied in practice. These safety-based constraints directly influence the feasibility of substituting timber for reinforced concrete or steel systems by impacting timelines and associated cost. From an embodied carbon perspective, this regulatory structure has important implications. While Executive Order 23 encourages early-stage evaluation of structural alternatives to reduce embodied carbon (Mayor's Office of Climate & Environmental Justice [MOCEJ], 2024), the building code governs material eligibility based on structural performance rather than carbon intensity.

A substantial body of literature finds that timber systems can reduce upfront embodied carbon relative to conventional concrete and steel construction, though these results are often based on controlled comparisons that isolate material substitution effects (Pomponi & Moncaster, 2017; Souaid et al., 2024). In practice, however, this relationship is more variable. The analysis conducted in this study does not identify a consistent reduction in embodied carbon associated with timber systems across the sample, which includes a wide range of building types, heights, and structural conditions. This suggests that observed carbon outcomes are highly dependent on building scale, structural requirements, and design decisions, rather than material selection alone.

Timber systems also introduce additional considerations not captured in conventional A1–A3 comparisons. Unlike concrete, which is emissions-intensive during production, timber can store biogenic carbon absorbed during tree growth, effectively acting as a temporary carbon sink over the building lifecycle (Intergovernmental Panel on Climate Change [IPCC], 2022). At the same time, timber components are generally more compatible with disassembly and reuse due to their lighter weight and mechanical connections, whereas reinforced concrete systems, heavily used within C&D in New York City, are typically cast in place and difficult to recover without degradation (Pomponi & Moncaster, 2017). However, the extent to which these benefits are realized depends on end-of-life scenarios, reuse infrastructure, and design decisions, reinforcing the importance of considering full lifecycle dynamics rather than material substitution alone.

EO 23 guidance also treats biogenic carbon reporting cautiously. Projects may report emissions and benefits from biogenic carbon separately from the primary embodied carbon calculation, but such reporting is optional and must be disclosed independently (MOCEJ, 2024). This reflects a conservative accounting approach that does not equate stored biogenic carbon with verified emissions reductions in the primary compliance metric. Taken together, these findings suggest that while timber can play a meaningful role in reducing embodied carbon, its impact depends on how it is deployed within structural systems and lifecycle strategies, and that current building code constraints limit the extent to which these system-level benefits can be realized in practice.

Overall Findings and Conclusion

Embodied Carbon Policy Combined Effect

The comparison of New York State's Buy Clean framework and New York City's Executive Order 23 reveals a complementary but incomplete approach to embodied carbon governance. At a high level, the two policies operate at different but interrelated scales. State-level policy influences material supply through public procurement, establishing carbon intensity limits for specific materials such as concrete. At the city level, EO 23 operates at the project scale, requiring lifecycle assessment and emissions reduction across entire building systems, thereby shaping how materials are selected and used in design. Together, this creates a dual structure in which both material production and project-level decision-making are addressed, but through separate and only partially aligned mechanisms. Importantly, both policies apply only to publicly funded or publicly controlled projects at the state and city level, respectively, and therefore do not typically operate on the same projects or extend to the majority of private construction activity in New York City.

This division of roles produces a number of important synergies. Buy Clean establishes minimum carbon performance standards for materials entering the market, effectively shifting what is available to designers and contractors. EO 23 builds on this by requiring project teams to evaluate and reduce embodied carbon at the building scale, influencing how those materials are selected, combined, and deployed. In this sense, the policies align material and structural choice: the State shapes the carbon intensity of materials, while the City shapes how those materials are used. This interaction has the potential to create a reinforcing feedback loop, where cleaner materials enable lower-carbon design outcomes, and project-level demand further incentivizes low-carbon production.

However, this alignment is partial rather than fully integrated. The two policies operate in parallel, with limited coordination between material-level thresholds and project-level decision-making processes. Data generated through EPDs is not yet systematically integrated into LCA workflows or digital modeling systems. Existing research identifies significant interoperability and standardization challenges in linking EPD data to BIM and LCA platforms, often requiring manual interpretation and limiting automated data exchange (Aragón et al., 2024; Almeida et al., 2023). As a result, while material-level carbon data is increasingly available, it does not function as a seamless or continuous dataset across project workflows, constraining its ability to support coordinated decision-making at the building scale. As a result, carbon information is produced at multiple stages but does not function as a continuous, interoperable dataset across the building lifecycle. This fragmentation limits the ability to track, compare, and optimize material for low embodied carbon beyond individual project boundaries.

Comparison of New York State and New York City Embodied Carbon Policies by Function and Scope

Category	**NYS Buy Clean/ EO 22**	**NYC EO 23**	**Combined Effect**
Policy Level	State	City	Operate at different governance scales, allowing alignment between broad regulation and local implementation
Primary Mechanism	Procurement based carbon limits	Procurement and Lifecycle Evaluation	Combines material-level screening with project-level optimization
Policy Type	Supply-side Regulation	Project Level Intervention	Aligns supply (what is available) with demand (what is selected)
Scope of Application	State-Funded Projects	City Funded Capital Projects	Expands total market coverage across overlapping public sectors
Material Coverage	Select Materials (e.g. Concrete)	Whole Project (Structural and Enclosure Systems)	Links targeted material improvements to whole-building performance outcomes
Carbon Accounting Scope	A1-A3 (Production Stages)	A1-C (Full Lifecycle, Including Use + End of Life)	Integrates upstream emissions control with full lifecycle accountability
Requirement Type	Mandatory Carbon Intensity Limits	Reporting and Reduction Targets (No Universal Hard Limits)	Pairs enforceable thresholds with flexible, project-specific strategies
Material Choice Constraint	Direct (Must Reach Threshold)	Indirect (Must Evaluate + Justify Choices)	Ensures minimum performance standards while enabling design flexibility
Design Influence	Limited	High (Affects System Selection + Design Decisions)	Allows NYC to shape design decisions using materials already improved by NYS standards
Data Requirements	EPD Submissions	EPD + Full LCA Modeling	Builds from product-level data to project-level carbon analysis
Enforcement Mechanism	Compliance with Thresholds in Contracts	Compliance Through Reporting and Procurement Review	Reinforces compliance through both hard limits and accountability processes
Market Impact	Shapes Material Supply	Shapes Project Demand and Decision Making	Creates feedback loop between supply and demand, supporting market transformation
Coverage Limitation	Narrow (Material Specific)	Broader but limited to Public Projects	Together, partially close gaps but still leave private sector underregulated
Key Limitation	Does Not Address Full Lifecycle Design	Does not Enforce Strict Carbon Limits	Each policy compensates for the other's weakness, but integration remains incomplete

Waste Management and Circularity Systems Gaps

The comparison of New York State waste policy and New York City circular economy initiatives reveals a fragmented approach to material lifecycle governance. At the state level, policy is largely oriented toward end-of-life waste management, focusing on landfill diversion, recycling targets, and extended producer responsibility. At the city level, circularity is framed through economic development and project-level design guidance, encouraging reuse and low-carbon construction practices in specific contexts. While these approaches address different points in the material lifecycle and linear economic model, they do not form a continuous system. Instead, they operate at opposite ends, leaving a critical gap in the middle stages of material use, recovery, and redistribution and falling short of successfully working to close the loop.

This "missing middle" is one of the most significant limitations. State policy governs what happens to materials after they become waste, while city-level efforts focus on early-stage design decisions. However, there is little policy addressing how materials are actually retained, recovered, stored, or reintroduced into the construction market. As a result, even when buildings are designed with reuse in mind or materials are successfully diverted from landfills, there is no consistent system to support their circulation. Without mechanisms for storage, processing, and redistribution, materials often fail to move beyond the point of recovery.

This gap is reinforced by the absence of integrated data systems. Material tracking at the state level is limited to waste stream reporting, while city-level efforts rely on project-specific documentation and emerging lifecycle assessment practices. These systems are not connected, and there is no standardized material passport or citywide inventory that tracks materials across buildings and over time. As a result, material flows remain largely invisible beyond individual projects, limiting the ability to coordinate reuse or scale circular practices across the sector.

Market development strategies further illustrate this disconnect. State policy supports recycling infrastructure and producer responsibility, while city initiatives frame circular construction as an emerging economic sector tied to job creation and industrial growth. However, the underlying market infrastructure needed to support material reuse remains underdeveloped. This limits the transition from isolated pilot projects to a functioning secondary materials market.

The regulatory structure also contributes to this fragmentation. State policies are partially binding but focused on specific waste streams, while city-level initiatives are largely implemented through guidelines, incentives, and project-specific agreements. Circular practices are therefore encouraged but not consistently required across the construction sector. This results in uneven adoption, where circularity is present in select projects but not embedded as a standard practice. These gaps result in a system that reduces waste and promotes circular practices in isolated contexts, but does not yet establish continuous material circulation. Materials are managed at the point of disposal and considered at the point of design, but the systems needed to

System Function	NYS Waste / Circular Policy	NYC Circular / Economic Policy	System Gap / Limitation
Policy Focus	End-of-life waste reduction (landfill diversion, EPR, recycling targets)	Economic development + project-level circular construction	No unified lifecycle approach to materials
Lifecycle Stage Addressed	Primarily end-of-life (waste management and disposal)	Early-stage design and pre-construction decision-making	Missing middle: material reuse, storage, and redistribution systems
Primary Mechanism	Extended Producer Responsibility (EPR), state waste planning, regulatory targets	Guidelines, RFP requirements, development agreements, incentives	No binding requirements for reuse or material circulation
Material Tracking and Data	Limited to waste stream reporting and product-level EPD expansion	Project-level documentation and emerging LCA practices	No integrated material passport system or citywide material inventory
Market Development Strategy	Supports recycling systems and producer accountability	Frames reuse and low-carbon construction as economic growth sectors	No stable secondary materials marketplace or logistics network
Regulatory Strength	Partial and sector-specific (focused on certain products and waste streams)	Largely non-binding (guidelines and contract-based implementation)	Circularity not mandated across the construction sector
Spatial / Infrastructure Strategy	Focus on waste processing and disposal facilities	Identifies need for storage, staging, and industrial space for reuse	Lack of dedicated infrastructure for material recovery and redistribution
Governance Approach	State-led regulatory and legislative framework	City-led economic development and procurement-based influence	Fragmented governance across agencies and scales
Key Limitation	Focuses on waste management rather than material reuse or retention	Relies on project-specific adoption rather than system-wide implementation	Policies operate in parallel rather than as an integrated system
System Outcome	Reduces waste at end-of-life	Encourages circular practices in select projects	Fails to establish a continuous material circulation system

connect these stages remain largely absent. As a result, circularity operates as a set of discrete interventions rather than as an integrated material lifecycle system.

VI. Industry Perspectives on Circular Construction: Qualitative Interview Findings

To better understand how embodied carbon reduction and circular construction practices currently operate within New York City's construction ecosystem, five semi-structured interviews were conducted with professionals working across different segments of the industry. Interview participants represented roles in materials manufacturing, structural design, distribution, economic development, and public-sector planning. Together, these perspectives provided insight into how embodied carbon considerations appear within real project workflows, and what structural conditions shape whether circular strategies are adopted in practice.

While participants are not identified by name or organization in order to preserve anonymity, they represent a range of mid- to senior-level professionals with direct experience in the design, construction, and governance of building projects. Several participants work directly on large-scale projects in New York City, while others bring experience from related regional or national markets. Collectively, they span both public and private sectors and engage with different phases of the building lifecycle, including early-stage design, material sourcing, procurement, and policy implementation. This range of perspectives allows for comparison across decision-making contexts, from project-level engineering constraints to broader institutional and market dynamics.

Interview Question Structure

Interviews were conducted using a semi-structured format that allowed conversations to follow participants' areas of expertise while still addressing several core topics relevant to the research questions. The goal of this structure was to understand how embodied carbon and circular construction considerations appear within real project workflows and to identify the structural barriers and opportunities shaping their adoption.

Interview topics were organized into several broad thematic areas and were tailored to the professional background of each participant. First, participants were asked to describe their professional role and how embodied carbon considerations, material choices, structural design implementation, and re-use appear in their day-to-day work, including when key decisions are typically made during the design and development process. Interviews then explored how industry norms, voluntary commitments, and sustainability frameworks influence decision-making in practice, including whether embodied carbon initiatives meaningfully shape project design or function primarily as internal guidelines.

These discussions focused on when and why circular economy and/or embodied carbon strategies are often removed from projects during budgeting or value engineering phases, and what presents the greatest barriers to adoption. Interviews further examined the feasibility of practices such as material reuse, deconstruction, and material tracking systems, with particular attention to the technical, logistical, and liability challenges associated with scaling reuse markets. Finally, respondents were asked to reflect on potential leverage points for accelerating embodied carbon reduction in the construction sector, including the roles of policy, procurement standards, industry culture, and market incentives. Together, these questions were designed to capture perspectives across different positions within the construction ecosystem and to identify recurring structural dynamics shaping the adoption, or constraint, of circular construction practices in New York City.

Thematic Matrix Interview Analysis

To systematically evaluate recurring themes across interviews, a thematic coding matrix was developed. While the preceding sections present qualitative insights from individual interviews, the matrix enables cross-case comparison to identify patterns that appear consistently across different roles within the construction ecosystem. Each interview transcript was coded for both the presence and relative salience of key structural dynamics identified through qualitative analysis.

These dynamics include: scale constraints, supply chain limitations, regulatory and institutional gaps, and knowledge or technical capacity challenges. Rather than focusing on isolated comments, the matrix captures how prominently each theme appeared within the overall discussion of each interview. Two coding layers were used. First, a binary presence indicator (0 or 1) recorded whether a theme appeared in the interview. Second, a salience score ranging from 1 to 3 was assigned to reflect how central the theme was within the participant's responses.

Salience scores were defined as follows:

1 – Brief or secondary reference

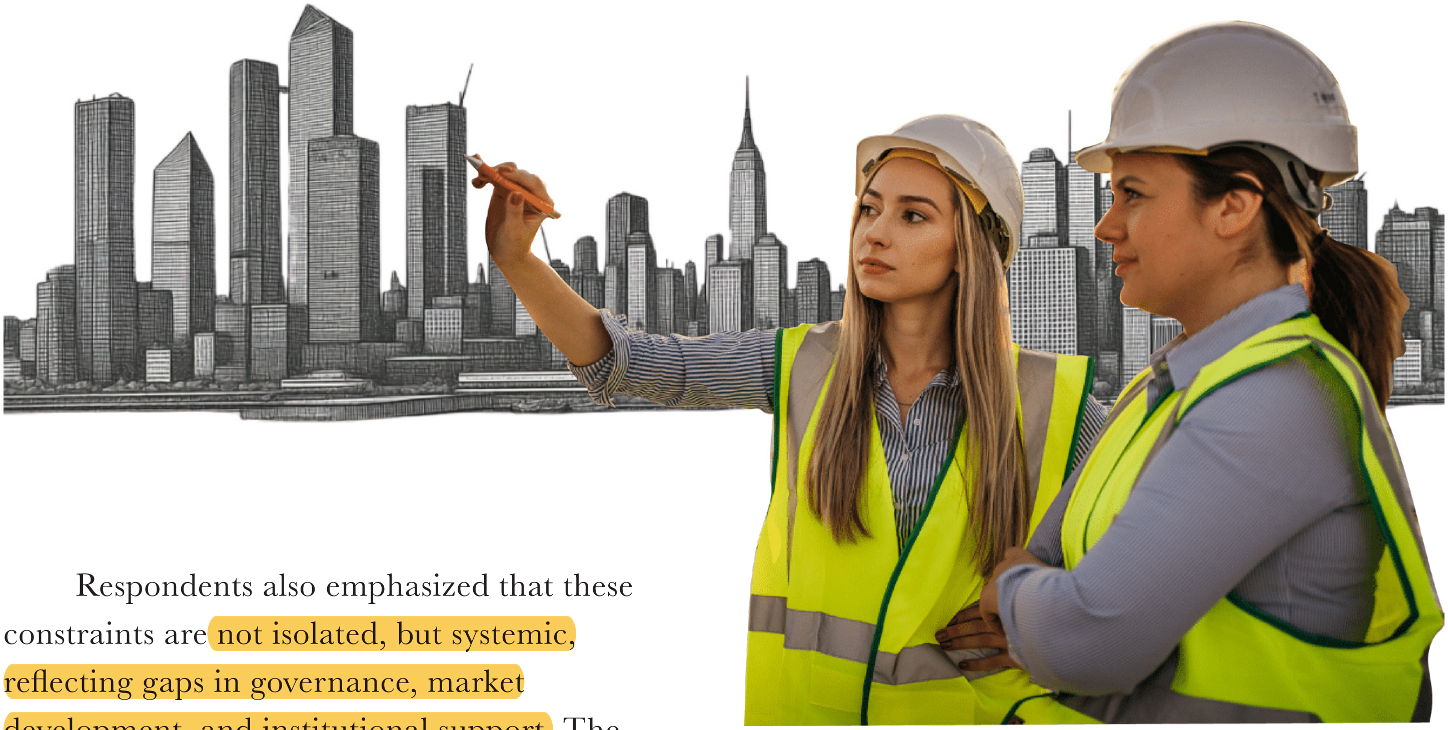
2 – Recurring discussion or moderate emphasis

3 – Dominant theme structuring a substantial portion of the interview

Coding was conducted at the level of the full interview transcript rather than individual questions. Because interview prompts varied depending on each participant's expertise, treating each interview as a unified analytical unit allowed themes to emerge organically while maintaining comparability across respondents. The resulting matrix provides a structured overview of how key structural dynamics appear across the five interviews.

Findings: Overview

Across interviews, respondents consistently described a gap between growing awareness of circularity and embodied carbon and their actual influence on project decisions. While sustainability is frequently emphasized in design conversations and policy frameworks, it rarely functions as a primary driver of material or system selection. As one interviewee noted, "they'll have sustainability all over their website… but in practice it's aesthetic, performance, and price—and sustainability comes last." Instead, decisions are shaped by structural constraints within the development process, particularly cost, supply chain coordination, and project timelines.



Respondents also emphasized that these constraints are not isolated, but systemic, reflecting gaps in governance, market development, and institutional support. The following sections synthesize these findings across interviews, highlighting how professionals working across different parts of the construction ecosystem understand both the opportunities and the structural limitations associated with reducing embodied carbon and scaling circular construction practices.

Structural Systems, Material Constraints, and Reuse Feasibility

Across interviews with professionals working in structural engineering and material supply chains, respondents consistently emphasized that the structural system used in a building plays a central role in determining whether circular practices such as reuse are feasible. Steel and wood structural systems were described as more adaptable to reuse because individual components can be disassembled and, in some cases, tested for reuse. In contrast, reinforced concrete structures, which dominate many mid- and high-rise buildings, particularly in New York City, were identified as significantly more difficult to recover in a reusable form. As one interviewee explained, "steel and concrete still have to be compared on price and speed… it's not like we just decide to use timber and move forward." These differences highlight that reuse feasibility is largely determined at the point of structural system selection, rather than at the point of demolition. In this sense, circular outcomes are shaped upstream through early design decisions, reflecting how buildings are conceived, assembled, and documented from the outset.

At the same time, structural reuse introduces significant practical and logistical challenges. While interviewees consistently noted that reuse is technically feasible, it is not currently embedded within standard engineering workflows and instead requires additional coordination, verification, and project-specific effort. As one respondent noted, reused materials require "testing, documentation, and verification," which introduces additional time, cost, and liability into conventional project delivery processes. Engineers emphasized that one of the primary barriers is the lack of consistent material traceability systems. Without reliable documentation of a material's origin, properties, and prior use, it becomes difficult to confidently specify reused components in new structural applications. As another interviewee put it, material tracking and traceability "doesn't really exist" in a way that can be applied across projects.

As a result, reuse often depends on project-specific data collection rather than standardized processes. In addition to documentation challenges, interviewees highlighted broader supply chain limitations. Reuse pathways require coordination across multiple actors, including material recovery, storage, testing, and redistribution, yet these systems remain fragmented and underdeveloped. Together, these constraints introduce additional time, cost, and uncertainty, making reuse difficult to pursue within conventional project timelines and budgets.

At the same time, wood presents a different, but still underdeveloped, pathway for structural reuse. Interview findings suggest that timber systems are organized as component-based products that move through a multi-stage supply chain, from sourcing and processing to fabrication and installation. This structure creates the potential for reuse, as individual elements can be tracked, handled, and potentially reintroduced into new applications. However, interviewees emphasized that the infrastructure required to support this process—particularly material traceability and coordinated supply chains—remains underdeveloped.

In practice, the wood industry remains fragmented, with limited geographic distribution of manufacturing and ongoing challenges in achieving consistent sourcing and material coordination. There is also a lack of standardized systems for tracking material flows, which makes it difficult to document, verify, and reintroduce materials into new construction projects. While wood reuse is occurring across a range of applications, systems for scaling reuse, particularly within structural applications, remain in early stages of development.

These findings suggest that the primary barriers to structural reuse are not technical feasibility alone, but the absence of coordinated systems linking design, material tracking, and recovery across the building lifecycle.

Market Dynamics, Procurement, and Economic Barriers

Public procurement can function as a critical market signal for circular construction and lower embodied carbon practices. Interviews with public-sector professionals emphasized that publicly funded projects and government purchasing standards are already being used to shape industry behavior. As one respondent explained, procurement can "signal to the market that [agencies] are interested in this type of expertise," encouraging consultants, contractors, and developers to build capacity in circular construction practices. By incorporating circular design requirements into publicly funded projects, agencies can create consistent demand for lower-carbon materials and services, influencing broader market adoption over time. This reflects the broader intent of the New York policies outlined above, which seek to leverage public investment to catalyze industry transformation.

At the same time, interview subjects from within the private sector emphasized that voluntary sustainability commitments often break down during procurement. While design teams frequently promote sustainability goals in early project stages, material selection is ultimately driven by cost, constructability, and performance. As one interviewee described, "a lot of the architects… will have this big statement on sustainability… and in actual conversation, a lot of that kind of goes away… performance is big, price is big, and then really sustainability kind of comes in at the end." As a result, sustainability considerations often become secondary once projects move into later development phases, particularly when financial and logistical constraints become more rigid.

The cost barrier associated with lower-carbon materials is also frequently misunderstood within industry practice. The price of the material itself is not always significantly higher. For example, lower-carbon concrete mixes can sometimes be comparable in cost to conventional alternatives. Instead, higher costs often arise from the systems required to implement these materials, including additional engineering analysis, supply chain coordination, specialized labor, and documentation needed to verify carbon performance. As one respondent noted, "I just don't think that many people want to pay the green surcharge," highlighting how even modest cost premiums can deter adoption in cost-sensitive project environments. This broader logistical and institutional infrastructure can make lower-carbon construction appear more expensive, even when material costs are comparable.

Interviewees also emphasized that market adoption is constrained not only by cost, but by uncertainty. In particular, the lack of consistent demand and end-use pathways for reclaimed materials limits the viability of circular systems. As one public-sector respondent explained, "there is not always an end use for every single material that's deconstructed," complicating efforts to scale reuse markets and integrate them into standard development processes. This uncertainty reinforces risk-averse decision-making, further limiting adoption.

When asked how these barriers could be addressed, interviewees consistently pointed to the need for stronger government incentives. Several emphasized that incentives should precede regulatory requirements in order to help standardize practices, reduce risk, and build industry capacity. One respondent also suggested integrating embodied carbon into existing certification frameworks such as LEED as a way to further normalize these considerations within design and construction workflows. These responses suggest that industry professionals do not expect widespread adoption of circular and low-carbon practices to occur without more active government intervention, but also do not view regulation alone as sufficient. Instead, they emphasize the need for early-stage incentives and market development strategies to establish the conditions under which regulatory approaches can be successfully implemented.

Supply Chains, Secondary Markets, and Material Availability

Circular construction depends on reliable secondary markets for materials.

Even when materials are successfully salvaged from demolition or deconstruction projects, reuse remains difficult without coordinated marketplaces that can match recovered materials with new projects. Without this market infrastructure, circular material systems remain project-specific and struggle to operate at scale. Reliable supply and buyer confidence remain major barriers for reclaimed materials. Buyers often face uncertainty about availability, quality, and delivery timelines. As one interviewee explained, "we don't actually know where materials are coming from in most cases," highlighting the lack of transparency and consistency in secondary material supply chains.

Unlike conventional building products that are stocked in warehouses and available on short notice, reclaimed materials frequently require sourcing, processing, and milling after a project order is placed. This creates longer lead times and more complex procurement processes, which can discourage project teams working under tight construction schedules.

Participants also highlighted that while certification frameworks such as LEED and the Living Building Challenge are intended to promote sustainable construction practices, they can unintentionally discourage the use of lower-carbon materials. In particular, materials with clear embodied carbon advantages, such as salvaged wood, are not always captured within existing certification criteria, which tend to prioritize operational performance or specific sourcing standards. As a result, project teams may prioritize compliance with certification requirements over selecting materials with lower embodied carbon impacts. As one respondent noted, projects are often constrained by certification requirements, even when lower-carbon alternatives are available, as these materials may "not fit within the criteria" required for approval [paraphrased].

Together, these findings suggest that the challenge of scaling circular construction is not only a matter of material availability, but of market coordination and institutional alignment. Without reliable supply chains, transparent material tracking, and certification systems that recognize embodied carbon benefits, reclaimed materials remain difficult to integrate into standard construction workflows, even when they are technically viable and environmentally advantageous.

Data Infrastructure and Lifecycle Tracking

Across interviews, data infrastructure emerged as a critical barrier to the broader adoption of circular construction and the reduction of embodied carbon. While tools for tracking materials and emissions are beginning to develop, there is currently no integrated or standardized system in New York that connects data across the full building lifecycle, from design and construction to demolition and reuse. Public-sector participants noted that multiple private actors are actively developing tracking platforms, but the city has not yet adopted a unified approach. At the same time, some interviewees suggested that this competitive landscape may ultimately produce more effective solutions than a single publicly developed system, while emphasizing that eventual convergence around a shared platform will be necessary to support circular construction and low embodied carbon outcomes at scale. As a result, data remains fragmented and project-specific, limiting its ability to support coordinated decision-making or enable material circulation across projects.

Interviewees consistently emphasized that material traceability is essential for enabling reuse, particularly within structural applications. As one respondent explained, material tracking and traceability "doesn't really exist… in a way that can be used across projects," underscoring the lack of interoperable systems capable of supporting reuse at scale. Engineers noted that reused materials cannot be specified without reliable documentation of their origin, prior use, and structural properties. In the absence of this information, materials must either undergo additional testing or are excluded from consideration altogether. As a result, reuse is often constrained not by technical feasibility, but by gaps in available data.

This fragmentation is further compounded by the absence of consistent data standards across actors and project phases. While individual firms may develop internal tracking tools or project-specific datasets, these systems are rarely interoperable or transferable across projects. As one interviewee noted, current tracking efforts are often limited to "specific projects" rather than functioning as shared infrastructure [paraphrased]. These findings suggest that while the technical capacity to track materials exists, the absence of industry- and city-wide data infrastructure limits its effectiveness. Without consistent and accessible lifecycle data, materials cannot be reliably recovered, matched to new uses, or evaluated for their carbon impact, constraining the development of circular construction systems.

Design Process, Regulation, and Institutional Constraints

Respondents indicated that early design stages are the most effective intervention point for embodied carbon reduction. Decisions related to structural systems, material selection, and demolition or reuse strategies are most effectively addressed during the earliest phases of development. Once projects move into later stages, financial and logistical constraints limit the ability to incorporate circular strategies. These decisions do not exist without context; however, as several engineers noted, these choices are impacted by regulation, and regulation is often impacted by choices outside of simple carbon accounting. For example, the usage of wood for large construction projects in New York does not simply come down to the choices of developers, architects, or engineers. The use of Timber in New York City is constrained by building code requirements and fire safety considerations. Advancing timber construction often requires coordination between project teams, the Department of Buildings, and the Fire Department to evaluate fire performance and structural compliance. These processes can introduce additional time, uncertainty, and administrative burden, particularly when projects must pursue approval through alternative materials pathways. This can make the use of lower carbon alternatives more expensive by slowing down approval processes.

City Planning

Interviews also indicated that at the planning level, embodied carbon is largely absent from current development review processes. Interview findings indicate that existing systems primarily focus on land use, zoning compliance, and environmental review, while policies such as Local Law 97 target operational emissions rather than material-related impacts . As a result, embodied carbon is not systematically evaluated in planning or development approvals.

Scale as a Structural Constraint

Across interviews, scale emerged as a consistent underlying constraint shaping the feasibility of circular construction and embodied carbon reduction. Participants repeatedly described the market for reused and lower-carbon materials as insufficiently developed to support widespread adoption within the construction industry. As one interviewee stated directly, "it's a scale problem," emphasizing that many of the barriers associated with circular construction stem from the limited size and maturity of existing markets. As a result, these materials and practices remain difficult to integrate into standard project workflows.

Interviewees emphasized that this limitation is not only a matter of price, but of market maturity and coordination. Reuse and low-carbon materials are often sourced on a project-by-project basis rather than through stable, well-established supply systems. This creates uncertainty in availability, delivery timelines, and coordination, making them more difficult to specify within projects that operate under tight schedules and financial constraints. As one respondent explained, current systems are not yet structured to support consistent sourcing at scale, requiring teams to assemble material flows on a case-by-case basis [paraphrased].

Participants also noted that many circular practices require additional effort relative to conventional approaches. Deconstruction, for example, involves more complex planning, specialized labor, and longer timelines than standard demolition. Similarly, designing for reuse or disassembly introduces additional coordination and documentation requirements during early project stages. In the absence of established systems to support these processes, these additional demands can make circular strategies difficult to implement within typical development timelines. As one interviewee noted, these approaches require "additional coordination, verification, and project-specific effort," reinforcing the extent to which circular practices remain outside standard delivery processes.

Several interviewees identified scale itself as the primary mechanism through which these constraints could be reduced. A larger and more consistent market for reused and low-carbon materials would help stabilize supply, reduce uncertainty, and allow industry actors to operate more efficiently. In turn, this could lower costs and make circular practices more compatible with standard project delivery processes. As one respondent explained, improving outcomes is not simply about increasing volume, but about developing the systems and processes that allow materials to move reliably through the market [paraphrased].

Finally, respondents indicated that achieving this level of scale is unlikely to occur through voluntary adoption alone. Instead, they emphasized the role of public procurement and policy in creating consistent demand. By requiring or incentivizing circular practices within public projects, governments can help expand the market, enabling suppliers, contractors, and designers to invest in the systems needed to support circular construction at scale. As one public-sector interviewee described, procurement can be used to “signal to the market” and generate the demand necessary for industry transformation.

VII. Quantitative Analysis of Structural Systems and Embodied Carbon

Quantitative Research Questions

As uncovered in the course of this study's qualitative research thus far, findings indicate that structural systems and material choices are major drivers of embodied carbon in the built environment. To evaluate these dynamics quantitatively, this chapter analyzes building-level embodied carbon data from a dataset of whole-building life-cycle assessments, alongside material-level embodied carbon coefficients derived from the Inventory of Carbon and Energy (ICE) database, a widely used resource that compiles peer-reviewed embodied carbon factors across over 200 construction materials.

These data are used to compare average embodied carbon intensities across material categories and to examine how variation within materials contributes to overall building-level emissions. The goal of this chapter is to test the theory developed through qualitative analysis by assessing how structural systems and building characteristics influence embodied carbon intensity across a large sample of buildings. This quantitative analysis provides greater clarity on how design decisions, procurement policies, and circular material strategies shape embodied carbon outcomes in the construction sector, with the aim of informing more effective policy and planning interventions.

This portion of the study focuses on three primary questions:

1. To what extent do building height and structural system determine embodied carbon in urban construction?
2. How much variation in embodied carbon exists within material categories based on specification decisions such as strength and composition?
3. How do differences in reuse, recyclability, and carbon storage across materials affect their long-term emissions profiles?

Methodology

To evaluate how structural systems, material choices, and levels of circularity influence embodied carbon outcomes, this study employs an ordinary least squares (OLS) regression model alongside a complementary machine learning approach (random forest), both informed by life cycle assessment (LCA) data. Emissions factors for key construction materials were derived from existing LCA literature and applied to estimate embodied carbon across a range of building scenarios. Independent variables include structural systems, building characteristics, and material categories, while the dependent variable is embodied carbon intensity.

The purpose of this analysis is not to produce precise project-level predictions, but to identify the direction and relative magnitude of relationships between design decisions and carbon outcomes. In particular, the model is designed to assess the extent to which embodied carbon is associated with structural requirements, such as building height and system type, while also capturing variation within material categories based on specification decisions.

The OLS framework allows for comparison across multiple variables simultaneously, making it possible to evaluate how differences in structural system, building scale, and material selection are associated with changes in embodied carbon while holding other conditions constant. In parallel, the random forest model captures non-linear relationships and interactions across variables, and is used to assess the relative importance of different features in explaining variation in embodied carbon intensity. Together, these approaches provide both interpretability and robustness in identifying key drivers of embodied carbon.

While the models focus on embodied carbon at the point of production (A1–A3), the results are later interpreted in relation to broader material lifecycle characteristics, including reuse, recyclability, and carbon storage potential. This enables the analysis to consider how differences in material behavior over time may influence overall emissions outcomes.

Data and Variables

This analysis draws on two complementary datasets to capture both material-level and building-level embodied carbon dynamics. Material-level embodied carbon coefficients were derived from the Inventory of Carbon and Energy (ICE) database, which compiles emissions factors for over 200 construction materials based on environmental product declarations and life cycle assessment studies. Building-level embodied carbon data were drawn from the Carbon Leadership Forum's Whole Building Life Cycle Assessment Benchmark Study dataset, which includes harmonized information on design characteristics, material quantities, and environmental impacts across a large sample of buildings.

The dataset used for this analysis contains whole-building life cycle assessment (WBLCA) results for 239 building projects. Each project includes information on building characteristics and embodied carbon intensity measured across life cycle stages A–C and normalized by gross floor area. The dependent variable in the analysis is embodied carbon intensity (ECI), measured in kilograms of CO2 equivalent per square meter of floor area.

The key explanatory variables include:

- Primary structural system
- Gross floor area (GFA)
- Number of stories
- Primary building use

Structural systems are categorized based on the predominant vertical structural material used in each building. These categories include systems such as reinforced concrete, steel, masonry, and other structural configurations. Building size is measured using gross floor area, while building height is represented by the number of stories above grade. This set of variables reflects several of the factors identified by practitioners during interviews, particularly the importance of structural materials and project size in shaping carbon outcomes.

Machine Learning Analysis of Embodied Carbon Drivers

To better understand which building characteristics are most strongly associated with variation in embodied carbon intensity, a machine learning model using a random forest algorithm was applied alongside the regression analysis. While the OLS model provides interpretable estimates of the direction and magnitude of relationships, the random forest approach allows for a more flexible assessment of how different features contribute to embodied carbon outcomes without imposing linear assumptions.

The model produced results consistent with the regression analysis, and feature importance analysis provides additional insight into the relative influence of different variables. As shown in Figure 7.1, building size, measured as the logarithm of gross floor area (log GFA), emerges as the dominant driver of embodied carbon intensity, accounting for approximately 69.5 percent of total feature importance.

All other variables—including structural system, project type, and climate zone—play a secondary role in explaining variation in embodied carbon intensity. The next most important variable, building completion year, accounts for approximately 8 percent of feature importance, while all remaining variables individually contribute less than 5 percent.

To further interpret this relationship, Figure 7.2 illustrates the marginal effect of building size on predicted embodied carbon intensity. The results show a clear upward trend: as buildings become larger, embodied carbon intensity increases steadily, with more pronounced increases at higher sizes. This reflects the growing structural demands associated with larger buildings, including greater material quantities and more complex structural systems.

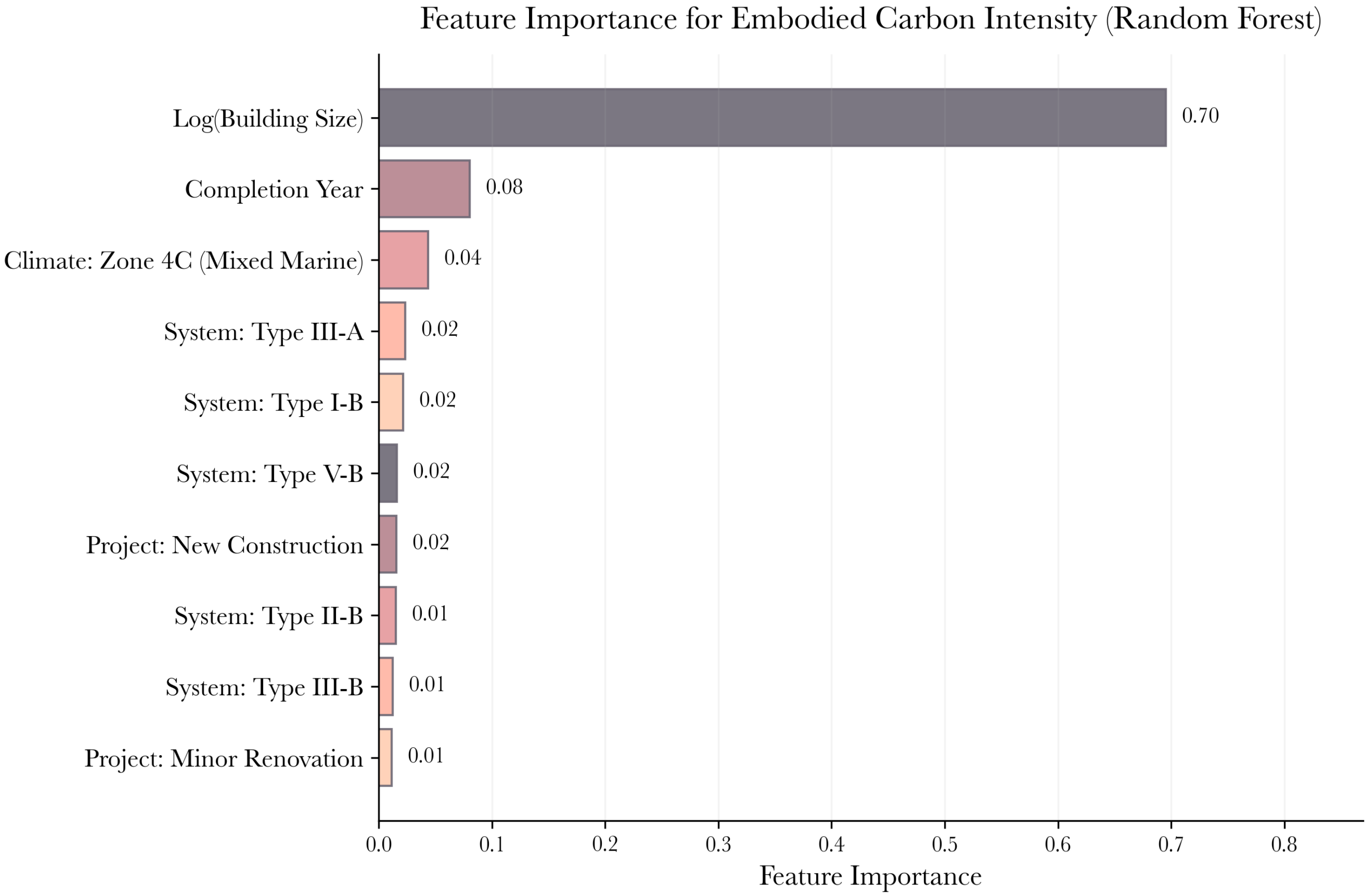


Fig. 7.1

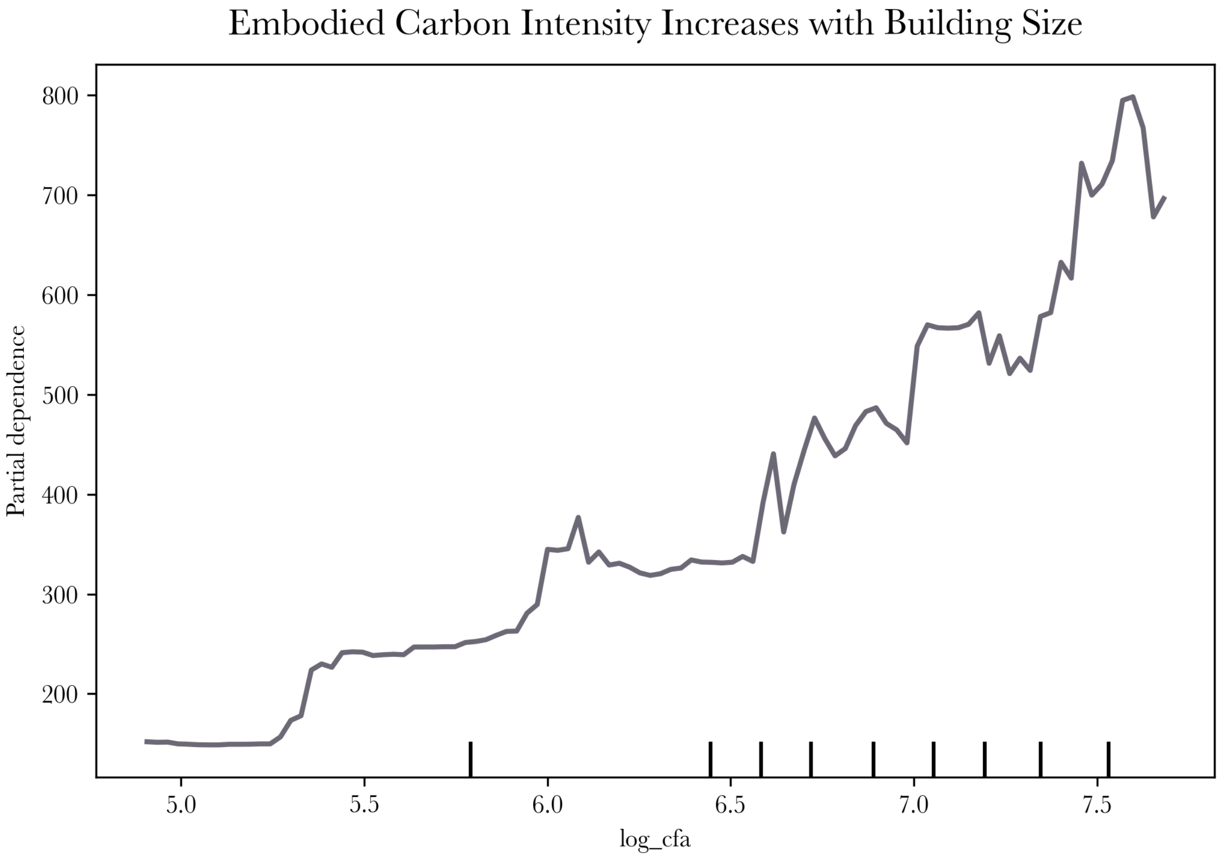


Fig. 7.2

Together, these results reinforce the importance of structural requirements associated with larger buildings in shaping embodied carbon outcomes. Rather than contradicting the qualitative findings, the model helps clarify their relationship: building size determines the overall level of embodied carbon, while structural system and material choices shape how that carbon is distributed and where reductions are possible. This provides a foundation for the subsequent analysis, which examines how embodied carbon varies across buildings and how structural system and material choices interact within these constraints.

Distribution of Embodied Carbon Across Buildings

The first step of the analysis examines how embodied carbon intensity varies across the dataset. The distribution shows a wide range of embodied carbon intensities across the projects. As shown in Figure 7.3, embodied carbon intensity varies widely across projects, with most buildings clustering within expected ranges but a pronounced upper tail.

Most buildings fall within ranges consistent with existing benchmarking research, which typically estimates embodied carbon intensities between 280 and 680 kgCO_2e per square meter, depending on building type and structural system (Carbon Leadership Forum, 2025). At the same time, the variation across projects supports findings from interviews that choice within the development process matters for reduction through material selection, structural design, and construction practices. This observed variation provides the foundation for the subsequent regression and machine learning analyses, which aim to identify the building characteristics most strongly associated with differences in embodied carbon intensity.

Embodied Carbon Intensity Analysis

Embodied carbon varies across structural systems, though there is still considerable overlap between categories. This suggests that while system type has an impact on ECI, the sources and implementations of those systems also matter. Carbon outcomes also depend on how materials are used, including design choices, material quantities, and construction methods. Again, this confirms findings within the interview stage that priorities by developers, engineers, designers and contractors have significant influence on ECI. These findings are also consistent with prior research showing that structural systems can produce a range of carbon intensities depending on design and material efficiency (Carbon Leadership Forum, 2025). As shown in Figure 7.4, embodied carbon intensity differs across structural systems, though there is considerable overlap between categories. This overlap indicates that system choice alone does not determine outcomes, and that variation in design, material quantities, and specification decisions plays a significant role within each category

Crucially, the data demonstrates that embodied carbon varies most dramatically as a result of building height. Very high-rise buildings show higher median values and a wider spread than mid-rise buildings.

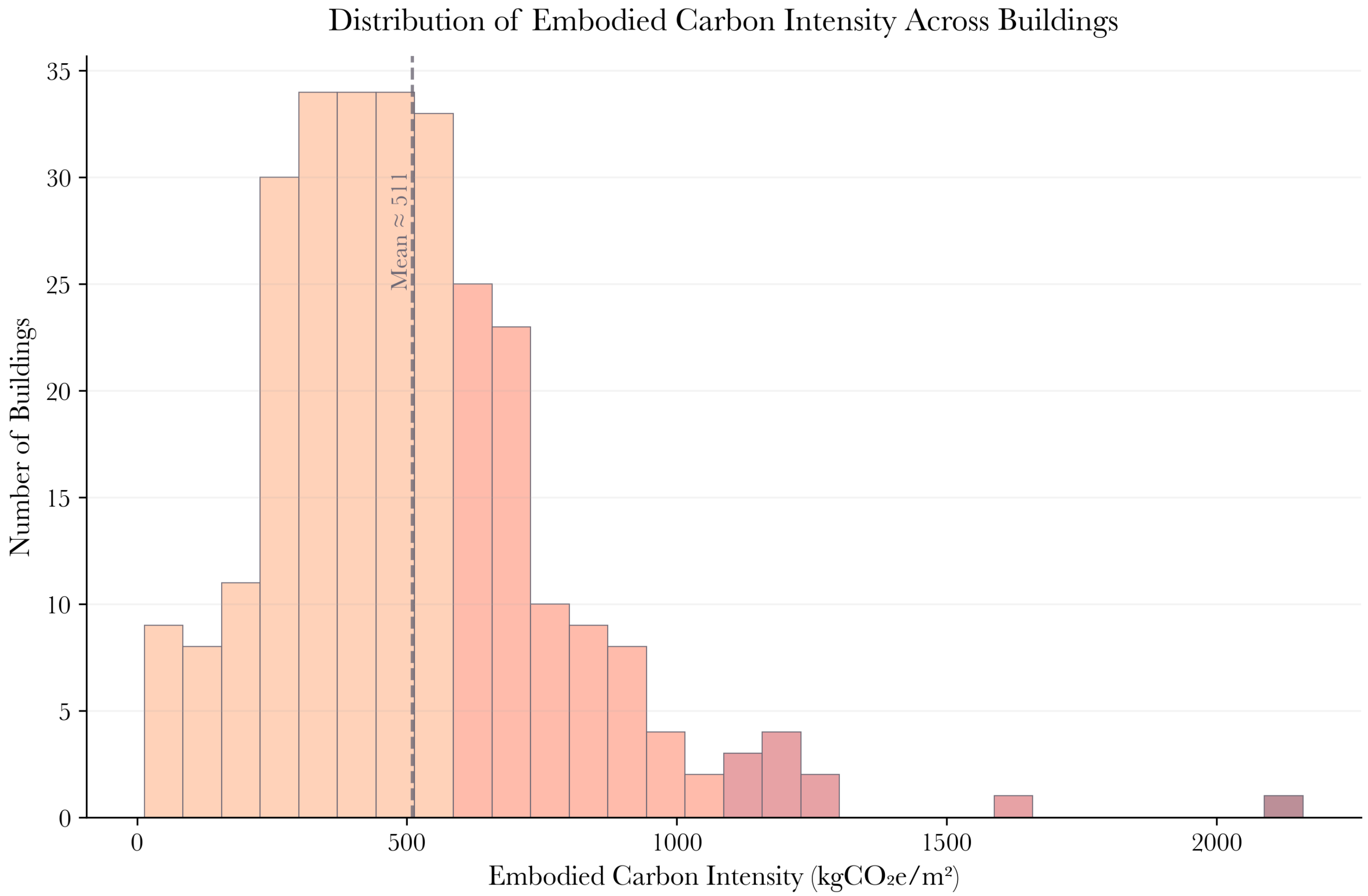


Fig. 7.3

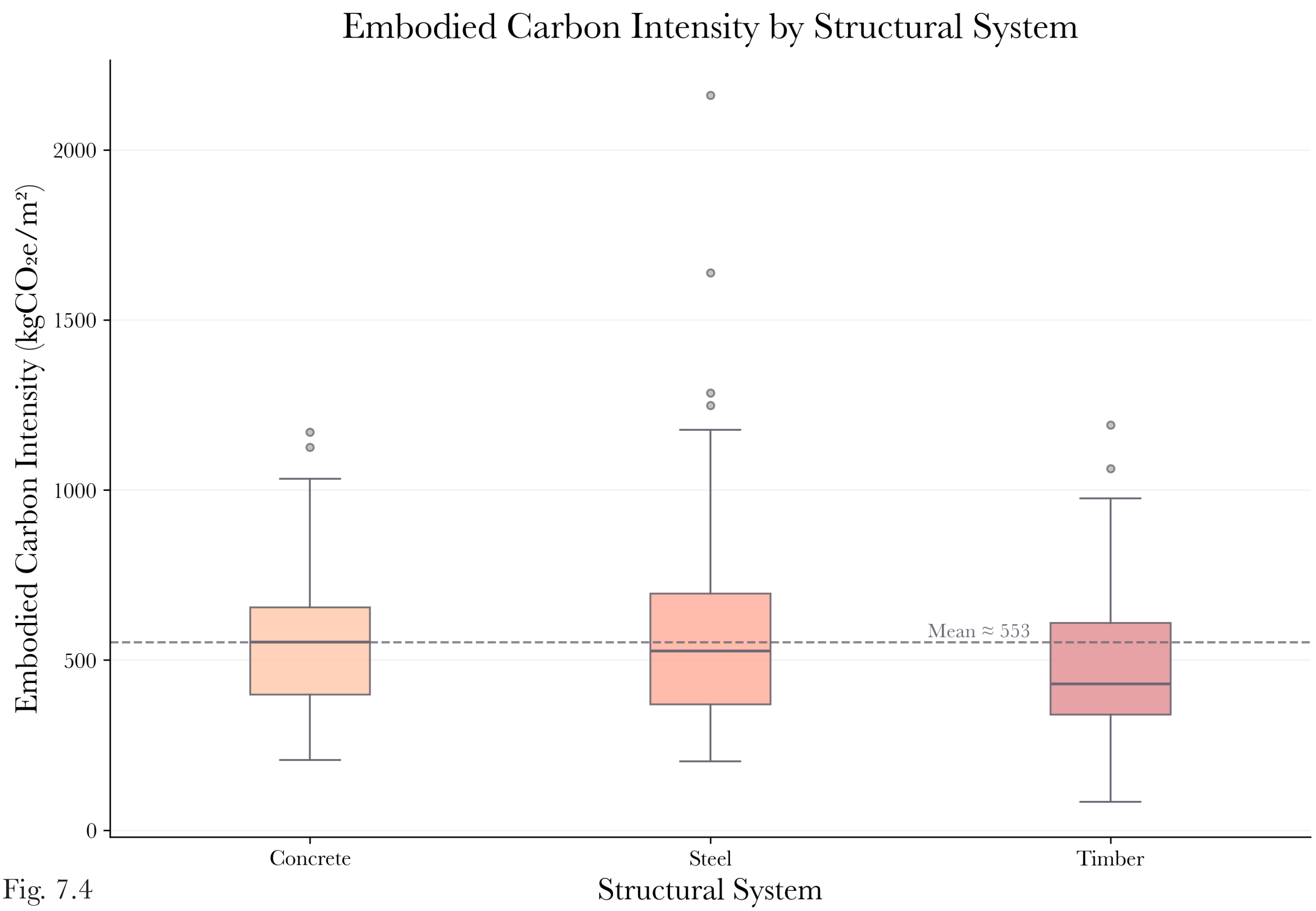

Embodied Carbon Intensity by Structural System
Embodied Carbon Intensity (kgCO₂e/m²)
2000
1500
1000
500
0
Mean ≈ 553
Concrete
Steel
Timber
Structural System

Fig. 7.4

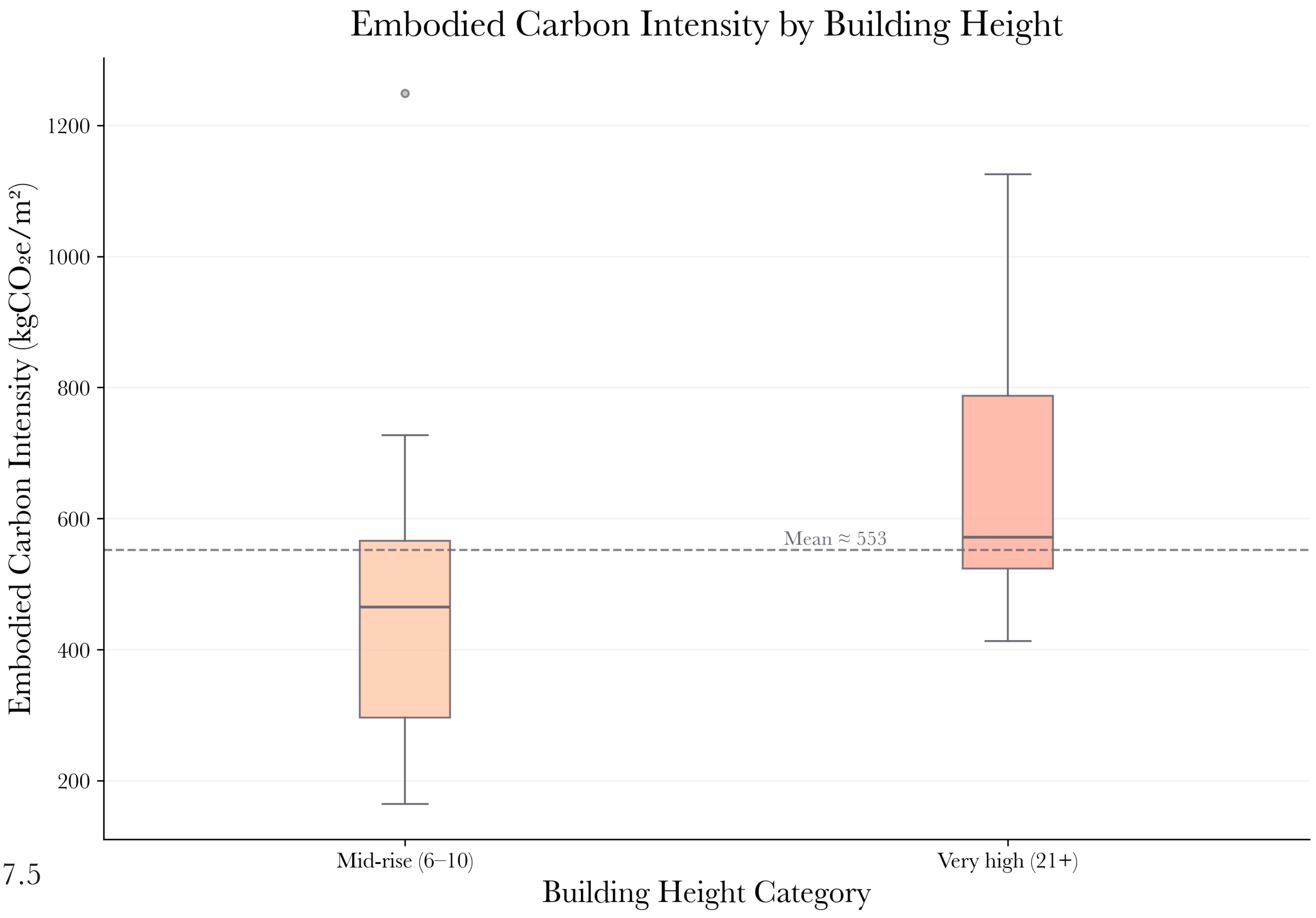

Embodied Carbon Intensity by Building Height
Embodied Carbon Intensity (kgCO₂e/m²)
1200
1000
800
600
400
200
Mean ≈ 553
Mid-rise (6–10)
Very high (21+)
Building Height Category

Fig. 7.5

The results of the random forest model confirm that building size is the dominant factor associated with variation in embodied carbon intensity. Gross floor area accounts for the largest share of feature importance, substantially outweighing all other variables. This suggests that building size and associated structural requirements play a central role in shaping embodied carbon outcomes, likely reflecting the increasing structural and material demands associated with larger and more complex buildings. This suggests that taller buildings generally require more carbon-intensive structural systems and greater material quantities. This aligns with structural and engineering constraints, as taller buildings demand stronger materials, increased reinforcement, and more complex systems, including vertical transportation. This is particularly significant in the context of New York City, where limited geographic space often necessitates greater building heights. Height also influences the feasibility of certain structural systems, which is further shaped by regulatory constraints.

When comparing systems at similar heights, mid-rise mass timber buildings tend to have lower embodied carbon intensities than steel-framed buildings, although there is still some overlap. This indicates that material choice continues to matter even when controlling for height, reinforcing the role of structural systems in shaping carbon outcomes.

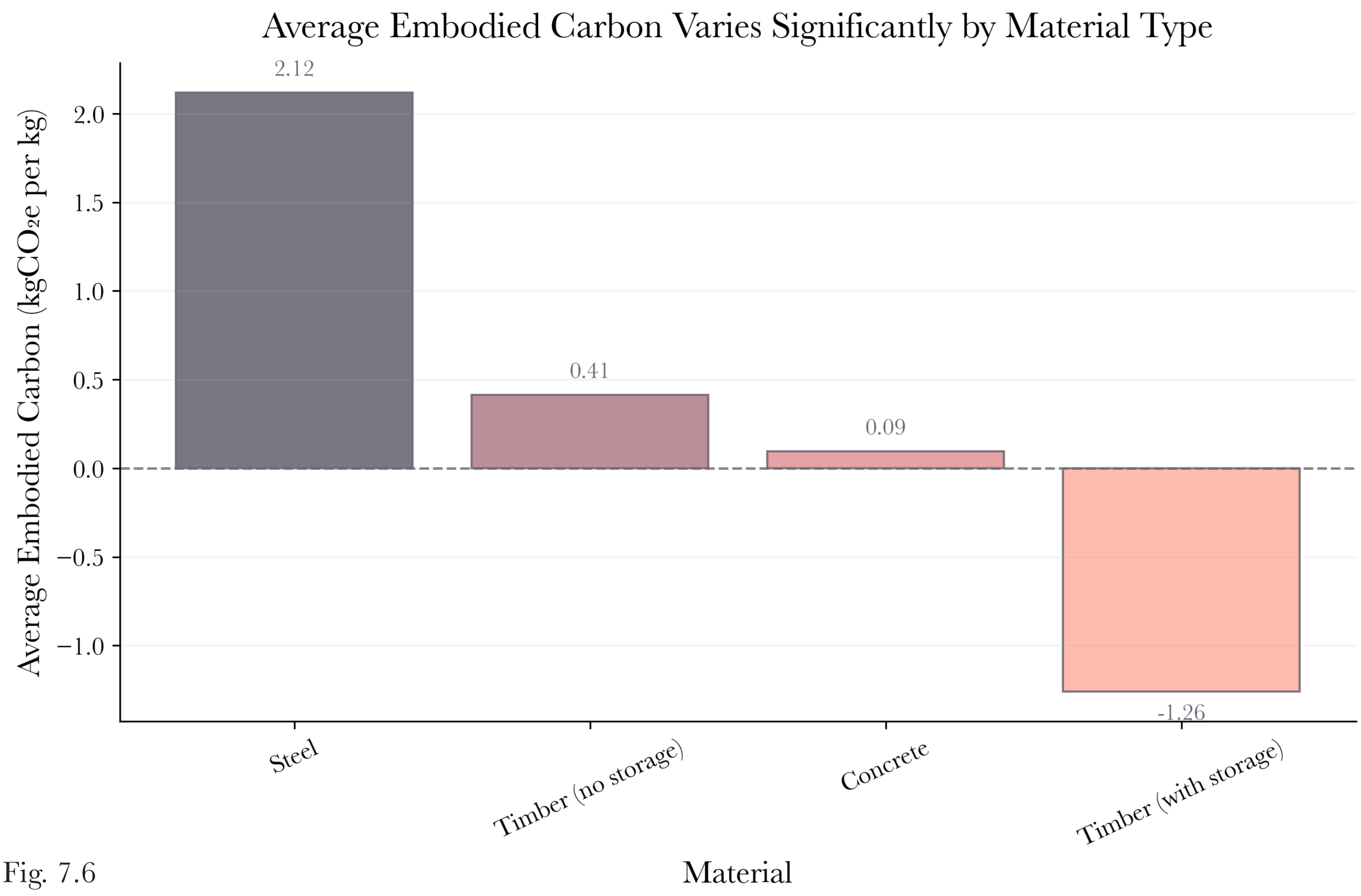


Fig. 7.6

Regression Analysis

To evaluate these relationships more systematically, an ordinary least squares (OLS) regression model was estimated with embodied carbon intensity as the dependent variable. The model evaluates how differences in structural systems and building characteristics are associated with variation in embodied carbon intensity across projects while holding other variables constant.

The model includes the following explanatory variables:

- Gross floor area
- Number of stories
- Primary building use
- Primary structural system

As shown in Figure 7.7, the regression results indicate that these variables collectively explain approximately 24.5 percent of the variation in embodied carbon intensity across buildings. While this level of explanatory power may appear modest, it is typical for building-level datasets where many project-specific factors influence outcomes. More importantly, the model is statistically significant overall, indicating that the included variables are meaningfully associated with embodied carbon intensity.

The regression results reinforce several patterns observed in the descriptive analysis. Structural system categories show variation in embodied carbon intensity, supporting interview

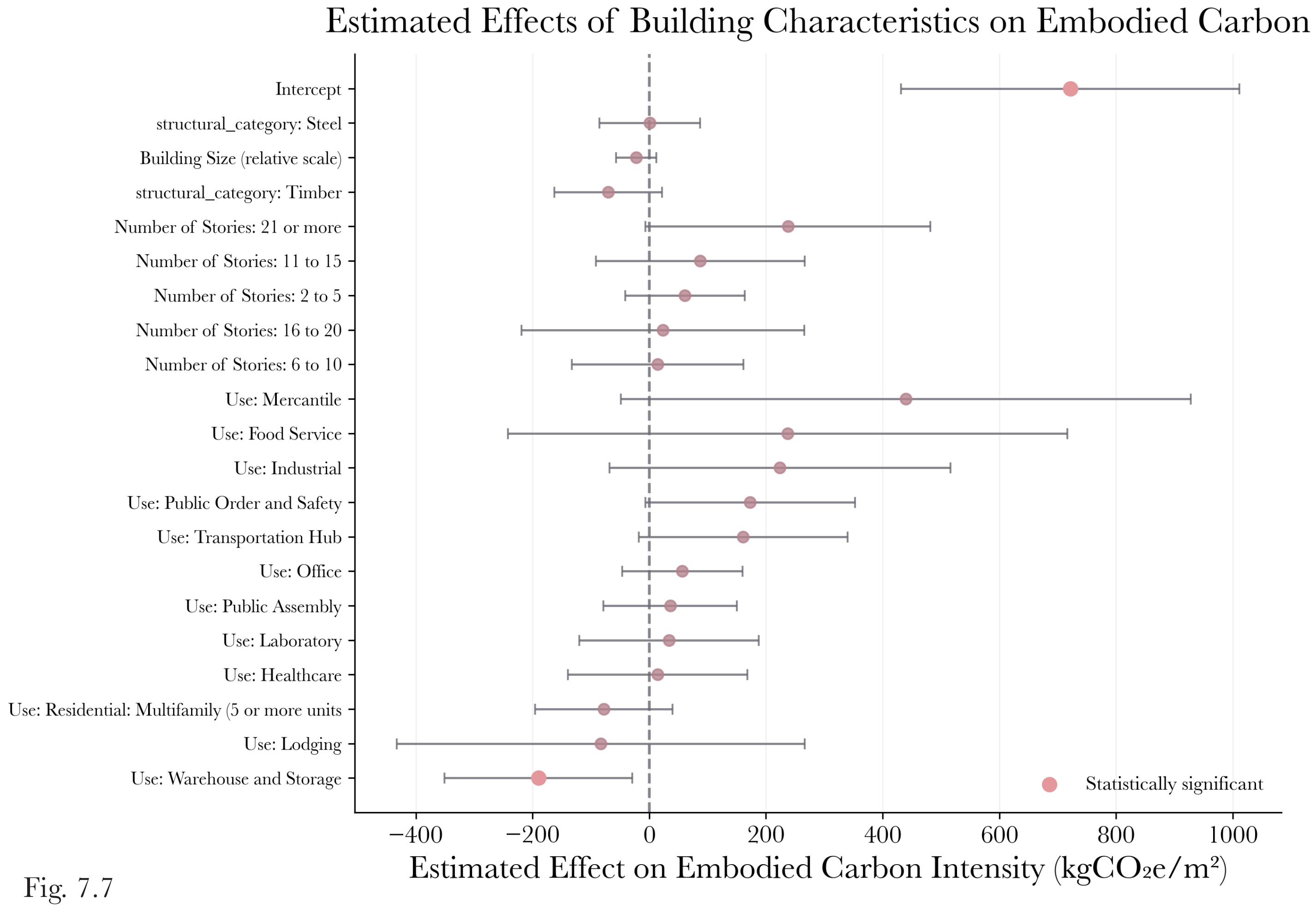


Fig. 7.7

findings that material selection plays an important role in shaping building carbon outcomes.

Reconciling a Seemingly Huge Contradiction

Structure size being the dominant driver of embodied carbon intensity within construction seemingly contradicts the findings within our qualitative analysis, by suggesting that it is not materials, but rather building height, that determines embodied carbon outcomes. However, a closer examination of material-level data reveals that this is not a contradiction, but rather a question of scale and interaction.

To better understand the role of materials within this system, this study supplements the building-level LCA dataset with material-specific embodied carbon coefficients derived from the Inventory of Carbon and Energy (ICE) database. These values were compiled into a structured dataset capturing variation across concrete mixes, steel products, and timber types. The goal was to isolate how embodied carbon varies within and across material categories, independent of building form.

A series of visualizations were developed to examine three key dimensions:

1. variation within a single material category (e.g., concrete),
2. variation across major structural materials (concrete, steel, timber), and
3. differences in average embodied carbon intensity between materials.
4. The results reveal several important patterns.

First, variation within material categories is substantial. As shown in the concrete comparison, embodied carbon varies significantly depending

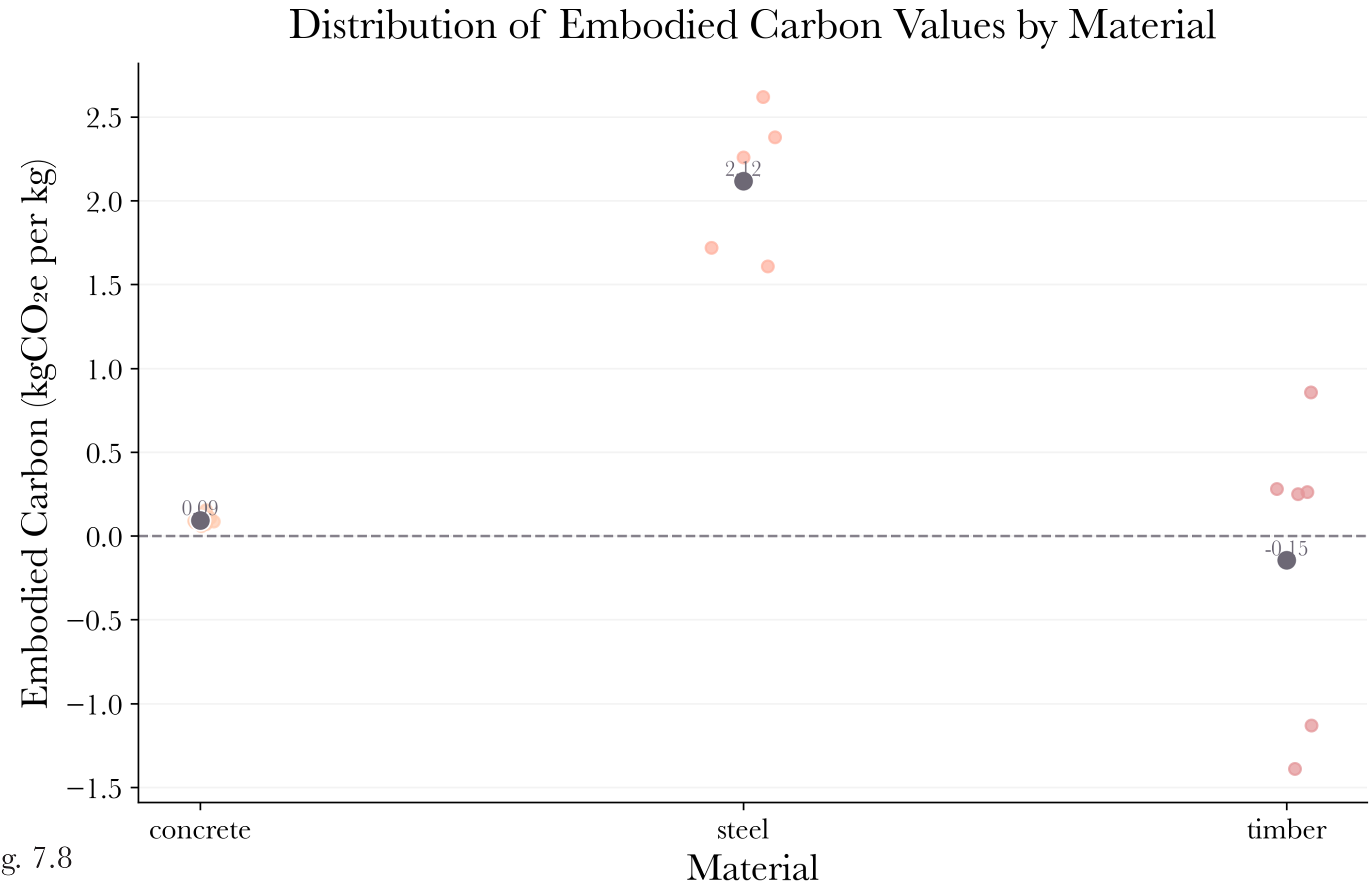


Fig. 7.8

on cement composition and replacement strategy.

Lower-carbon mixes using supplementary cementitious materials such as GGBS and fly ash achieve materially lower emissions than standard concrete mixes. This demonstrates that even when the structural system is fixed, specification decisions meaningfully influence embodied carbon outcomes.

Second, differences across material categories are even more pronounced, as shown in Figure 7.8, where steel consistently exhibits the highest embodied carbon intensity per unit mass, concrete remains relatively low, and timber spans a wide range depending on whether carbon storage is included. Steel consistently exhibits the highest embodied carbon intensity per unit mass, while concrete remains relatively low, and timber spans a wide range depending on whether carbon storage is included. The distribution plots further highlight this spread, showing tight clustering for concrete, higher but consistent values for steel, and a much wider distribution for timber due to its sensitivity to lifecycle assumptions.

Third, average comparisons reinforce these distinctions. Steel emerges as the most carbon-intensive material to produce, while timber can achieve significantly lower or even negative upfront emissions when carbon storage is accounted for. However, this apparent advantage is conditional and depends on assumptions about end-of-life scenarios and long-term material retention.

These findings clarify the relationship between structure and materials. Building height and structural system determine the quantity of material required, and therefore dominate total embodied carbon at the building scale. However, material choice and specification determine the carbon intensity of that material, introducing significant variability within those structural constraints.

Rather than contradicting one another, these two dynamics operate simultaneously. Structural decisions set the scale of emissions, while material decisions shape their magnitude and lifecycle trajectory. This interaction is critical for understanding how embodied carbon can be reduced in practice, as it highlights that meaningful reductions can be achieved both by rethinking structural demand and by optimizing material selection within those systems.

Implications

The regression findings help contextualize the barriers and opportunities identified through interviews. Empirical analysis of building life-cycle assessments confirms that structural materials, particularly concrete and steel, account for a substantial share of embodied carbon. Interventions that target these systems, including structural reuse, material salvage, and lower-carbon substitutions, therefore offer meaningful opportunities for emissions reduction.

At the same time, the analysis makes clear that material choice does not operate independently of building form. Taller buildings are consistently associated with higher embodied carbon due to increased structural demands, which are typically met through steel and reinforced concrete systems. Steel is highly carbon-intensive to produce, but its capacity for reuse and recycling allows those emissions to be distributed across multiple lifecycles. Timber presents a different set of trade-offs. While it can store biogenic carbon and, in some cases, achieve negative upfront emissions, this benefit depends on long-term material retention and end-of-life outcomes. When reused, timber can extend carbon storage over time, but this does not eliminate eventual emissions. These findings challenge the idea that embodied carbon can be reduced through material substitution alone. Material selection is not a simple hierarchy of "low" or "high" carbon options, but rather a balance between upfront carbon intensity, structural requirements, and lifecycle behavior.

The central implication is that reducing embodied carbon at scale requires a shift beyond one-time material optimization toward systems that extend material lifecycles. While current policy efforts in New York City, including Local Law 97 and emerging low-embodied-carbon initiatives, have made important progress in addressing emissions at the building level, they remain largely focused on individual projects and upfront impacts. This approach is insufficient to address the structural drivers identified in this analysis.

VIII. Scenario Analysis: Estimating the Carbon Reduction Potential of More Direct Circular Construction Policy in New York City

Introduction

Industry experts consistently emphasized that reused materials, deconstruction services, and low-carbon construction technologies remain expensive, elusive, and difficult to implement, largely because markets for these practices are still small and fragmented. Without sufficient and consistent demand, supply chains remain limited, reuse infrastructure is underdeveloped, and costs remain higher than conventional construction approaches. This study has also found that the shift to lower carbon materials is not enough. Across both public- and private-sector interviews, respondents pointed to the need for greater government involvement to overcome these barriers and enable meaningful reductions in embodied carbon within the construction and demolition sector.

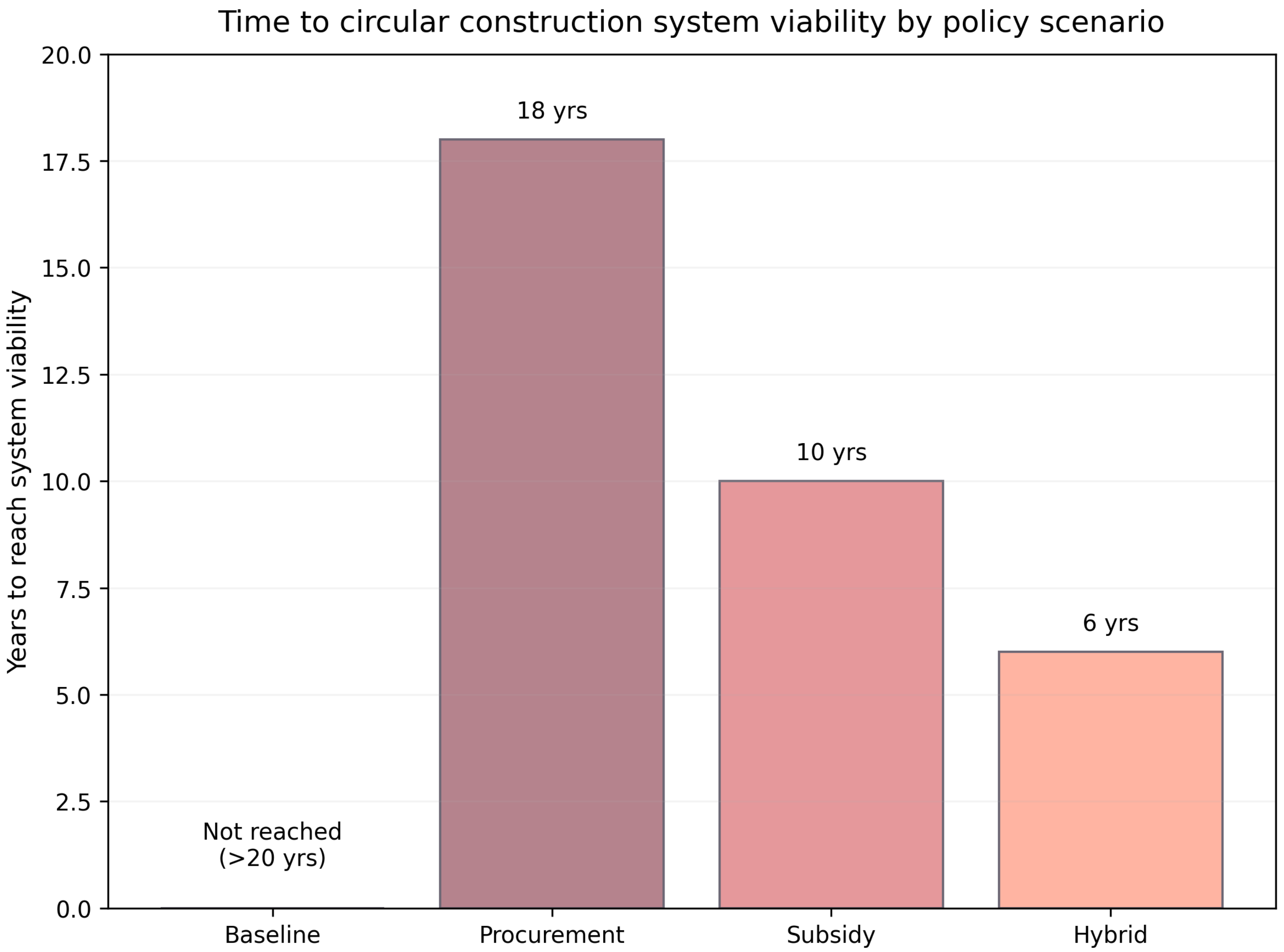
To evaluate how public policy can generate the level of demand required to shift market conditions, this research develops a simplified scenario model that estimates the scale of embodied carbon associated with construction activity in New York City and the potential reductions achievable through circular construction strategies spurred on by subsidies and regulatory requirements. The model provides an order-of-magnitude assessment of how different levels of policy intervention could influence emissions across the sector.

Methods: Economic Framing and Market Formation

This approach is informed by economic research on market formation and the adoption of emerging practices. Existing literature shows that new technologies often fail to scale not because they are technically infeasible, but because early-stage markets lack sufficient and consistent demand to reduce costs, coordinate supply chains, and build industry capacity (Fowler & Sparkman, 2017). In the context of re-use and low carbon alternative adoption, fragmented or intermittent demand limits private sector investment in closing the loop, reinforcing higher costs and preventing market stabilization, and limiting the impact on embodied carbon emissions. By varying the level of public-sector engagement, through expanded subsidies and eventual regulatory requirements, the model evaluates how increasing demand could influence market development, reduce costs over time, and enable the broader adoption of circular construction practices.

Establishing the Baseline Scale of Construction Activity

The first step in the model is estimating the overall scale of construction activity occurring in New York City. The municipal capital program provides a useful baseline for this calculation because it represents the portion of the construction market most directly



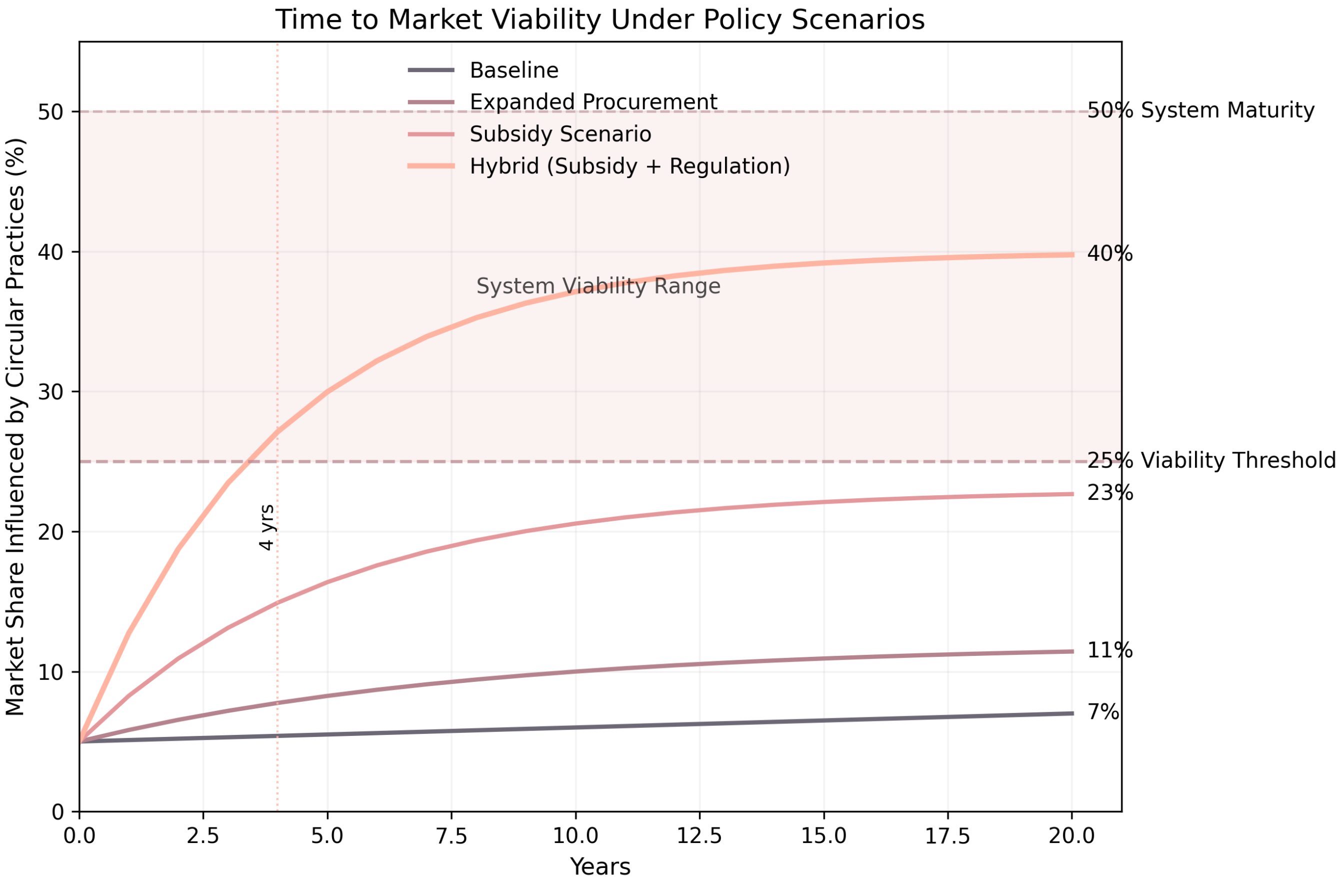
influenced by public policy. According to the New York City Office of Management and Budget Ten-Year Capital Strategy, the city plans to invest approximately $173.4 billion in capital infrastructure between fiscal years 2026 and 2035, corresponding to roughly $17 billion in annual capital spending (City of New York, Office of Management and Budget, 2025).Annual capital spending fluctuates depending on project timing and financing structures, and has historically been in the $15 billion range. This study adopts this estimate of $15 billion per year as a conservative baseline estimate of publicly funded construction activity.

Municipal capital construction represents only a portion of the broader construction sector. Industry reports estimate the total construction spending in New York City is approximately $70–80 billion annually. This includes private residential, commercial, and infrastructure development. For the purposes of this model, the midpoint estimate of $75 billion per year is used to represent the scale of construction activity across the entire city.

Methods: Applicable Capital Projects

Scenario	Market Coverage	Annual Influence	Time to Viability
Baseline	~5%	~$4B	Not reached (>20 years)
Expanded Procurement	~9–12%	~$7–9B	Not reached (>20 years)
Subsidy	~11–23%	$8.5–17B	8–12 years
Hybrid	~30–40%	~$22–30B	5–8 years

Executive Order 23 requires city agencies to measure and reduce embodied carbon emissions in certain municipal construction projects, particularly new buildings and major renovations involving structural systems or building envelopes (City of New York, 2023). Infrastructure projects such as roads, bridges, and sewer systems generally fall outside the scope of the policy (City of New York, 2023). To estimate the portion of the capital program affected by this policy, it is necessary to understand how capital spending is distributed across project types. Capital budget documents show that sectors such as education facilities, housing development, and public buildings represent a significant share of construction spending, while transportation and environmental protection investments are largely infrastructure-focused (NYC Office of Management and Budget, 2023; NYC Office of Management and Budget, 2024).



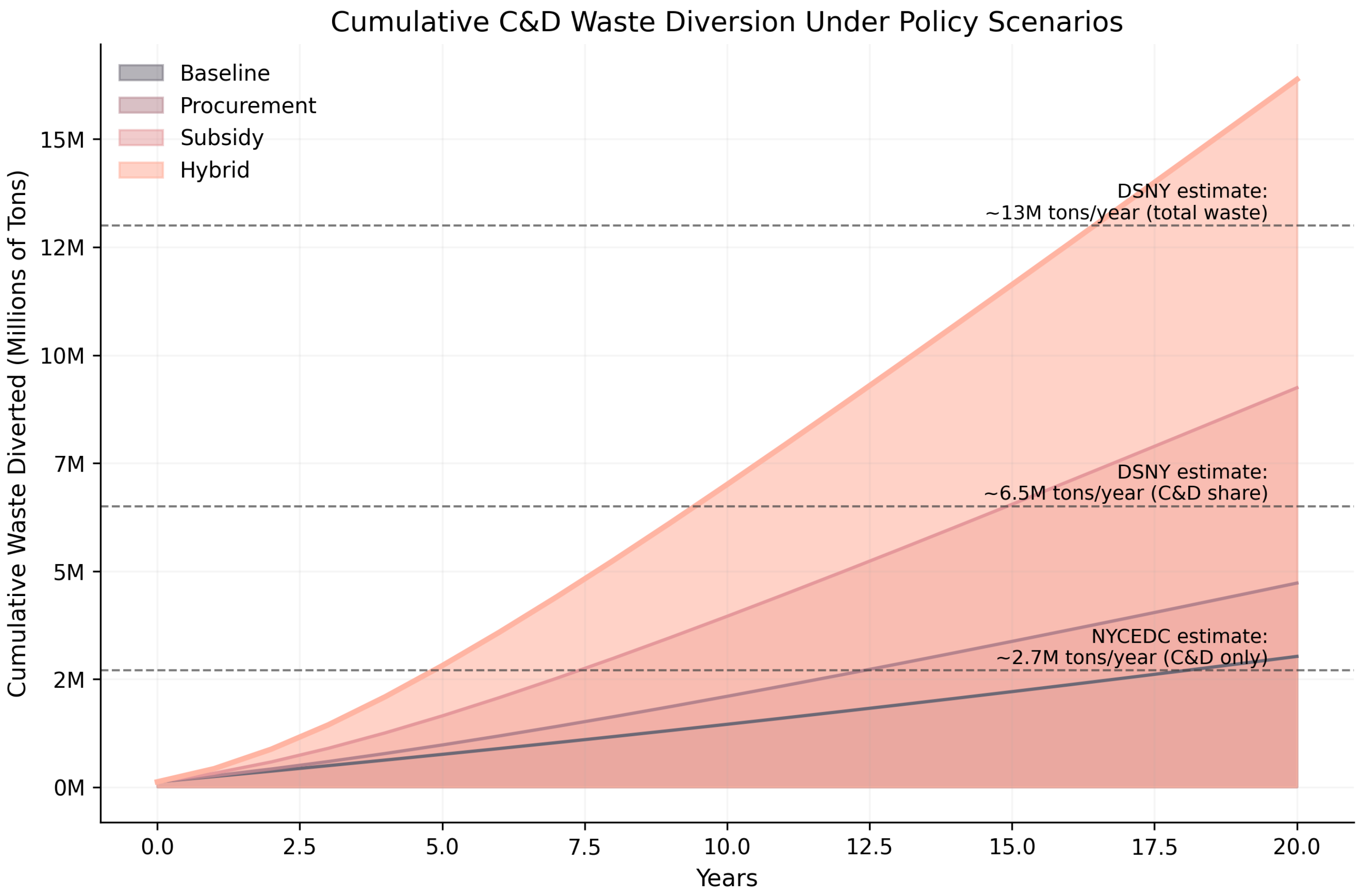
Building on this, the analysis uses capital budget data to isolate spending associated with building-focused agencies. This approach provides a more precise estimate of policy-relevant construction activity and indicates that approximately 32 percent of total capital spending is directed toward building construction. Within this group, not all projects involve construction activity that falls under EO 23. Many projects are limited to interior renovations, system upgrades, or smaller interventions that do not require embodied carbon reporting. Based on the scope of the policy and the typical mix of municipal projects, this analysis assumes that roughly 60 to 75 percent of building-related construction activity is covered by EO 23. These filters suggest that about 19 to 24 percent of total capital spending is currently subject to embodied carbon policy. With annual capital spending levels of roughly 15 to 17 billion dollars, this corresponds to about 3 to 4 billion dollars per year in construction activity covered by EO 23.

While EO 23 does not establish hard limits or performance thresholds for embodied carbon, it introduces emissions considerations into procurement decisions, effectively directing a portion of public spending toward lower-carbon material options. In doing so, the policy begins to generate consistent demand within the low-carbon materials market, helping to stimulate the economic conditions necessary for broader adoption, even if its overall market influence remains limited in scale. For this reason, EO 23 triggering spending is used as a baseline for economic investment throughout this analysis.

Minimum Viability for Scaling Circularity

Rather than trying to define an exact dollar amount required to scale circular construction, this analysis looks at how these systems actually function in practice. The Dutch case provides a useful reference point. In Amsterdam, consistent public procurement has helped create demand for reused and low-carbon materials (Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2016). However, even with strong policy support, reuse markets remain inconsistent and do not yet operate reliably at scale (Dunant, C. F. et al., 2018; Ezrapour, S. et al., 2024; Markou, E. et al., 2025; Costa, F. et al., 2025). This suggests that policy alone is not enough. What matters is whether demand is large and consistent enough to support the systems behind it.

This pattern is consistent with findings from New York City. Interviews conducted as part of this study identified fragmented and inconsistent demand as a primary barrier to implementation. When only a small number of projects use circular practices, companies have little incentive to invest in deconstruction, material processing, or reuse logistics and costs remain high across the board. As a result, supply chains remain underdeveloped and costs remain high. To understand what level of activity is needed to change this, the analysis shifts from thinking about individual projects to thinking about the share of the total construction market. At low levels of participation, circular construction remains project-specific and does not influence how the broader system operates. As participation increases, demand becomes more predictable, which allows suppliers to scale, infrastructure to develop, and material flows to become more consistent.



Drawing on both the Dutch case and the New York City findings, this analysis suggests that circular construction begins to function as a stable system only when it reaches a substantial share of total construction activity. In practical terms, this corresponds to roughly 25 to 50 percent of the market. Below this range, demand remains too limited and inconsistent to support investment. Within and above this range, circular practices begin to shape supply chains, reduce costs, and operate as a normal part of the construction process rather than an exception.

This interpretation is consistent with systems-based approaches to market development, which define scale not simply as the number of participants, but as the extent to which a behavior spreads across a system in a self-sustaining way (Fowler & Sparkman, 2017). In this context, the estimated 25–50 percent range reflects the level of market participation at which circular practices are likely to diffuse beyond policy-driven adoption and begin to reproduce through market dynamics.

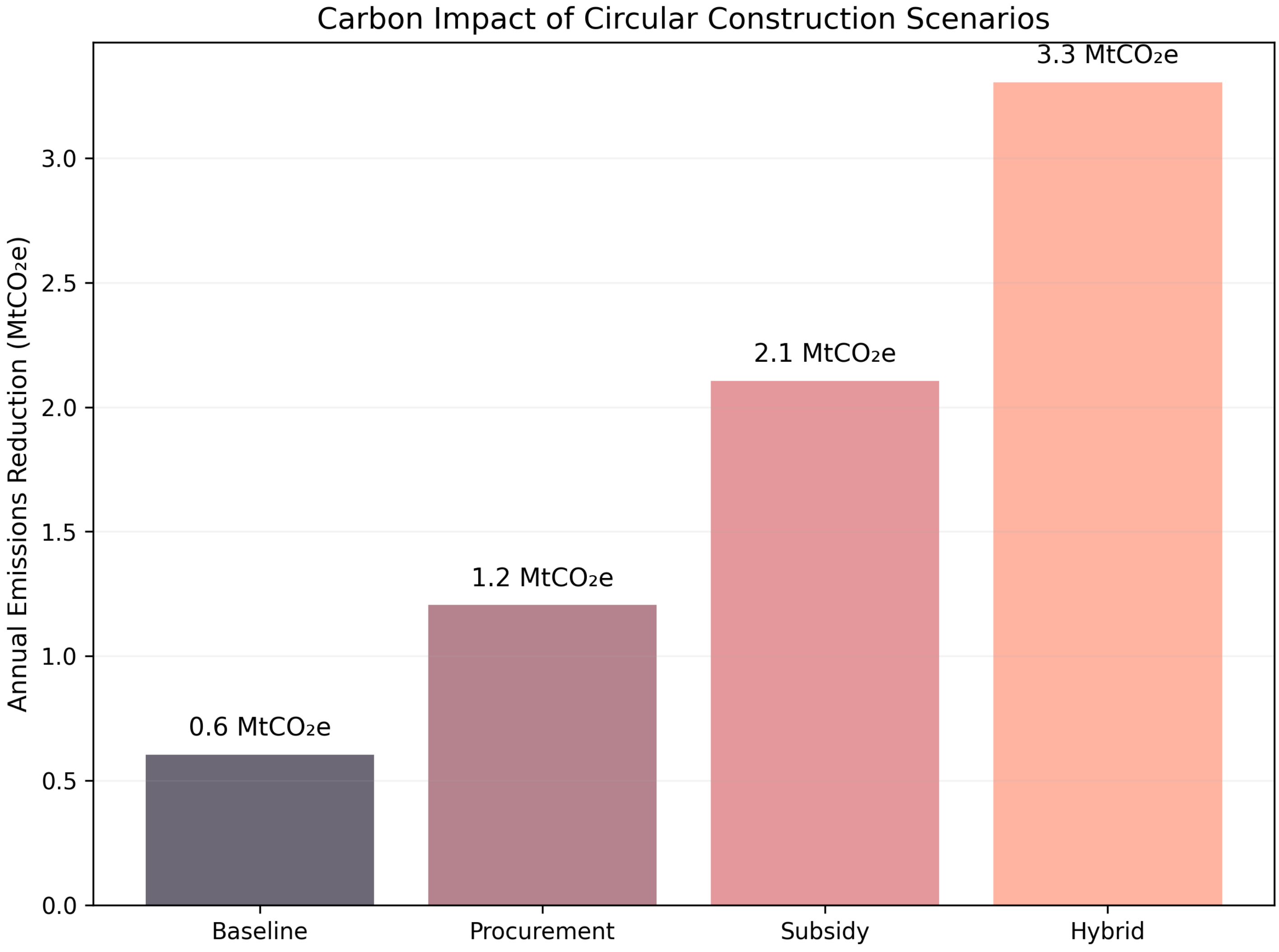
Estimating Embodied Carbon in Construction Activity

This analysis applies estimated embodied carbon intensity factors of 400–700 kgCO2e per $1,000 of construction, derived from a synthesis of building-level embodied carbon benchmarks and environmentally extended input–output models that estimate emissions per unit of economic activity (Carbon Leadership Forum, 2025; Circular Ecology, 2024; De Wolf et al., 2017; U.S. Environmental Protection Agency, 2023; GHG Protocol, 2011). This results in an estimated total embodied carbon footprint of approximately 30–52 million metric tons annually across the full construction market, with publicly funded construction accounting for roughly 6 -- 10.5 million metric tons.

Applying the estimated policy coverage of 19–24 percent of public capital spending, Executive Order 23 currently influences approximately 1 -- 2.5 million metric tons of embodied carbon emissions per year. This represents a relatively small share of total citywide construction emissions, highlighting the limited scale at which current policy operates. These estimates show that while publicly funded construction represents a meaningful portion of embodied carbon emissions, it captures only a small share of the broader construction market, constraining the ability of current policy to drive system-wide reductions.

Even within the public sector, the majority of embodied carbon remains outside the reach of Executive Order 23. When compared to the full construction market, this gap becomes even more pronounced. The majority of embodied carbon emissions in New York City are generated through private development, which is not currently subject to embodied carbon requirements.

This gap between total emissions and policy coverage underscores a central challenge for reducing embodied carbon in New York City. While procurement-based policies establish an important foundation, their climate change



impact is constrained by the scale of public investment. Achieving meaningful emissions reductions will therefore require expanding policy coverage and increasing market demand for lower-carbon materials across both public and private construction activity.

Projecting Market Transformation: Policy Scenarios and Time Horizons

This analysis models how varying levels of policy coverage and financial support could shift market conditions in New York over time. Rather than predicting exact adoption rates, the goal is to estimate order-of-magnitude timelines for when circular construction systems may begin to operate at scale, defined here as the point at which demand is sufficient to support stable supply chains, consistent material flows, and competitive pricing for reused and low-carbon materials.

Scenario 1: Baseline

As established above, current conditions only make up 4–6 percent of the total $75 billion construction market. At this level of coverage, demand for low-carbon and reused materials remains limited to a relatively small subset of projects. If this level of policy coverage remains constant over time, cumulative exposure to circular construction practices grows only incrementally. Over a 20-year period, this would correspond to approximately $60–80 billion in cumulative circular-influenced construction activity. While this represents a substantial total investment, it remains dispersed across time and project types, limiting its ability to generate the consistent, large-scale demand necessary to stabilize reuse markets or justify significant private investment in deconstruction infrastructure. This trajectory aligns with interview findings, which suggest that current levels of demand are insufficient to overcome cost barriers or supply chain fragmentation. As a result, under a baseline scenario, circular construction practices are likely to remain niche, with system-wide operationalization occurring slowly, if at all.

Scenario 2: Expanded Procurement

Modeled on NYC EDC Circular Construction Recommendations

To evaluate the impact of stronger public-sector leadership, this scenario models an expansion of procurement requirements consistent with the direction of NYCEDC circular construction guidelines (NYCEDC, 2024). While the guidelines themselves are not mandatory, they emphasize material reuse, deconstruction, and embodied carbon reduction as priority strategies for public projects. Because these strategies directly influence embodied carbon outcomes, they are treated here as an extension of existing procurement-based carbon policy frameworks such as Executive Order 23.

In this scenario, the NYCEDC Circular Construction Guidelines are modeled as mandatory procurement requirements applied across the agency’s capital portfolio, representing approximately $9 billion in annual construction activity (NYCEDC, 2024). This marks a substantial expansion from Executive Order 23, which currently influences an estimated $3 to $4 billion per year. This raises total market coverage from roughly 5 percent to approximately 9–12 percent of citywide construction activity. At this level, demand begins to approach, but does not reach, the lower bound of system viability.

The expanded procurement scenario is likely to produce partial system viability. Over a 20-year period, cumulative circular-influenced construction activity would increase to approximately $140–180 billion in that time, significantly strengthening demand consistency. This level of activity could support the emergence of specialized contractors, improved material tracking systems, and early-stage reuse infrastructure. However, without additional policy or financial support, cost premiums and supply limitations would likely persist.

Scenario 3: Subsidy-Driven Market Acceleration

This scenario introduces targeted subsidies over the next 20 years ofmarket development. To estimate an upper-bound scale of investment required to achieve system-level adoption, this analysis draws on New York City's broader fiscal capacity. Property tax revenues alone generate approximately $34 billion annually (NYC Comptroller, 2025), a portion of which is linked to value created through real estate development. This scenario models an allocation equivalent to 5 percent of property tax revenue, or approximately $1.7 billion annually, as a high-investment case to understand the magnitude of resources required to shift market conditions. This level of investment is not intended as a near-term policy proposal, but rather as an illustrative upper-bound scenario used to understand the magnitude of resources required to shift market conditions at scale. These subsidies are applied over a twenty year period to offset the incremental costs associated with reused materials, deconstruction practices, and low-carbon alternatives.

In practice, funding at this scale would likely be assembled through a combination of mechanisms rather than a single revenue source. One potential source is revenue generated through carbon pricing or cap-and-invest programs established under the Climate Leadership and Community Protection Act, which could be directed toward embodied carbon reduction strategies (Resources for the Future, 2025). Additional funding could be derived from avoided costs associated with waste transport and disposal, as reduced reliance on landfilling and export systems frees up existing expenditures that can be reinvested into circular material systems (New York City Department of Sanitation, 2024; New York State Department of Environmental Conservation, 2023). Capital-intensive components, such as material recovery, storage, and redistribution infrastructure, could also be financed through municipal bonds or other green financing mechanisms, allowing costs to be distributed over time (City of New York, 2015; Climate Advisers, 2024). Together, these approaches suggest that while the model assumes a concentrated public investment, the equivalent level of investment could be mobilized through a diversified and more politically feasible set of financing strategies. Additional mechanisms may include value capture strategies tied to real estate development, such as zoning incentives or negotiated public benefits, which shift a portion of the cost burden onto projects that directly benefit from increased land value and public investment, reducing the need for direct public subsidy.

While the literature does not converge on a single estimate for the cost premium associated with circular construction, policy frameworks consistently identify financial, logistical, and institutional barriers that inhibit adoption. The Dutch Government's circular economy program emphasizes the need for targeted financing mechanisms, market incentives, and regulatory support to overcome these constraints, indicating that circular practices introduce additional coordination, supply chain, and implementation challenges that are not yet fully internalized by the market (Ministry of Infrastructure and the Environment, 2016) .

Given this combination of evidence, this study adopts a 10–20 percent incremental cost premium as a conservative modeling assumption. This range is intentionally bounded between two observed conditions: on one end, low-carbon strategies that can be implemented at little to no additional cost within existing systems; and on the other, more complex circular interventions that require new processes, labor inputs, and coordination across fragmented supply chains. The selected range therefore reflects a middle-ground estimate that captures the additional effort required to implement circular practices without overstating costs observed in early-stage or highly constrained case studies. Importantly, the model assumes that subsidies apply only to the additional cost of implementing circular practices, rather than the full cost of construction. In other words, public funding is used to cover the gap between conventional and circular approaches, making lower-carbon options financially viable without subsidizing entire projects.

By reducing upfront costs, subsidies accelerate adoption across both public and private sectors and significantly expand market participation relative to procurement-only approaches. This level of intervention enables faster scaling of supply chains, encourages private investment in reuse infrastructure, and improves contractor familiarity with circular practices. However, while this scenario brings the market close to the lower bound of system viability, it does not fully reach the threshold at which circular practices become system-defining.

Scenario 4: Hybrid Model

The final scenario combines financial support with longer-term regulatory and institutional reinforcement. Rather than operating as strictly time-bound interventions, these mechanisms are modeled as overlapping forces that are strongest in the early years and gradually diminish as circular practices become more established. In the initial phase, subsidies play a critical role in accelerating adoption by reducing cost barriers and supporting the development of supply chains, labor capacity, and market familiarity. Over time, as these systems mature, regulatory requirements and procurement policies sustain continued growth by normalizing circular practices across both public and private development.

While the model does not explicitly segment these phases, the shape of the growth curve reflects this transition: rapid early adoption driven by financial incentives, followed by slower but sustained expansion as circular construction becomes embedded within standard industry practice. In this way, regulatory mechanisms function less as a discrete policy shift and more as an ongoing structural force that reinforces adoption, ensuring that circular practices move from niche application to industry norm.

This approach reflects a common policy sequencing strategy observed in environmental transitions, where incentives are used to build market capacity before stricter regulations are introduced (Byrne, J. et al., 2022; Ellen MacArthur Foundation, 2013, 2019, 2020; C40 Cities, 2020; Climate Advisers, 2024)

Under this hybrid model, market coverage increases rapidly during the subsidy phase and continues to expand through regulatory enforcement, ultimately reaching approximately 30–40 percent of total construction activity. At this level, circular practices become embedded within standard industry workflows rather than remaining optional or experimental. Over a 20-year period, cumulative circular-influenced construction activity is estimated to reach approximately $350–500 billion, based on projected adoption rates affecting roughly 25–35% of New York City's $75 billion annual construction market. More importantly, this scenario produces the most rapid transition to system-wide viability, with operational circular supply chains emerging within approximately 5–8 years. By aligning financial incentives with regulatory mandates, this approach addresses both cost and demand barriers simultaneously, creating the conditions necessary for long-term market stability.

Waste and Carbon Reduction Scenario and Results

To understand what scaling circular construction actually means in practice, this analysis translates market share into three outcomes: avoided C&D waste, reduced embodied carbon, and associated economic value. C&D waste is the largest component of the waste stream in New York State, accounting for approximately 46 percent of total waste generation (New York State Department of Environmental Conservation, 2023). In New York City, estimates vary due to fragmented reporting, but generally fall between 2.7 and 6.5 million tons annually (NYCEDC, 2024; DSNY, 2024). To keep the analysis grounded, this study uses a midpoint estimate of 4 million tons per year. While a large share of this material is technically recoverable, real-world recovery is constrained by cost, logistics, and market conditions. Rather than relying on idealized recovery rates, this analysis assumes that circular construction reduces waste by 50 to 70 percent within projects where it is applied, reflecting a more realistic implementation range.

Under the hybrid scenario, where circular practices reach 30 to 40 percent of total construction activity, this translates to approximately 1.2 to 1.6 million tons of material influenced annually. This corresponds to roughly 600,000 to 1.1 million tons of waste avoided each year. At this scale, the impact is substantial: it is equivalent to approximately 6 to 11 percent of the total plastic waste entering the ocean annually (United Nations Environment Programme, 2021), or the annual waste generated by roughly 750,000 to 1.3 million people, comparable to the population of a mid-sized U.S. city (EPA, 2018). These comparisons help situate the magnitude of material diversion enabled by circular construction. Rather than operating at the margins, circular practices at this level begin to meaningfully alter material flows across the construction system.

The material reduction translates directly into embodied carbon savings. As established earlier in this chapter, total construction activity in New York City is associated with approximately 30 to 52 million metric tons of embodied carbon annually, based on standard intensity factors. Circular construction strategies are assumed to reduce embodied carbon by approximately 20 percent within affected projects. This estimate represents a midpoint within the range of reductions identified in prior research on material efficiency and circular construction, which generally find emissions reductions on the order of 10 to 40 percent depending on the depth of intervention (International Energy Agency, 2019; Ellen MacArthur Foundation, 2019; Carbon Leadership Forum, 2025). Applying this reduction across the hybrid scenario results in estimated emissions savings of 1.8 to 4.2 million metric tons of CO2e per year.

This corresponds to approximately 1.8 to 4.2 million metric tons of CO2e annually, equivalent to eliminating the emissions of a mid-sized U.S. city such as New Orleans, which emits roughly 3.2–3.5 million metric tons of CO2e per year (City of New Orleans, 2022). In the context of New York City, which emits on the order of 50 million metric tons of CO2e annually according to the NYC Greenhouse Gas Inventory (City of New York, 2023), this represents approximately 3.5 to 8 percent of total annual emissions, indicating that circular construction has the potential to produce system-level impacts rather than incremental reductions.

Avoided waste also carries direct economic value. Using conservative estimates of $100 to $300 per ton for recoverable material, including avoided disposal costs and resale potential, the avoided waste corresponds to approximately $60 million to $330 million annually. The larger economic impact, however, comes from shifting how materials move through the construction system. With total construction activity at approximately $75 billion per year, even partial circulation of materials represents a significant economic opportunity. Under a mature circular system, this analysis estimates that 3 to 8 percent of total construction value can be recovered through reuse and reduced material demand, resulting in approximately $2 to $6 billion in annual value. This estimate is intentionally conservative and reflects real constraints such as material degradation, transaction costs, and incomplete secondary markets.

Across scenarios, the difference is not just magnitude but behavior. At baseline levels, impacts remain limited and project-specific. Expanded procurement increases activity but does not fundamentally change system dynamics. Only under the hybrid scenario, where circular practices reach 30 to 40 percent of the market, do both environmental and economic outcomes begin to scale in a way that reflects structural change. What this makes clear is that the impact of circularity is significant and that it is possible.

The systems required to support reuse and material recovery already exist in partial form. The challenge is generating enough consistent demand for those systems to stabilize and expand. Without that, circular construction remains incremental. With it, it becomes a defining feature of how the construction sector operates.

The Overall Cost of Circular Integration into C&D

The results of this analysis suggest that transitioning to circular construction in New York City requires meaningful but manageable public investment, and that this investment functions less as a cost than as a catalyst for broader economic and environmental gains. Under the hybrid scenario, which achieves system-level adoption, the city would need to allocate approximately $1.7 billion annually in targeted subsidies, equivalent to roughly 5 percent of annual property tax revenue. Over a twenty-year period, this corresponds to a total public investment of approximately $34 billion.

In return, circular construction is estimated to generate approximately $2 to $8 billion in annual economic value within the construction sector. This value is derived from a combination of avoided disposal costs, material reuse, reduced demand for virgin materials, and improved system efficiency. When sustained over time, this corresponds to approximately $40 to $160 billion in cumulative economic benefit over twenty years, exceeding the total public investment required to initiate the transition. Beyond direct financial returns, circular construction also produces structural economic benefits. It increases labor demand, particularly in deconstruction and material processing, supports the development of local reuse markets, and reduces exposure to volatile global material supply chains (Ellen MacArthur Foundation, 2013, 2019, 2020; Mair, C. & Stern, T., 2020; Brussels Environment, 2016; McKinsey Global Institute, 2017). In doing so, it strengthens the resilience and productivity of the construction sector rather than simply reducing its environmental impact.

The environmental implications are equally significant. Over time, these reductions accumulate into a meaningful contribution toward the city's long-term climate goals. These findings suggest that circular construction is not a marginal intervention, but a system-level strategy. The level of public investment required to initiate this transition is modest relative to both the size of the construction sector and the scale of benefits it unlocks. Rather than representing a net cost, this investment enables the development of a more efficient, lower-carbon, and economically generative construction system. In this context, the question is not whether New York City can afford to invest in circular construction, but whether it can afford not to.

IX. Insights and Recommendations

The Limits of the Current System

New York City's approach to reducing emissions in the built environment remains largely embedded within a linear construction model, in which materials are produced, used once, and discarded. While recent policies have begun to address embodied carbon, they do so within a system that has not fundamentally changed. As a result, progress remains partial and uneven.

At the state level, Executive Order 22 targets emissions associated with material production, while at the city level, Executive Order 23 focuses on project-level decision-making and embodied carbon assessment. Together, these policies begin to align supply and demand for lower-carbon materials. However, they operate in parallel rather than as a unified system, limiting their ability to produce sustained, system-wide change. Embodied carbon is increasingly measured, but it is not yet meaningfully regulated or consistently reduced. As a result, while important progress has been made in developing the framework for tracking embodied carbon, these efforts fall short of fully addressing it.

In addition, the statewide Solid Waste Management Plan and the city's Circular Design & Construction Guidelines begin to engage with the waste stream and the broader linear economic model. However, fragmentation remains most evident in the "missing middle" of the material lifecycle. While early design and end-of-life waste management receive growing attention, there is little coordinated infrastructure for material recovery, storage, tracking, and redistribution. Materials that could be reused are routinely discarded, not because reuse is infeasible, but because the systems required to support it are underdeveloped or absent. As a result, circular practices emerge in isolated pockets rather than at scale.

Across interviews, this structural limitation is reflected in practice. Although awareness of circularity and embodied carbon is becoming more widespread among enthusiasts and practitioners, implementation is consistently constrained by cost, timelines, and coordination challenges. These pressures are not simply the result of individual project decisions, but of a broader system that prioritizes speed, predictability, and established supply chains. Circular strategies are often considered early in the design process, yet are frequently abandoned as projects move into procurement and construction, where financial and logistical constraints intensify.

Incremental Approaches Are Insufficient

Efforts to reduce embodied carbon have largely focused on improving material efficiency or substituting lower-carbon materials within existing construction practices. This is admirable and represents New York's commitment to its climate goals. However, the findings of this research indicate that these approaches are inherently limited when applied within a linear system. The quantitative analysis demonstrates that structural systems, building height, and lifecycle behavior play a more decisive role in determining emissions than any single material choice. While steel and timber offer greater potential for reuse, and timber can store carbon under certain conditions, no material consistently performs as "low-carbon" across all contexts. Reinforced concrete, which dominates construction in New York City, remains particularly difficult to recover and reuse at scale. As a result, material substitution alone cannot achieve meaningful reductions in embodied carbon. Instead, emissions outcomes depend on how materials are used, how long they remain in circulation, and whether they can be recovered and reused over time. Without systems that support reuse at scale, even lower-carbon materials will continue to generate emissions through repeated production cycles.

These findings reveal a critical limitation in current policy approaches. By focusing on individual buildings, specific materials, singular sectors, or upfront emissions, existing frameworks fail to address the system-level drivers of material consumption, waste, and excess carbon production in the built environment. While the efforts of the city and state represent important progress, they do not fundamentally alter the linear structure of the construction sector. As a result, they are unlikely to produce the sustained reductions in embodied carbon and reliance on virgin material required to achieve long-term climate goals or truly reckon with the magnitude of the global waste crisis.

Scale and Market Dynamics as the Central Constraint

If circular construction is technically feasible, this study has found that its limited adoption can be explained by the absence of fully scaled economic markets. Existing reuse markets are fragmented, inconsistent, and difficult to rely on, creating longer lead times, higher perceived risks, and increased costs for developers and contractors. Even when circular strategies are viable, these conditions make them difficult to prioritize within conventional project delivery frameworks. This dynamic produces a self-reinforcing cycle. Limited scale leads to higher costs and uncertainty, which discourages adoption. Low adoption then prevents markets from reaching the level of stability required to reduce costs and improve reliability. As a result, circular construction remains marginal rather than mainstream.

The interview findings reinforce this dynamic. Reuse requires coordination across recovery, storage, testing, and resale, yet these systems are not only not fully developed, but not adequately funded by the government. Supply chains are fragmented, and knowledge remains concentrated among a small number of practitioners rather than distributed across the industry. The absence of standardized workflows and reliable material streams adds time, cost, and uncertainty to projects, further discouraging adoption. Breaking this cycle requires deliberate intervention to generate consistent demand and support early-stage market development. Without scale, circular systems cannot stabilize. Without stability, they cannot compete with conventional construction practices.

Economic Viability and System-Level Opportunity

While circular construction is often perceived as costly, the economic analysis presented in this research suggests the opposite. Transitioning to a circular construction system in New York City is estimated to require approximately $1.7 billion in annual public investment, equivalent to roughly five percent of property tax revenue. Over a twenty-year period, this corresponds to a total investment of approximately $34 billion. Crucially, this is an investment that functions as a catalyst rather than a cost. This study has found that the system it enables could generate between $2 and $8 billion in annual economic value through avoided disposal costs, reduced reliance on virgin materials, efficiency gains, and the expansion of local reuse markets. Over time, these returns exceed the initial investment, producing cumulative benefits that significantly outweigh public expenditures.

Beyond direct financial returns, circular construction offers broader structural advantages. By increasing demand for deconstruction, material processing, and reuse, it supports the growth of local industries and labor markets. It reduces dependence on volatile global supply chains and mitigates the environmental impacts associated with continuous resource extraction. In this context, circular construction is not simply a sustainability strategy or a system-level economic development opportunity. It is also an opportunity for New York City to use the full power of its urban laboratory to enable a new, more efficient and sustainable model. To become a national and/or global leader in the race for climate mitigation and resilience. The implication is clear: the question is not whether New York City can afford to invest in circular construction, but whether it can afford not to.

Governance and Data as Structural Barriers

Despite its economic and environmental potential, circular construction cannot scale without institutional alignment. Responsibility for construction, materials, and waste is currently distributed across multiple agencies, including the Department of Buildings, NYCEDC, various offices within the Mayor’s administration and beyond. Planning institutions play a limited role, and no single entity is responsible for coordinating circular construction as a system. This fragmentation contributes directly to inconsistent standards, limited knowledge sharing, and a lack of long-term strategic coordination. Without a central body to align policies, markets, and infrastructure, efforts remain dispersed and difficult to scale.

At the same time, data infrastructure remains underdeveloped. There is no unified system for tracking materials across building lifecycles, and existing data is often project-specific and non-interoperable. This limits the city’s ability to measure embodied carbon, enforce policy requirements, and identify opportunities for material reuse. It also prevents the accumulation of institutional knowledge, leaving expertise concentrated among a small number of practitioners. These governance and data gaps are not secondary challenges. They are foundational constraints that prevent circular systems from functioning effectively. Without coordinated oversight and transparent information flows, even well-designed policies and market interventions will struggle to achieve lasting impact.

From Fragmentation to System Coordination

Given these constraints, the transition to circular construction requires a shift from isolated interventions to coordinated system design. Expanding public procurement represents the most immediate and effective starting point. New York City already controls a substantial volume of construction spending, and even under current conditions, this spending influences a meaningful share of the market. By expanding the scope of procurement policies, establishing minimum thresholds for reused and low-carbon materials, and requiring whole-life carbon assessments, the city can create the consistent demand necessary to stabilize reuse markets and reduce uncertainty.

However, demand alone is insufficient without the physical systems required to support it. Even when materials are recoverable, they are frequently discarded due to the absence of storage facilities, processing centers, and coordinated logistics networks. Investment in material reuse hubs, deconstruction infrastructure, and integrated transportation systems is therefore essential. These systems must be designed to function at scale and integrated with existing waste management frameworks. At the same time, the development of a unified data framework is critical. Establishing standardized life cycle assessment requirements, implementing material passports, and creating a centralized data platform would enable materials to be tracked across their lifecycle, improve transparency, and support more effective policy enforcement. These systems would also allow institutional knowledge to accumulate over time, reducing reliance on individual expertise.

Regulatory reform is similarly necessary to address barriers embedded within existing codes and approval processes. Developing clear pathways for the use of reused materials, adopting performance-based standards, and streamlining permitting processes would reduce uncertainty and make circular practices more accessible. Embedding circularity within design processes is equally important. Decisions made early in the design phase determine whether materials can be recovered and reused in the future. Requiring or incentivizing design for disassembly, promoting modular construction, and prioritizing adaptive reuse over demolition would shift the built environment toward long-term material circulation.

To coordinate these efforts, New York City should establish a dedicated institutional entity responsible for circular construction. Such an office would align policies, manage data systems, coordinate across agencies, and ensure that circularity is treated as a system-wide priority rather than a collection of isolated initiatives.

Transition and Long-Term Transformation

The transition to circular construction will require a phased approach that addresses short-term barriers while building toward long-term system stability. In the immediate, and some of this is already being done, efforts should focus on expanding procurement, launching pilot projects, standardizing data systems, and supporting needed operational infrastructure. These actions will reduce uncertainty and create the foundation for broader adoption. As markets continue to materialize, in the near term, strategies should focus on scaling adoption through targeted financial incentives for private actors and strengthened regulatory requirements.

Subsidies for deconstruction, support for reuse infrastructure, and adjustments to waste policies can help accelerate this transition while gradually shifting industry norms. Over the long term, circular construction should become embedded within standard practice, supported by mature markets, integrated data systems, and coordinated governance structures. At this stage, the need for direct subsidies diminishes as circular systems become economically self-sustaining.

X. Circularity: A

Planners Role

This research demonstrates that circular construction is not a niche sustainability strategy, but a necessary evolution of urban development. It offers a pathway to reduce emissions, decrease waste, stabilize material supply chains, and generate new forms of economic value without limiting growth. The construction and demolition sector presents a particularly effective entry point for this transition. Unlike consumer-facing markets, it is highly coordinated, professionally managed, and already embedded within regulatory and technical systems, making it well suited for large-scale implementation.

The findings also point to a broader shift in the role of planning. Planning is no longer only concerned with shaping where and how cities grow, but with managing how resources move through urban systems over time. This requires a transition from short-term construction cycles to long-term material lifecycles, and from fragmented governance to more integrated approaches that align decision-making across institutions. In this context, planning extends beyond regulating individual projects to structuring the systems that underpin material use, recovery, and circulation. Within this context the planner must not only think of a project, nor can she only focus on neighborhoods, urban systems, or regional issues. She must use her role to work to solve both urban and global problems within the urban context. Decisions must be made using a fully integrated understanding of the short term goals, the economic possibility, the human impact, the long term costs, and the profound consequences of inaction.

This shift repositions the built environment itself. Buildings can no longer be understood solely as static assets, but as dynamic material stocks that carry long-term value. Treating existing structures as repositories of reusable materials, rather than as obstacles to redevelopment, opens new opportunities for reducing waste and retaining embodied value within the city. This reframing has implications not only for environmental performance, but for how urban development is conceptualized more broadly.

New York City is uniquely positioned to lead this transition. Given the scale of its construction market and its existing institutional capacity, the city has the potential to shape not only local practices, but broader industry standards. The tools, immediate knowledge, and initial policy frameworks are already in place. What is required is the coordination, scale, and political commitment necessary to move from fragmented efforts to a fully integrated system.

The future of urban development will not be defined only by what cities build, but by how they structure systems that are more sustainable, equitable, and resilient. Circularity is not peripheral to this shift—it is fundamental to it.

XI. Conclusion

This research began with a central question: how can New York City reduce embodied carbon in its built environment in a way that is both scalable and economically viable? The findings point to a clear answer. Circular construction is not only feasible, but necessary. Across policy analysis, interviews, and quantitative modeling, the same pattern emerges. New York City already has many of the components required to support a circular construction system, including technical expertise, policy momentum, and a large and stable construction market. What is missing is not innovation, but alignment. Existing efforts remain fragmented, limiting their ability to scale and produce meaningful system-wide change.

At the same time, the urgency of the problem continues to grow. While the city has made significant progress in building a framework to begin addressing operational emissions, embodied carbon remains a large and underregulated source of emissions. This is directly tied to the city's construction and demolition waste stream, which continues to operate within a linear model of extraction, use, and disposal. These are not separate issues. They are two sides of the same system. This research shows that circular construction offers a pathway to address both. By reducing reliance on virgin materials, extending material lifecycles, and keeping resources in use, circular systems can significantly reduce emissions while also decreasing waste. Importantly, this transition does not require a contraction of the construction economy. Instead, it reshapes it by shifting activity toward reuse, deconstruction, and local material processing, creating new forms of economic value in the process.

The key constraint is scale. Circular practices already exist, but they remain limited in reach and consistency. Without coordinated demand, enabling infrastructure, and supportive policy frameworks, these practices cannot compete with the speed and cost efficiency of linear systems. This is where planning becomes critical. Planning has the ability to align fragmented systems, shape markets through procurement and regulation, and create the conditions necessary for circularity to operate at scale. The implications extend beyond construction. At its core, this research reflects a broader shift in how cities must operate. The assumption that urban growth can continue indefinitely through extraction and disposal is no longer viable. Climate change, resource constraints, and the limits of ecological systems make this clear. Planning must now operate within these limits, and in doing so, redefine what sustainable growth looks like.

Circular construction is one pathway forward. It allows cities to continue building and evolving while reducing environmental impact and strengthening economic resilience. The tools, technologies, and strategies required to implement it already exist. What is needed now is coordination, commitment, and the willingness to move beyond incremental change. It is therefore inherently a planning problem that planners must set out to solve. For New York City, the opportunity is significant. With its regulatory capacity, market scale, and global influence, the city is well positioned to lead this transition. Doing so would not only reduce emissions locally, but also help establish a model for other cities facing similar challenges.

Ultimately, the future of urban development will not be defined only by what we build, but by how we use, reuse, and value the materials already around us. The systems that have shaped cities for the past century were built on the assumption that resources were infinite and impacts could be ignored. That assumption no longer holds. Circular construction offers a way forward, not by stopping growth, but by changing how growth happens. The question is no longer whether this transition is possible. It is whether we choose to make it.