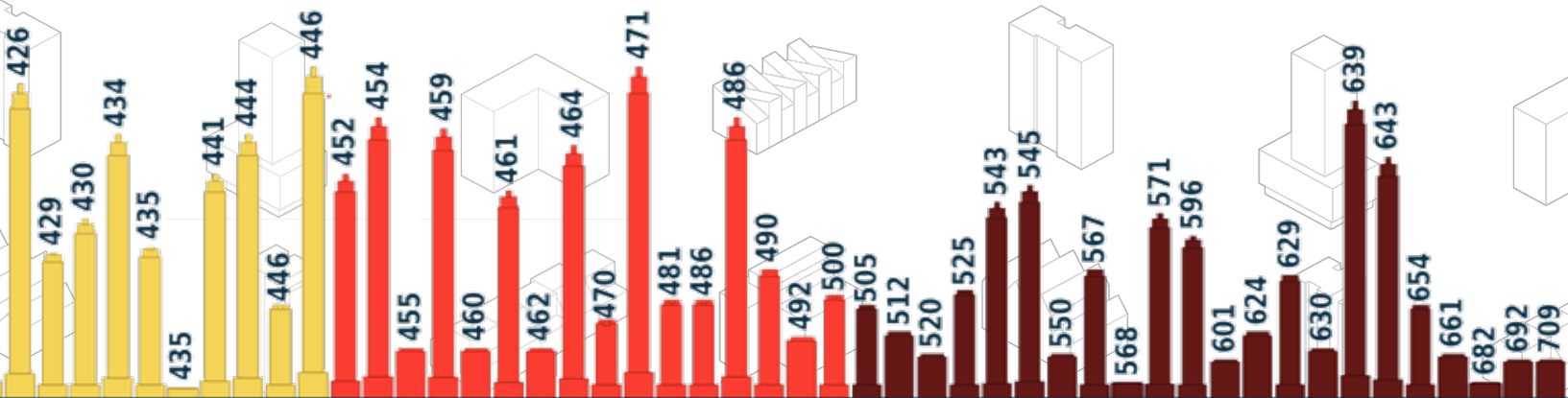


How Design Drives Carbon II

Upfront Embodied Carbon in 100 Projects



BDP. Quadrangle

Built Original.

BDP. Quadrangle



**JABLONSKY, AST
AND PARTNERS**
CONSULTING ENGINEERS



Creative Thinking
Practical Results



Salas O'Brien



HONEYCOMB

ENTUITIVE



engineeringlink
building envelope & structure

Blackwell



UNIVERSITY OF TORONTO
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ARCHITECTURE, LANDSCAPE, AND DESIGN

Special thanks to Jablonsky Ast & Partners, RJC Engineers, Salas O'Brien, Honeycomb Engineering, Entuitive, Engineering Link Inc., and Blackwell for their contributions in completing the structural component of this study. Thank you also to the student contributions from the Design Research Internship Program (DRIP) at the Daniels School at the University of Toronto and the Eco Canada Employment Program.

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Terms and Definitions

Embodied Carbon (EC)

Embodied carbon emissions are the total greenhouse gas emissions produced throughout the lifecycle of building materials, from extraction and processing to transportation, construction, maintenance, and disposal. Unlike operational carbon, which occurs during the building's use, embodied carbon is associated with materials and processes, often "locked in" before the building is occupied.

Embodied Carbon Intensity (ECI)

ECI measures embodied carbon emissions per square meter of building area (kgCO₂e/m²). It allows for assessing and comparing the carbon footprint of building materials and construction processes.

Environmental Product Declaration (EPD)

An EPD is a standardized document that provides transparent and verified information about the environmental impacts of a product or material throughout its life cycle. EPDs are based on a Life Cycle Assessment (LCA) and follow specific guidelines outlined in Product Category Rules (PCRs) for consistency and comparability within a product category.

Floor Space Index (FSI)

FSI is the ratio of a building's total floor area to the size of its plot, used in urban planning to regulate building density and land use.

Gross Floor Area (GFA)

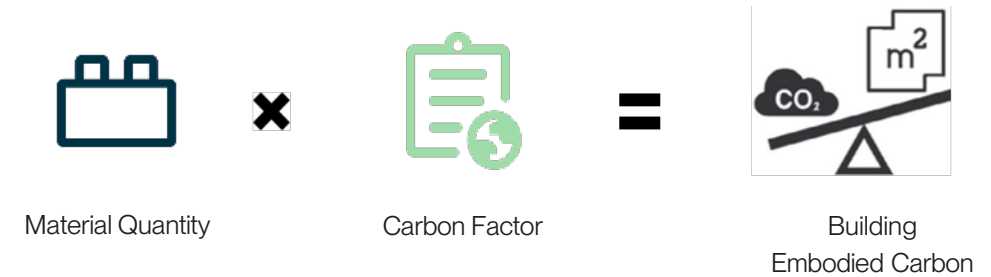
GFA as defined by NRC is the area of all fully enclosed spaces measured from the outside face of enclosing walls for each floor including interior walls and structure, with no deductions for openings and excluding parking. This provides a consistent and reliable basis for comparing carbon performance across various projects, ensuring that carbon emissions are consistently reported per square meter of building area.

National Research Council of Canada (NRC)

The NRC is a government agency responsible for supporting and promoting research and development in various scientific and technological fields. It has provided guidelines for architects on whole- building carbon life cycle assessments.

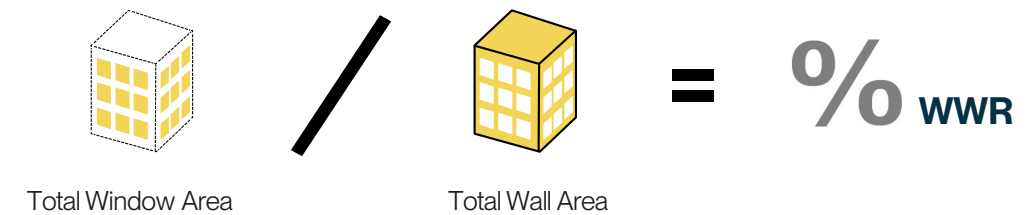
Upfront Embodied Carbon Emissions

Greenhouse gas emissions that are generated during the extraction, production, transportation, and assembly of building materials before a building becomes operational (carbon life cycle stages A1-A5).



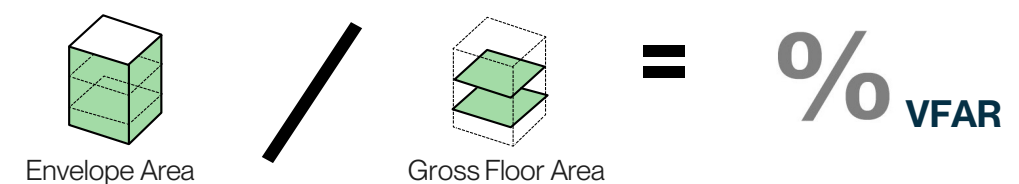
Window to Wall Area Ratio (WWR)

WWR is the percentage of a building's wall area covered by windows. It affects energy efficiency, with higher WWR generally increasing heat gain and loss. Optimal WWR balances natural light and thermal performance, reducing energy demand and improving building performance.

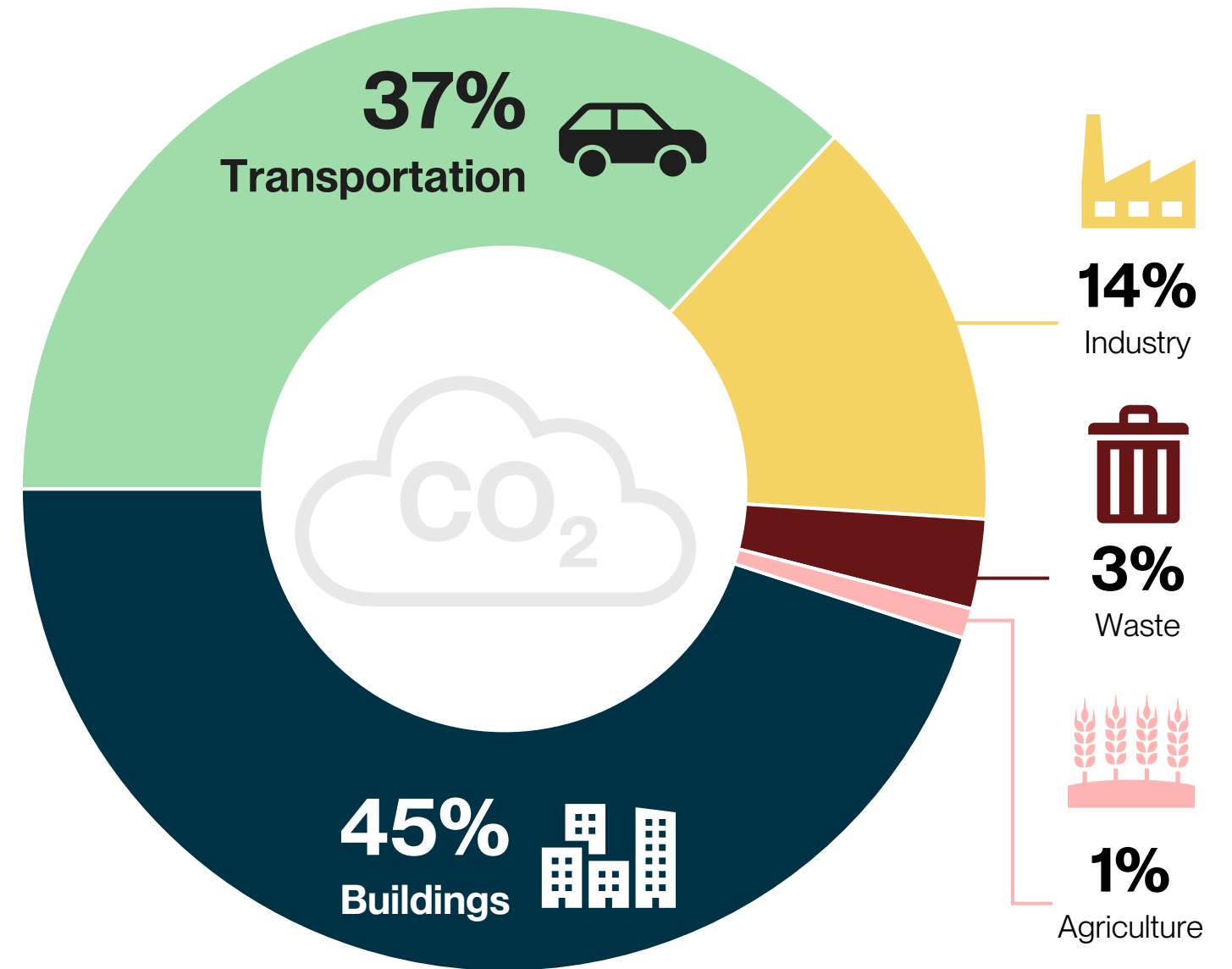


Vertical Floor Area Ratio (VFAR)

VFAR measures the relationship between a building's vertical surface area and its floor area to assess heat loss potential due to building shape. A lower VFAR indicates a more compact form, which reduces heat loss by minimizing envelope surface area and thermal bridging points.



01 Introduction



From Envelope to Whole Building

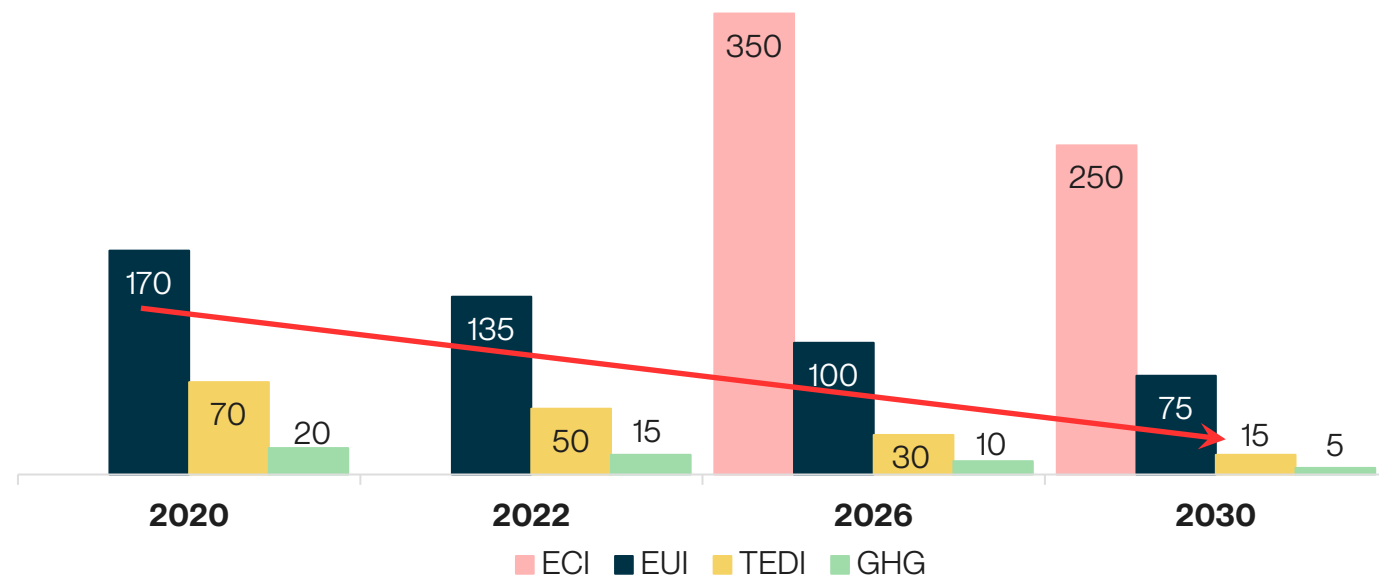
Globally buildings account for 34% of energy- and process-related CO₂ emissions, of which 10% is attributable to embodied carbon from material production, transportation, and construction.¹ In the Greater Toronto and Hamilton Area, buildings represent 45% of community greenhouse gas emissions, making the upfront carbon of new construction one of the most consequential climate levers available to the design profession.²

Figure 1 - Carbon Emission Inventory Report, The Atmospheric Fund, 2024

¹ UNEP, Global Status Report for Buildings and Construction, 2024.

² Carbon Emission Inventory Report, The Atmospheric Fund, 2024.

Our Net Zero Carbon Pathway



In May 2023, Toronto became the first North American jurisdiction to regulate upfront embodied carbon through the Toronto Green Standard (TGS) Version 4. Upfront embodied emissions (LCA stages A1–A5) are capped at 350 kgCO₂e/m² for Tier 2 and city-owned buildings; This tightens to 250 kgCO₂e/m² for Tier 3.³ Private Part 3 developments currently have no mandatory reporting requirements, but and were anticipated to require reporting with the introduction of TGS v5, followed by progressively tighter thresholds after that. The Building Code is anticipated to include new requirements for embodied carbon reporting by 2030 which will make quantified, portfolio-scale the new operating context.⁴

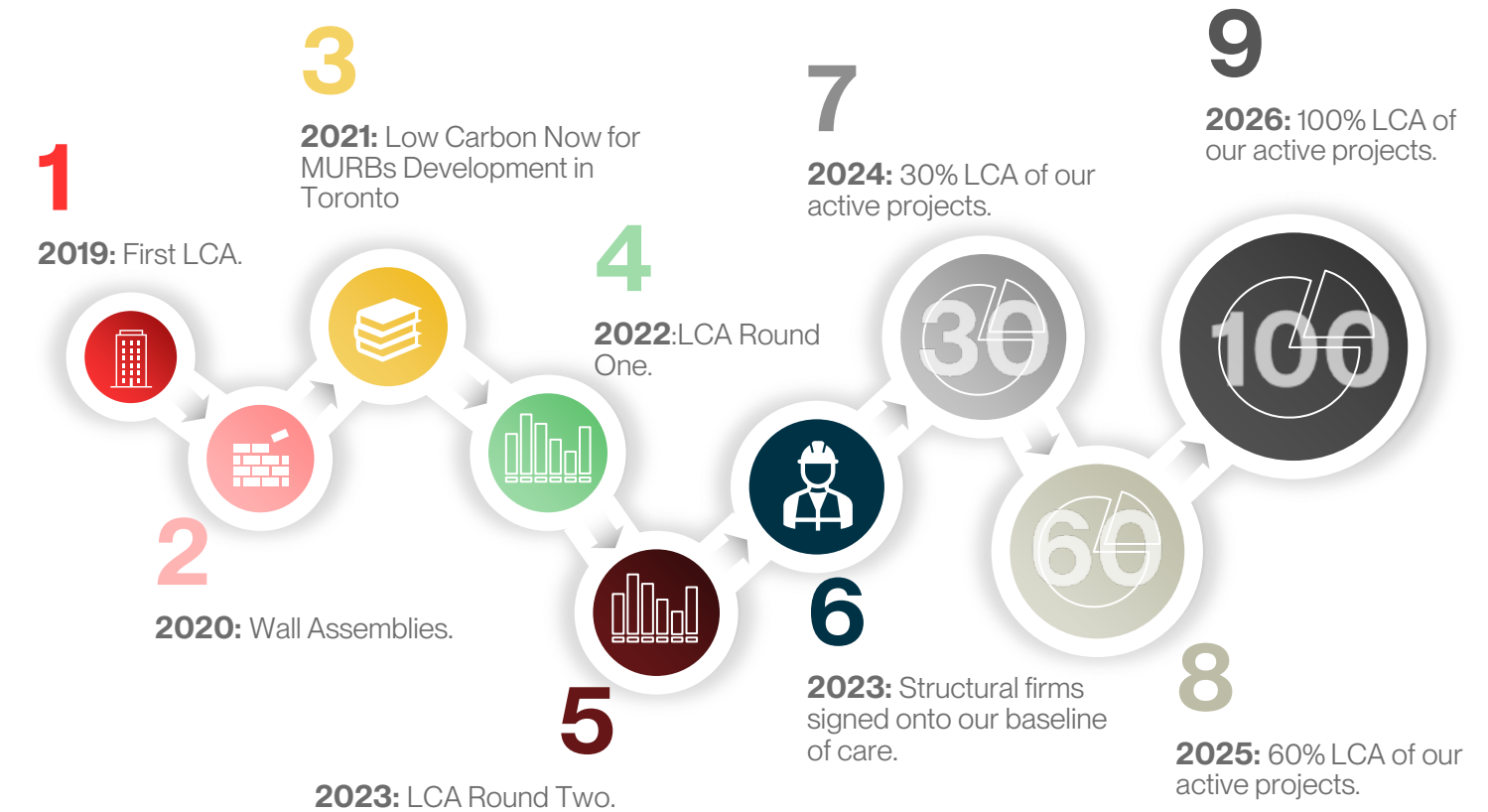
Against the backdrop of this anticipated change, BDP Quadrangle committed to reporting on 100% of our projects by the end of 2026 and designing all projects with an SPA date of 2030 to be net-zero-carbon-ready with a whole-building upfront embodied carbon intensity of 250 kgCO₂e/m². In support of this goal, we have been making strategic to move to integrate embodied carbon into our design process.

Figure 2 - BDP Quadrangle's evolving sustainability targets

³ City of Toronto, Toronto Green Standard V4, 2022.

⁴ On 3 June 2026, Chief Planner and Executive Director, City Planning issued a report on the implications of Bill 98 which shows that embodied carbon reporting will shift from mandatory to voluntary for the interim.

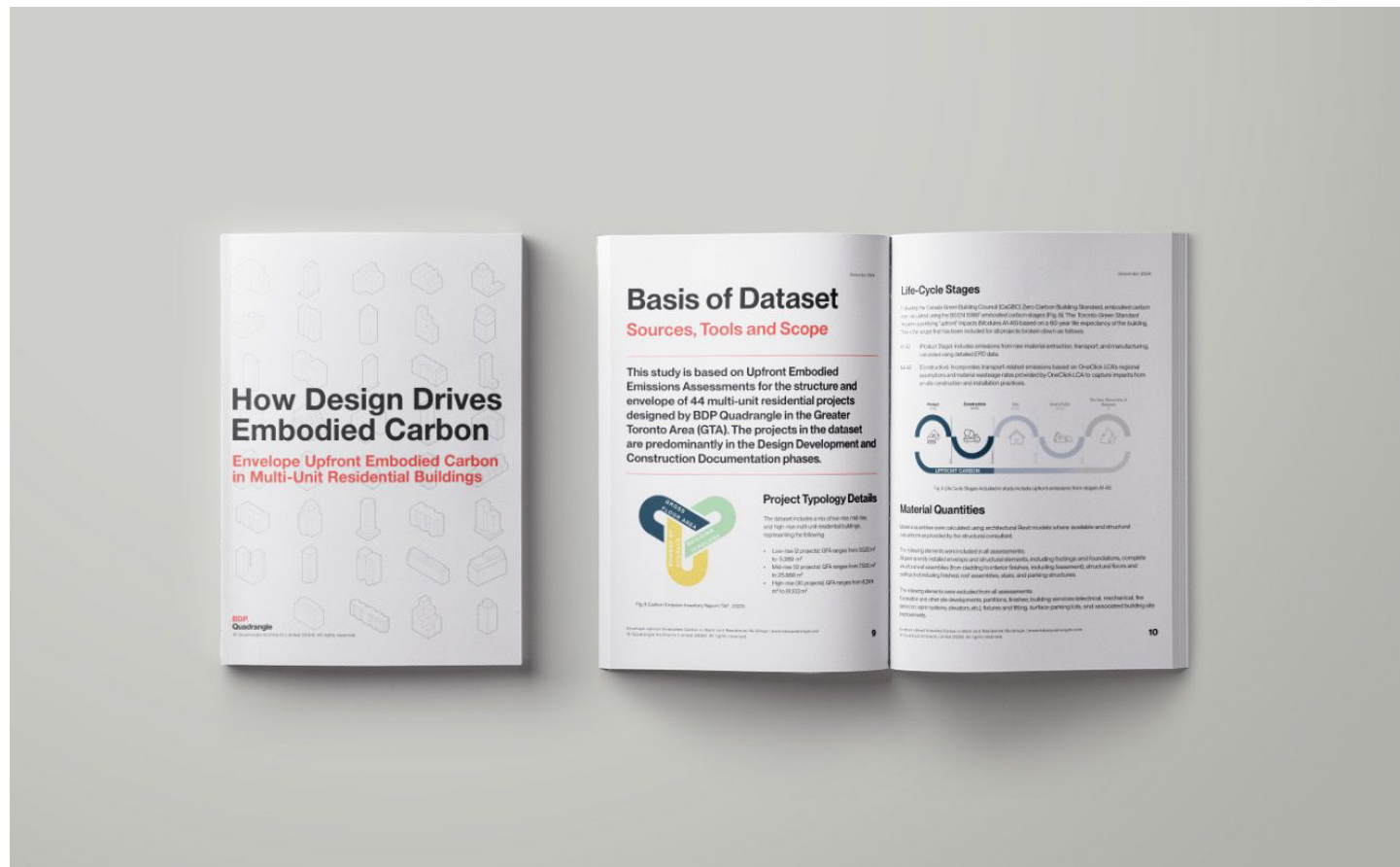
Embodied Carbon Journey



In 2019, we completed our first LCA - just one project-but it gave us a baseline. In 2020, we went deeper-looking at 29 of our standard wall assemblies. That's when we started thinking in terms of components. Then 2021 was the real shift. We launched *Low Carbon Now* engaging several other multi-disciplinary firms to develop a pathway to net zero for Toronto MURBs. By 2022 and 2023, we scaled up our reporting-two LCA rounds, eight projects, and we brought five structural firms into the process, engaging them in the signing of a baseline of care between our firms. In 2024, we reached 30% of our active projects and published a study of envelope upfront carbon across 44 multi-unit residential buildings.⁵ In 2025, we analyzed 60% which is reflected in this report. By the end of 2026, we're targeting 100% of our projects.

Figure 3 - BEP Quadrangle's embodied carbon journey

⁵ BDP Quadrangle, How Design Drives Embodied Carbon, 2024.



From the 2024 initiative, we produced How Design Drives Embodied Carbon: Envelope Upfront Embodied Carbon in Multi-Unit Residential Buildings, LCAs for 30% of our active projects. The study analyzed 44 GTA multi-unit residential projects and identified how VFAR, WWR, density, typology, and cladding material selection influence envelope upfront embodied carbon. Across the dataset envelope represents an average of 23% of total embodied carbon, with compact forms, balanced WWR, and lower-carbon cladding choices such as brick and precast concrete helping reduce carbon intensity.

This work established practical envelope design guidelines and a more robust internal LCA workflow, allowing carbon insights to be generated earlier and translated into design guidance rather than late-stage reporting.

Figure 4 - How Design Drives Embodied Carbon: Envelope Upfront Embodied Carbon in Multi-Unit Residential Buildings

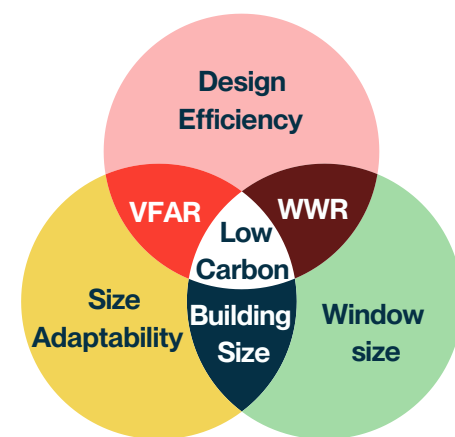


Figure 5 - Low carbon envelope design is determined by design efficiency, window size, and size adaptability.

Carbon Tool

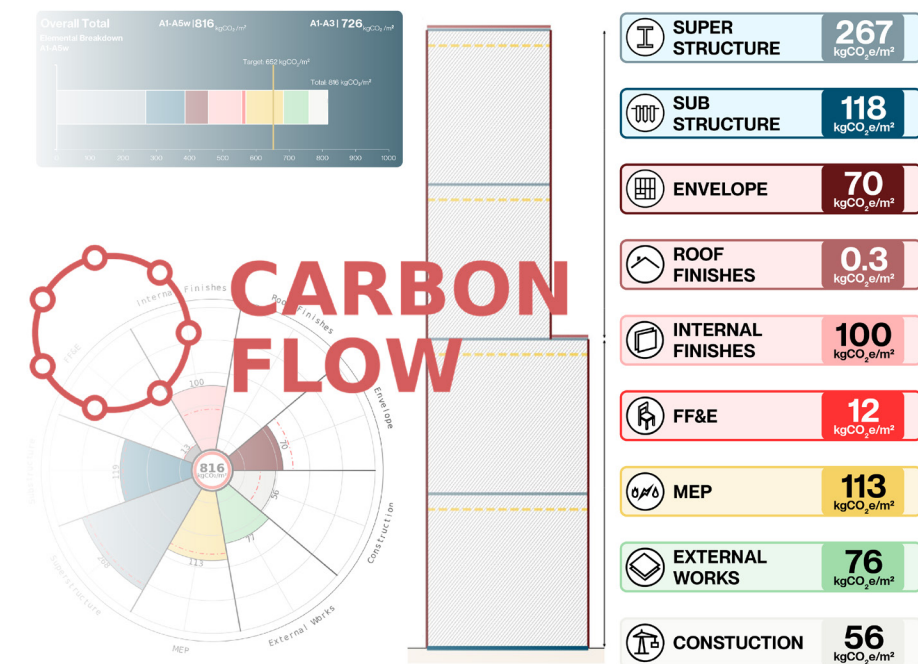
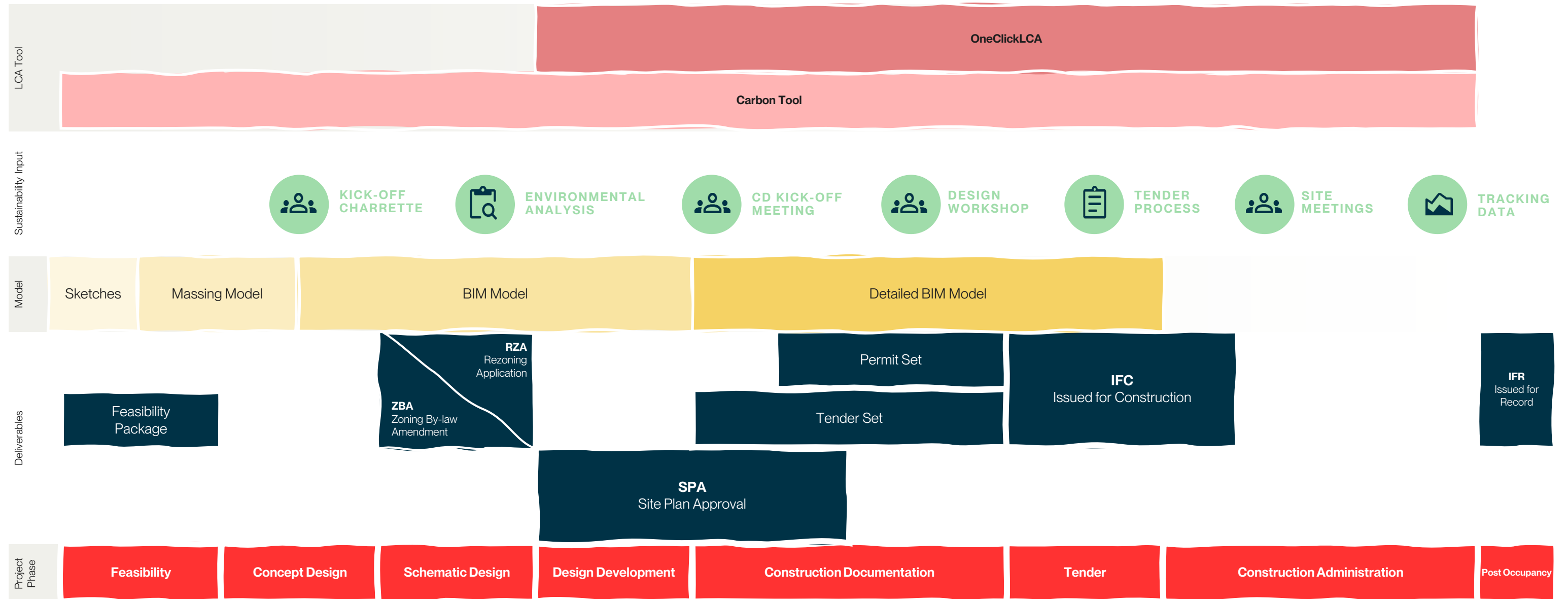


Figure 6 - Carbon Tool

These findings motivated us to go further. LCAs taking too long, discouraging designers to engage. They were also happening too late in the design process, when projects had already progressed too far to meaningfully change direction. To create an earlier feedback loop, we developed the Carbon Tool, an internal early-stage platform that translates key design inputs, such as structure type, wall assembly, WWR, foundation system, and building form, into approximate A1–A5 embodied carbon results.

The Carbon Tool acts as a rapid decision-support and communication tool rather than a detailed LCA Tool. It allows teams to test options parametrically, compare structure and envelope contributions, and identify major carbon drivers before detailed material quantities are available. Its goal is simple: embed sustainability directly into design thinking, rather than treating it as an afterthought.

Carbon Flow



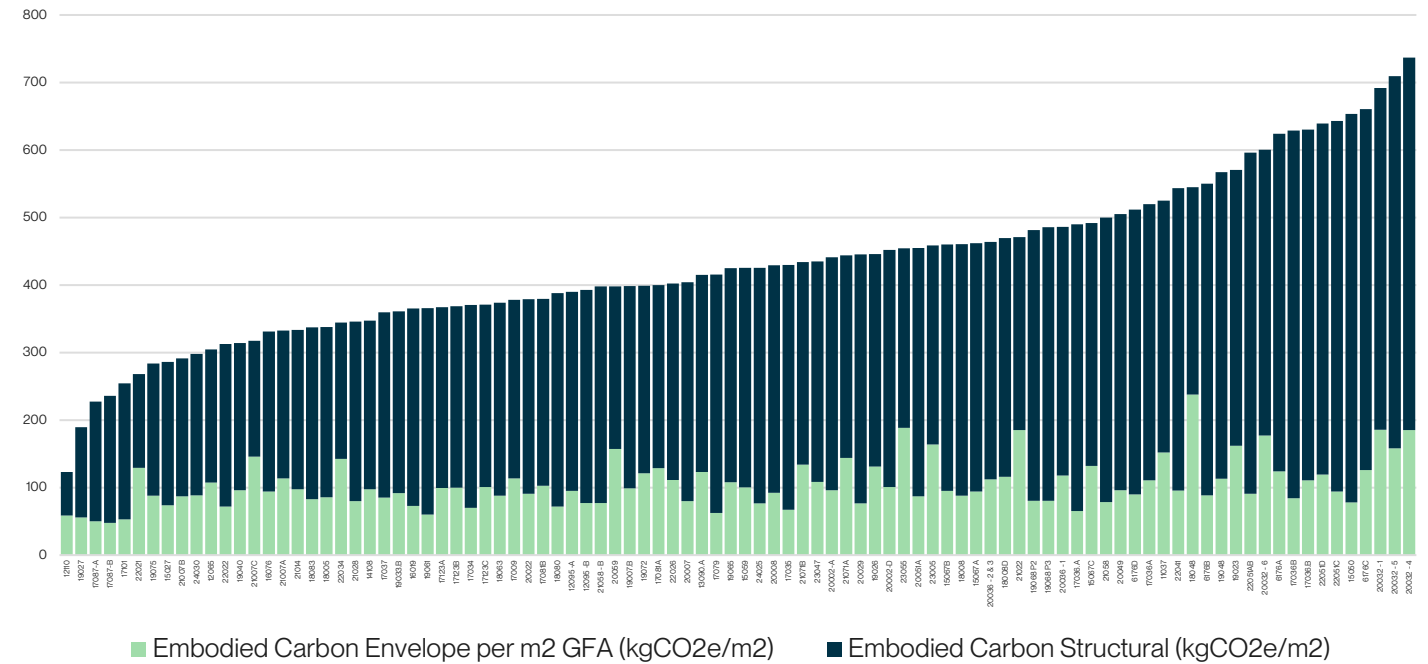
Based on our past project experience, our workflow has evolved into Carbon Flow: a structured and iterative process that integrates sustainability from the earliest design stages. It begins with a kick-off charrette and early environmental analysis, using the Carbon Tool to test high-level strategies and provide rapid feedback on form, WWR, VFAR, structure, and envelope options. As the project develops, workshops, coordination meetings, One Click LCA validation, and post-occupancy tracking help refine decisions, verify outcomes, and strengthen future projects. This year, we expanded our effort in three directions:

- **Scope Increase** - from 44 to 100 projects, including projects that incorporate adaptive reuse, building retention, and modern methods of construction (MMC).
- **Holistic Budgeting** - deriving component carbon budgets for both structure and envelope at TGS Tier 2 (350) and Tier 3 (250)
- **Threshold Setting** - identifying where design effort will deliver the greatest embodied carbon reduction

Figure 7 – BDP Quadrangle’s Carbon Flow workflow diagram illustrating how project phases align with deliverables, model resolution, sustainability inputs, and the LCA tools used throughout the design process.

02 Executive Summary

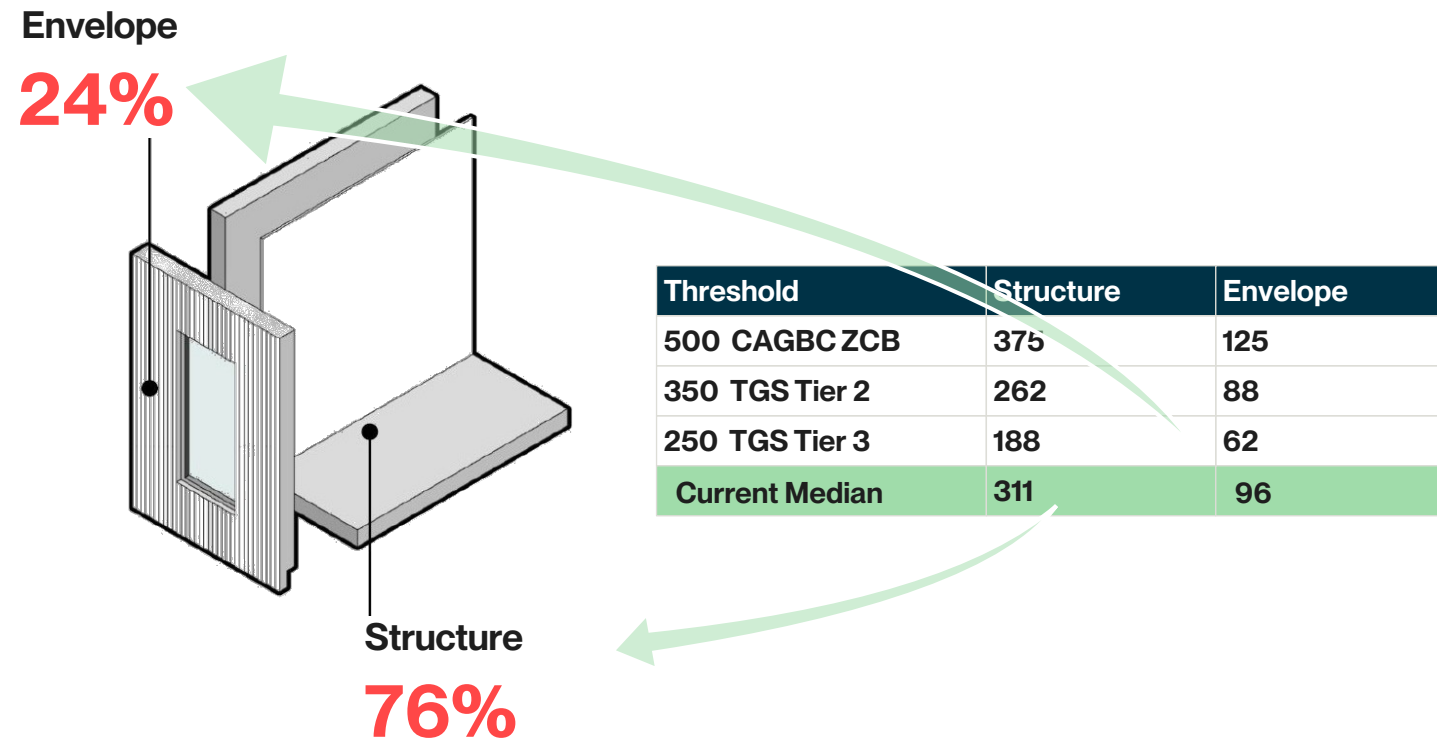
Key Takeaways



This report analyses upfront embodied carbon (life-cycle stages A1–A5) across 100 BDP Quadrangle projects completed or in delivery between 2020 and 2026. Of these, 94 multi-unit residential buildings in the Greater Toronto Area form the primary dataset; six automotive projects are included only for reference. The assessments were carried out with the OneClick LCA platform using the Canada Green Building Council (CaGBC) Zero Carbon Building Standard methodology.

Figure 8 - Portfolio summary statistics for 94 multi-unit residential projects, the focus for this report

Across the residential cohort the median total embodied carbon intensity (ECI) is approximately 425 kgCO₂e/m², with an average of 435 kgCO₂e/m². Structural components contribute about 75 percent of that total, yielding a median structural ECI of 311 kgCO₂e/m². Envelope components account for roughly 25 percent, with a median envelope ECI of 96 kgCO₂e/m². These proportions reaffirm that structure sets the carbon baseline.



The portfolio’s current median sits at 311 kgCO₂e/m² for structure and 96 kgCO₂e/m² for envelope. The regulatory thresholds reveal the magnitude of change required. At the TGS Tier 2 limit of 350 kgCO₂e/m², a project’s envelope budget is around 88 kgCO₂e/m² and its structural budget about 262 kgCO₂e/m², already below the portfolio’s median structural performance. Achieving the TGS Tier 3 target of 250 kgCO₂e/m² lowers the structural budget to roughly 188 kgCO₂e/m², a level that none of the cast-in-place concrete projects in this dataset currently meet.

Figure 9 – Based on the 24/76% split between envelope and structure defined through the dataset, the table shows the EC budgets for each of the standard’s thresholds listed.

Structure sets the carbon baseline, accounting for approximately 76% of upfront embodied carbon across the residential dataset, while envelope systems account for the remaining 24%. The path to 250 kgCO₂e/m² therefore depends on structural carbon reduction first, supported by envelope optimization, material selection, and early carbon budgeting.

Headline Figures

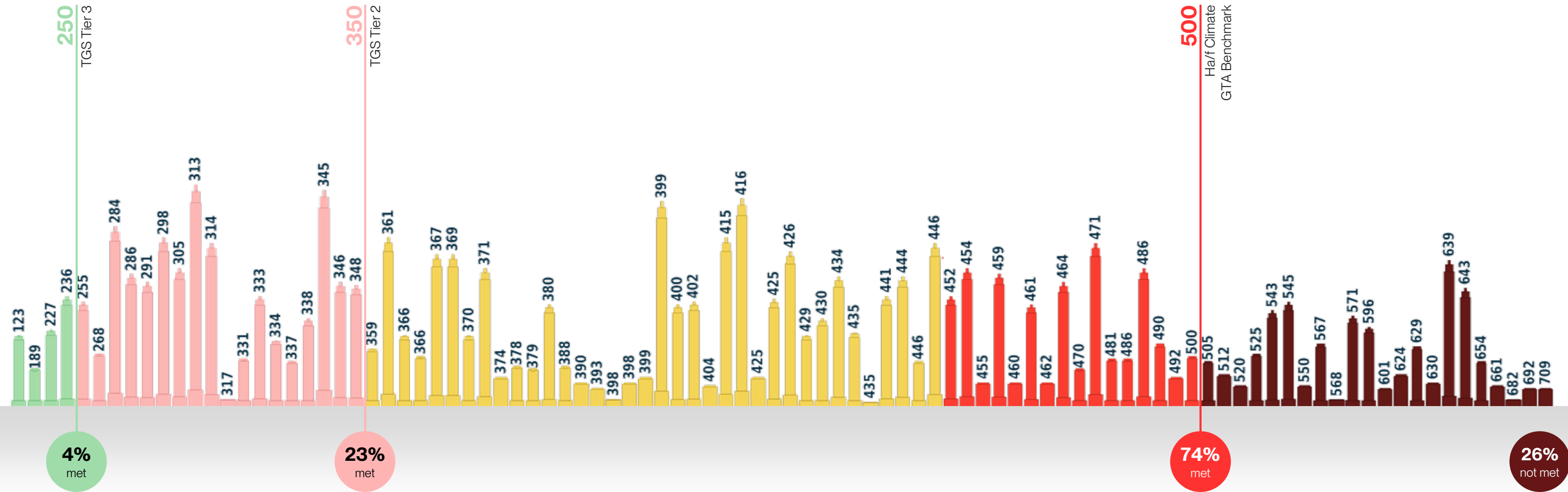
Metric	Median	Mean	Range
Total upfront ECI (kgCO ₂ e/m ²)	425	432	123–737
Structural ECI (kgCO ₂ e/m ²)	311	328	65–576
Envelope ECI (kgCO ₂ e/m ²)	96	105	48–238
Structural share of total	75.8%	75.0%	51.9%–88.1%
Envelope share of total	24.2%	25.0%	11.9%–48.1%
WWR	39.0%	39.8%	12.4%–65.9%
VFAR	57.0%	62.2%	36.8%–164.0%

Figure 10 - Portfolio summary statistics for 94 multi-unit residential projects.

Compliance against Targets

Threshold	% of portfolio compliance	Design implication
≤ 250 kgCO ₂ e/m ² (TGS Tier 3)	4%	Requires structural system innovation
≤ 350 kgCO ₂ e/m ² (TGS Tier 2)	23%	Requires coordinated form + material strategy
≤ 500 kgCO ₂ e/m ² (Ha/f)	74%	Majority of portfolio is meeting Greater Toronto Area average
Exceeding all targets	26%	Large sites, full below grade, multiple buildings with poor soil conditions

Figure 11 - Portfolio compliance with upfront embodied carbon thresholds of listed standards.



Key Findings

- 1. Structure drives embodied carbon.** Structural systems account for approximately 76% of total embodied carbon, compared to 24% for the envelope. Even with overlapping drivers, it is important to set targets for each and work iteratively across disciplines.
- 2. 350 is optimization; 250 is transformation.** The 350 kgCO₂e/m² benchmark may be achievable through improved business-as-usual practice, but reaching 250 kgCO₂e/m² requires deeper innovation and rigorous early carbon budgeting and iteration.
- 3. Structural systems are not carbon-equivalent.** Significant variation exists between structural approaches. Emerging structural systems have tremendous opportunity to speed up construction, and we need to work with suppliers to address the hidden carbon impacts.
- 4. Mid-rise is a carbon opportunity area.** Mid-rise buildings show a higher median total Embodied carbon intensity than high-rise projects, largely due to transfer slabs, podium conditions, and less efficient structural repetition.

- 5. The envelope rules still matter.** The 2024 findings remain valid: WWR around 40 percent and VFAR below 50 percent continue to be effective design ceilings, although wall assembly choices affect how much flexibility is available.
- 6. Mass intensity is the new carbon signal.** Because mass intensity explains more than half of the variation in ECI, reducing material use per square metre is one of the most direct pathways to lower embodied carbon
- 7. The portfolio is moving in the right direction.** Recent projects show lower mass intensity and lower total ECI, but continued improvement will require carbon budgets to be established early and tracked through design and delivery.
- 8. Adaptive reuse and retention show promise.** Case studies demonstrate the potential to reduce embodied carbon by preserving existing buildings, structures, and foundations, avoiding some of the emissions associated with new construction.

Figure 12 - Portfolio compliance with TGS upfront embodied carbon thresholds.

03

Basis of Dataset

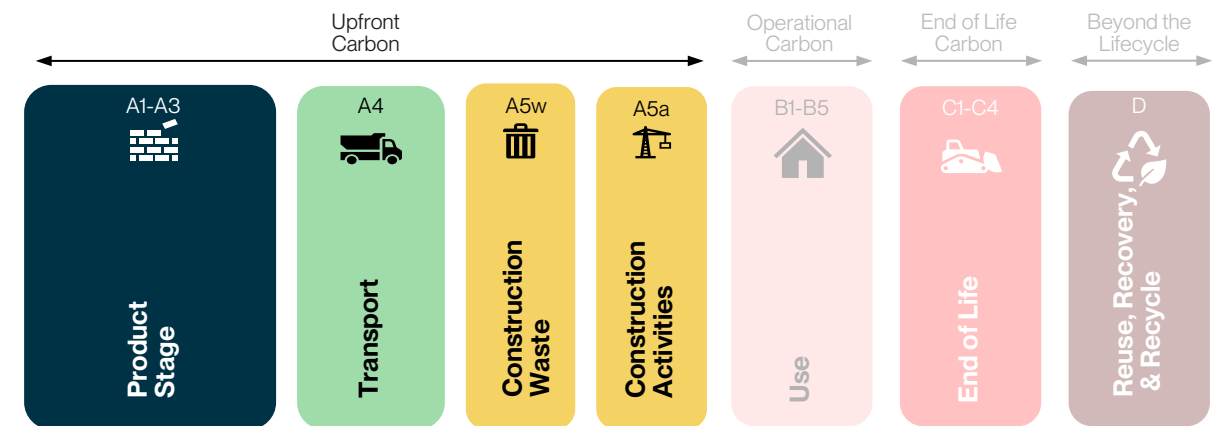
Sources

Typology	Count	GFA range (m ²)	Storey range
Low-rise (< 4 storeys)	2	998 – 6,179	2 – 3
Mid-rise (4 – 11 storeys)	29	3,070 – 34,857	6 – 13
High-rise (≥ 12 storeys)	63	8,249 – 144,190	12 – 65
Automotive (reference only)	6	3,626 – 8,795	2 – 4

This study draws on upfront embodied emissions assessments performed in-house on 100 active BDP Quadrangle projects between 2020 and 2025. Projects span Schematic Design through Construction Administration, giving the dataset a breadth of design maturity and providing confidence that findings represent realistic as-designed conditions rather than idealized early-stage scenarios.

Figure 13 - Dataset composition by typology. Automotive projects are reported for comparison but excluded from residential analysis.

Scope



Following the CaGBC Zero Carbon Building Standard and BS EN 15978, upfront embodied carbon is the sum of Modules A1–A5:

Figure 14 - Life Cycle Stages included in study include upfront emissions from stages A1-A5

Included	Excluded
Footings, foundations, basement walls	Excavation and site preparation
Complete structural system (concrete, steel, timber)	Interior partitions and finishes
Structural floors and roof assemblies	Mechanical, electrical, plumbing, fire systems
Full envelope build-up: cladding, insulation, backup wall, interior finish of exterior walls	Elevators, escalators, fixtures
Windows and glazing systems (framing + IGU)	Surface parking, landscaping, site improvements
Stairs and parking structures	

- **A1–A3 Product Stage** - raw material extraction, transport to manufacturer, and manufacturing. Calculated from product-specific Environmental Product Declarations (EPDs) where available; regional averages otherwise.
- **A4 Transport** - delivery of materials to site. OneClick LCA regional transport assumptions for the GTA.
- **A5 Construction / Installation** - on-site assembly, construction energy, and material wastage factors applied per OneClick LCA defaults calibrated to Canadian practice.

Figure 15 - Material inventory scope, aligned with CaGBC Zero Carbon Building Standard and the Toronto Green Standard V4 reporting schema.

Operational carbon (B1–B7), end-of-life (C1–C4), and beyond-building-life benefits (Module D) are outside the scope of this study, consistent with the TGS reporting framework.

Tools



Material quantities were extracted from architectural Revit models using BDP Quadrangle’s in-house carbon assessment toolchain.

Structural quantities were provided by project structural engineers, including Jablonsky Ast & Partners, RJC Engineers, Salas O’Brien, Honeycomb Engineering, Entuitive, Engineering Link Inc., and Blackwell. EPDs and carbon factors were sourced from the current OneClick LCA database. Where structural take-offs were unavailable or not feasible, structural embodied carbon was calculated using the Carbon Tool. Gross Floor Area definitions follow the National Research Council of Canada’s National Guidelines for Whole-Building Life Cycle Assessment (NRC, 2022), Appendix A, measured from the external face of enclosing walls and inclusive of parking garages.

Figure 16 - Diagram of formula to calculate embodied carbon emissions

From Component Contribution to Carbon Budgets

The 2024 study established that the envelope contributes approximately 23% of total upfront embodied carbon in multi-unit residential buildings, enabling the derivation of an envelope-specific carbon budget (80.5 kgCO₂e/m² at the TGS 350 threshold). The 2025 study sees a rise in envelope to 24% and an envelope-specific budget of 84 kgCO₂e/m² at the TGS 350 threshold.

EPD Selection

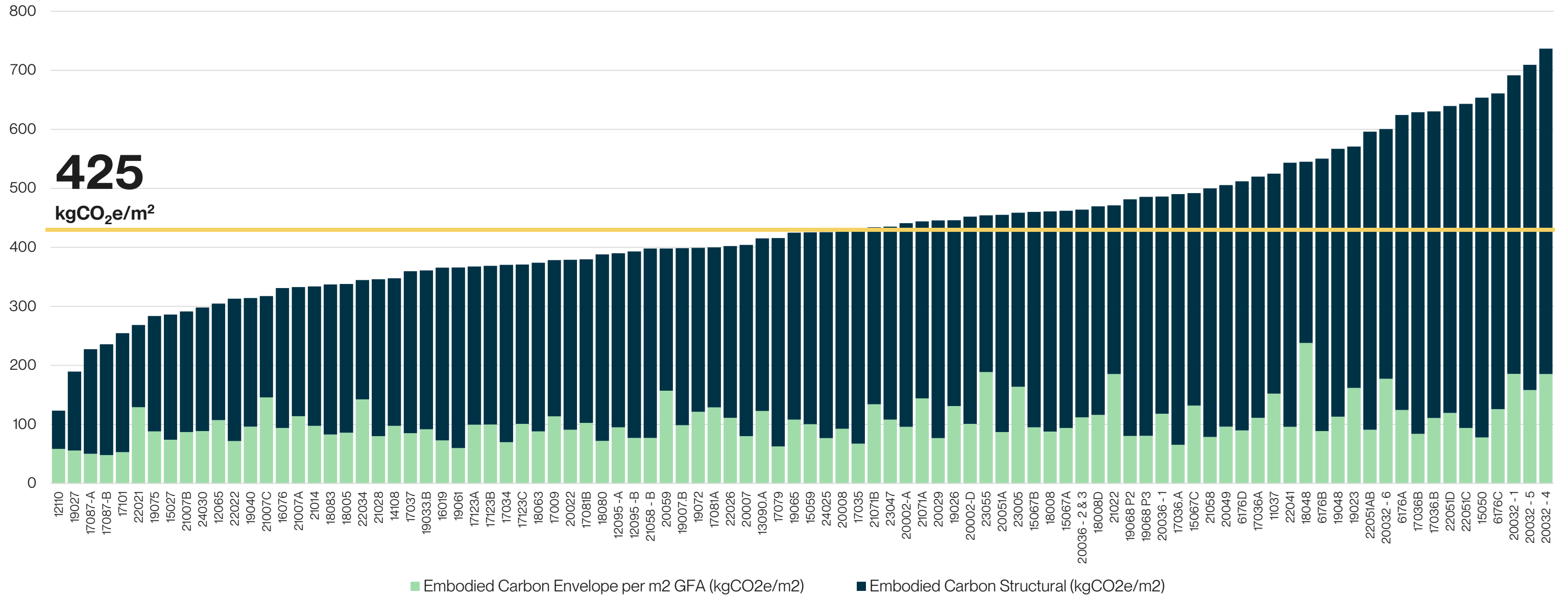
EPD selection has been standardized by material across all. Where applicable, EPDs were selected in the following order of priority: product-specific EPDs, industry-average EPDs, and OneClick LCA generic averages. Material assumptions were kept consistent across all models to enable comparison of design-related impacts only.

Analytical Steps

1. Separate structural and envelope embodied carbon for each project and express each as both an absolute value (kgCO₂e) and an intensity (kgCO₂e/m² GFA).
2. Calculate the percentage contribution of each component to total upfront ECI, and derive median and mean component shares across the portfolio.
3. Derive component carbon budgets at each TGS threshold by multiplying the threshold by the component share.
4. Assess the influence of design variables - Gross Floor Area (GFA), Floor Space Index (FSI), Vertical Floor Area Ratio (VFAR), Window-to-Wall Ratio (WWR), wall assembly, and structural system - on the two component ECI values.
5. Quantify portfolio compliance with each threshold and segment by typology to identify where the largest reductions are needed.

04 Findings

Structure Sets the Baseline



Across the 94-project residential projects, structure accounts for roughly three-quarters of upfront embodied carbon. The median structural ECI is 311 kgCO₂e/m² compared with 96 kgCO₂e/m² for the envelope. The combined median total ECI of 425 kgCO₂e/m² sits above the TGS Tier 2 limit, underscoring that most projects currently exceed the regulatory target and that structure defines the baseline from which reductions must be made.

Figure 17 - Total upfront embodied carbon by project (n=94)

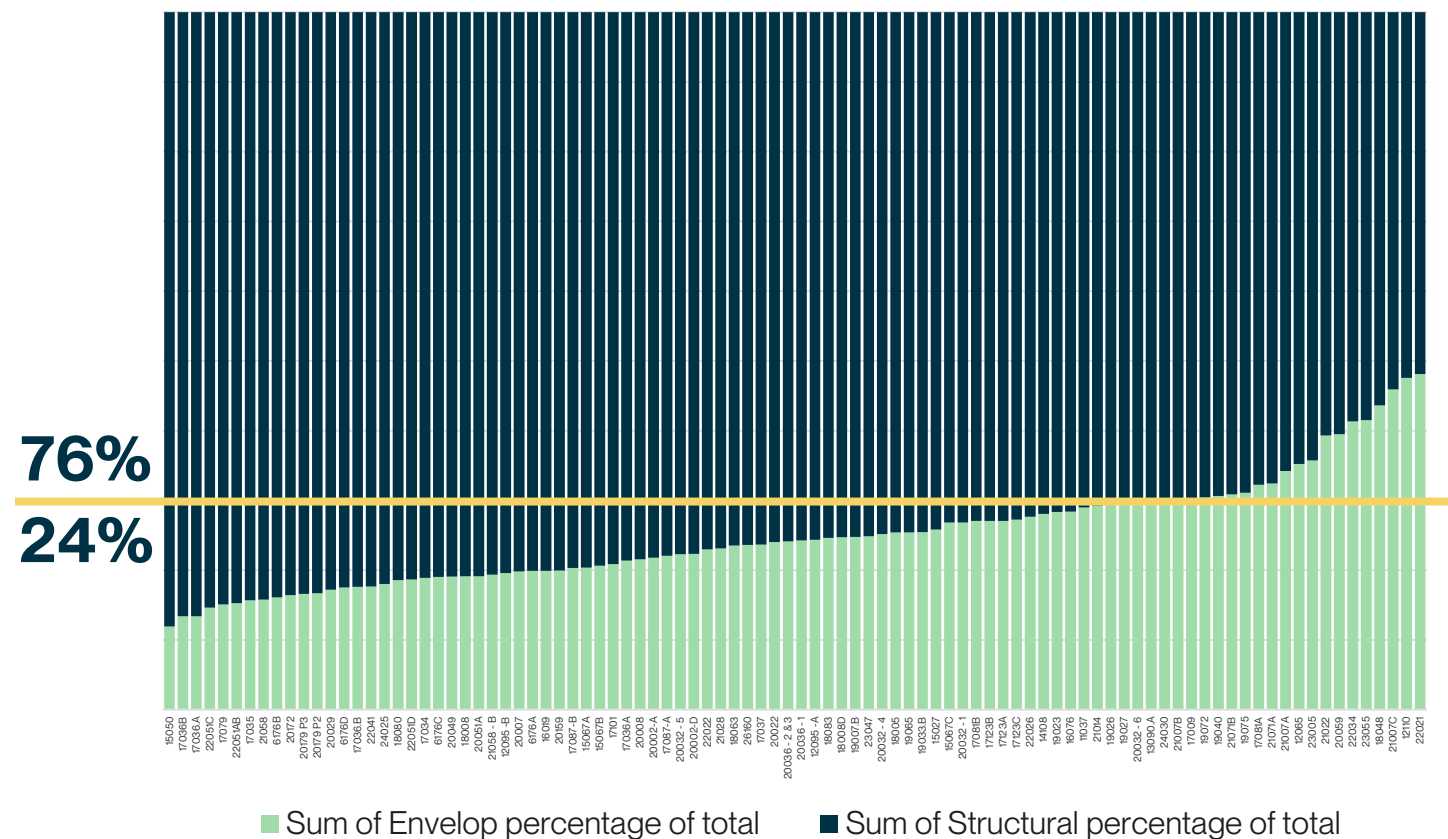


Figure 18 - Average share of total upfront embodied carbon attributable to structure vs. envelope

This dominant share has two implications. First, carbon budgets must be component-specific: allocating 76 percent of a project’s carbon budget to structure and 24 percent to the envelope aligns design focus with impact. Second, envelope optimization alone cannot deliver deep reductions. Even if envelope emissions were cut in half, the structural component would still determine whether a project meets the 250 kgCO₂e/m² target.

Most projects begin with a structural carbon load that already exceeds future targets. Reducing total ECI therefore depends on shifting structural decisions upstream, before system, grid, span, and transfer conditions are locked in. Beyond structural optimization, retaining existing buildings, structures, and foundations should be evaluated as an additional pathway for reducing upfront embodied carbon.

Influence of Structural Systems Within the Dataset (Without Low Carbon Material Substitution)

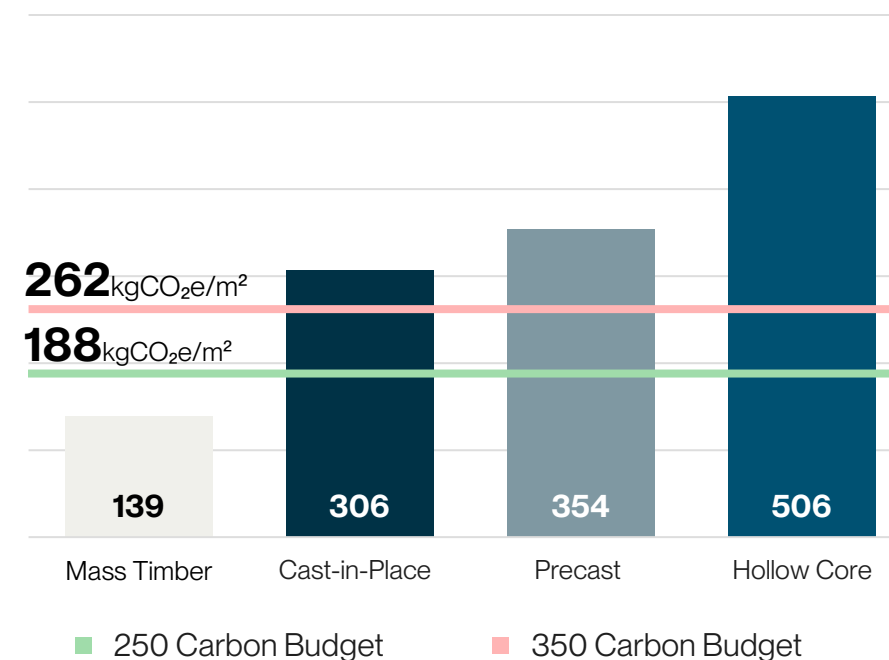


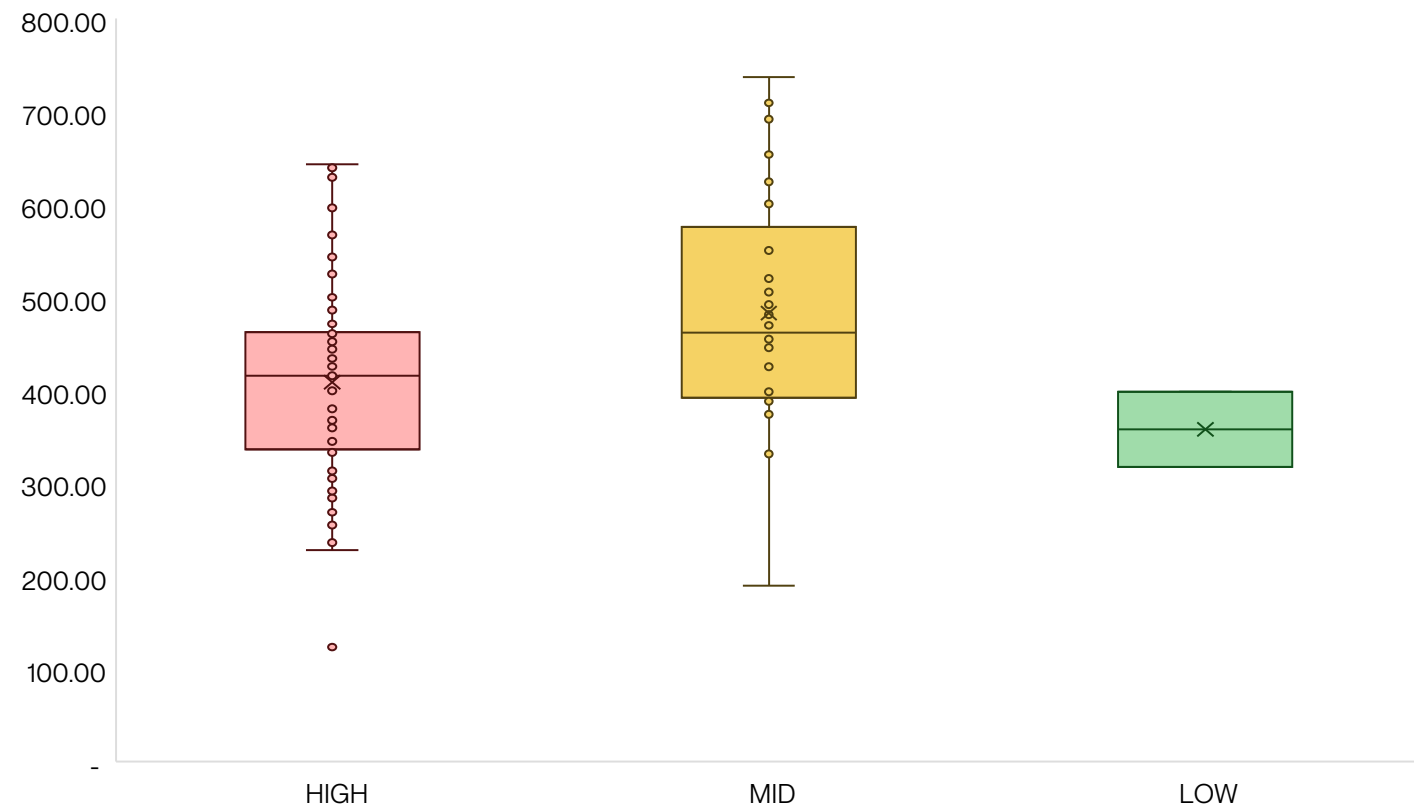
Figure 19 - Median structural ECI by structural system.

Structural system selection emerged as the single most consequential design decision. Cast-in-place concrete slab construction dominates the dataset (83 projects) with a median structural ECI of 307 kgCO₂e/m². Although this system is familiar and cost-effective, it does not meet either the TGS Tier 2 structural budget of roughly 262 kgCO₂e/m² or the tier 3 structural budget of about 188 kgCO₂e/m².

Projects utilizing hollow-core slab systems exhibited a median structural ECI of 506 kgCO₂e/m², approximately 65 percent higher than cast-in-place slab projects within the study dataset. These results reflect the combined influence of structural design, material specifications, and project-specific conditions. As the study did not evaluate alternative material scenarios or normalize concrete mix designs across projects, the findings should not be interpreted as indicating that hollow-core systems are inherently higher carbon or unable to achieve lower embodied carbon targets.

Mass-timber structures, though represented by only one project in the current dataset, demonstrate the potential of alternative systems. The timber project recorded a structural ECI of 139 kgCO₂e/m², well below the TGS Tier 3 structural budget and directionally consistent with international benchmarks. Expanding the pipeline of timber and hybrid structures is therefore a strategic priority for achieving deep carbon reductions.

Total Embodied Carbon Intensity by Typology



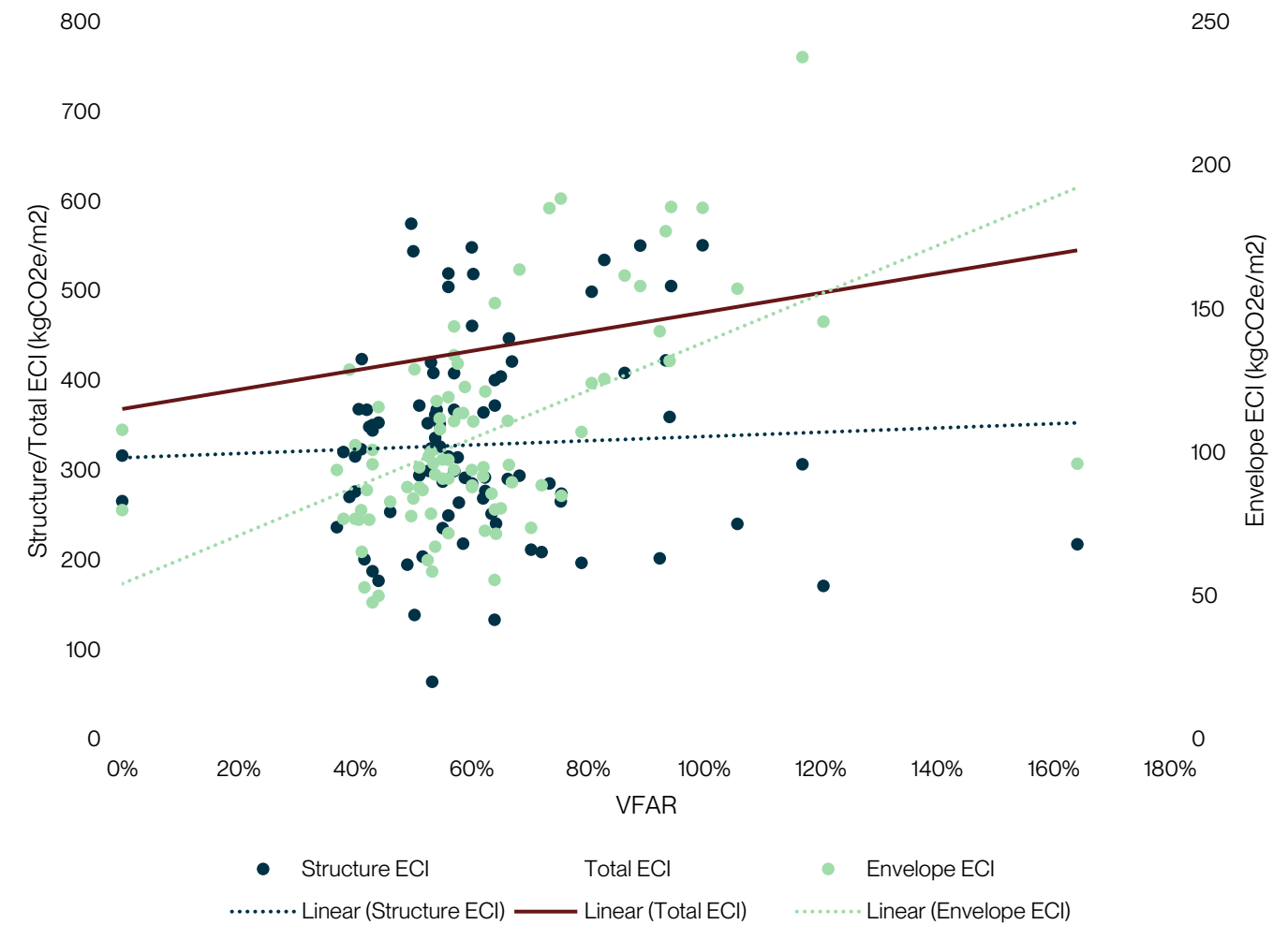
Typology establishes the first layer of carbon context. In this dataset, mid-rise projects have a higher median total ECI than high-rise projects, suggesting that smaller buildings are not automatically lower-carbon. Transfer slabs, podium conditions, irregular grids, and reduced floor-plate repetition can make mid-rise buildings structurally inefficient compared with more repetitive high-rise forms. This finding challenges the assumption that smaller buildings are inherently lower-carbon and highlights the importance of structural efficiency regardless of building height.

Mid-rise typologies were previously subject to front and rear angular plane requirements.⁶ As the updated mid-rise guidelines have simplified setback requirements, they are expected to support simpler building forms and, in turn, reduce embodied carbon.

Figure 20 - Total ECI distribution by typology.

⁶ City of Toronto, Report for Action: Housing Action Plan: Mid-Rise Building Design Guidelines, 2024.

Form and Structure



Vertical Floor Area Ratio (VFAR), the ratio of envelope surface area to gross floor area, captures how compact or articulated a building form is. While VFAR is often treated as an envelope metric, the 2025 dataset shows that it also correlates with structural and total ECI. This suggests that higher VFAR may be capturing broader design complexity, including step-backs, irregular massing, slab-edge conditions, transfer conditions, and structural inefficiencies. Projects with VFAR below 50 percent generally show lower envelope ECI and stronger total ECI performance.

Figure 21 - Envelope, Structure, and Total ECI vs. VFAR.

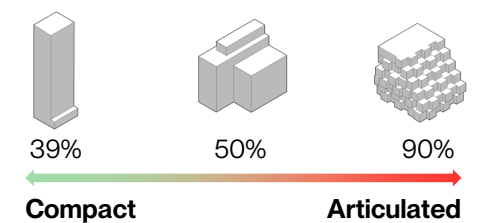
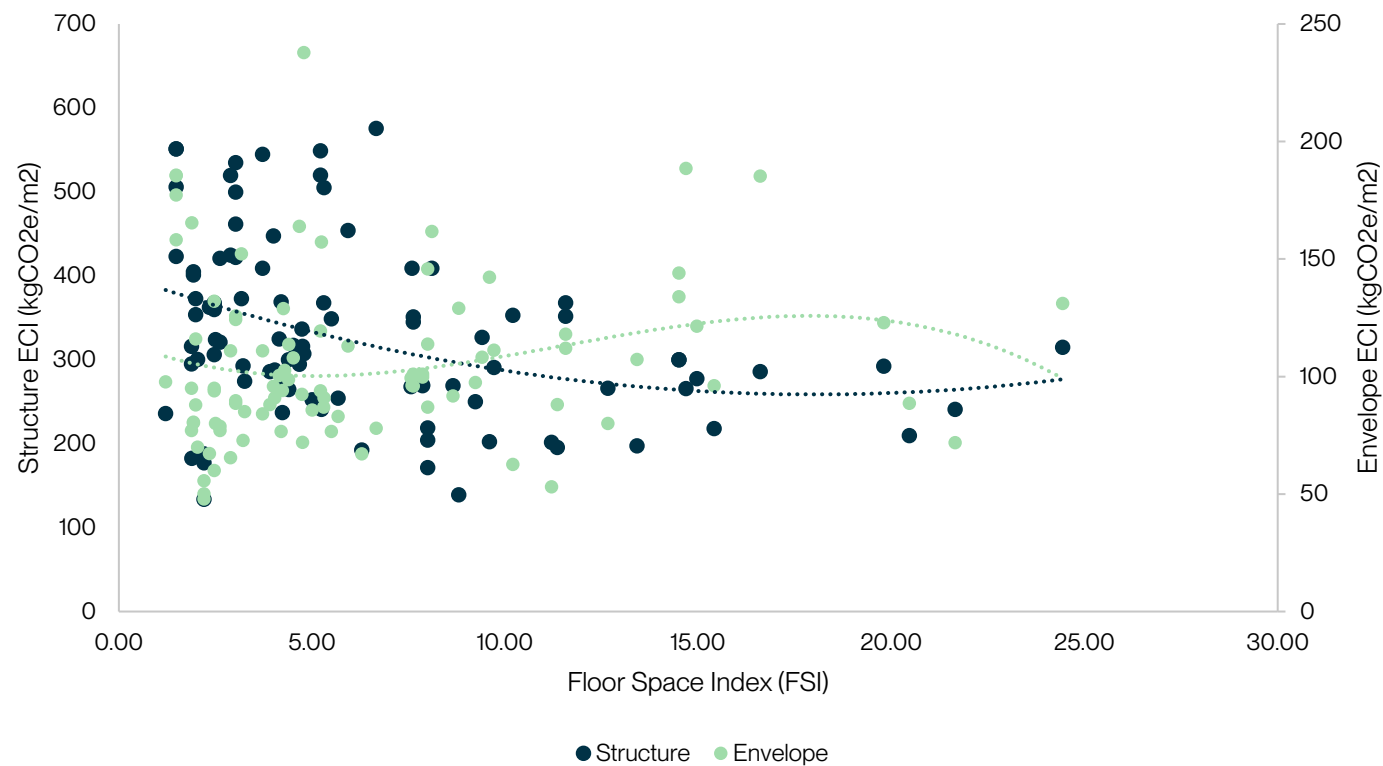


Figure 22 - Diagram demonstrating VFAR. More articulated the form, higher the VFAR. More compact the form, lower the VFAR.

Density and Structure



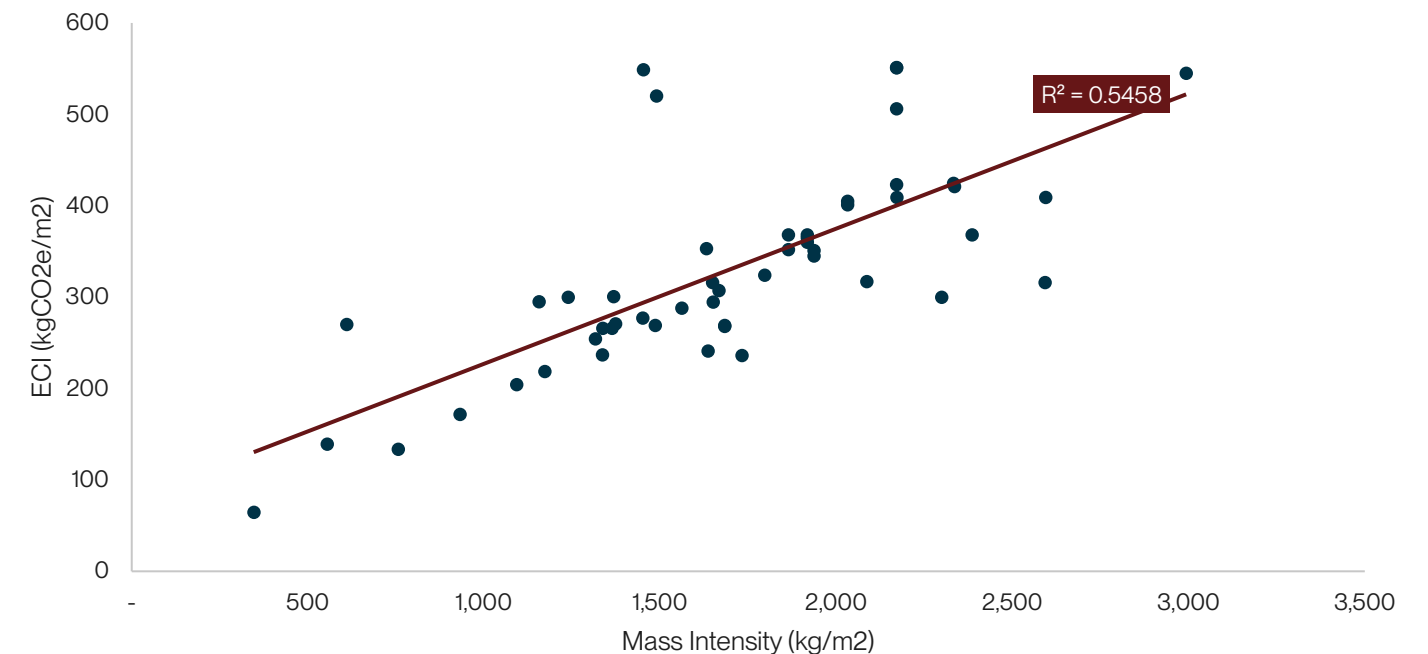
Floor Space Index (FSI) measures density relative to site area and affects structure and envelope differently. Low density (FSI 1–5) schemes tend to be inefficient because material is spread across a small floor area, while moderate densities (FSI 6–15) improve carbon efficiency through repetition and structural rationality. However, envelope intensity increases because higher density does not necessarily mean a more compact envelope. In high densities (FSI 16–20), density is achieved through taller articulated forms, resulting in higher VFAR, while structural efficiency is lower due to more efficient distribution of structural carbon across greater GFA. Extremely high densities can introduce structural complexity and material escalation; thus, carbon-efficient density is not synonymous with maximum density but with compact, well-ordered massing.

Figure 23 - Structure and Envelope ECI vs. Floor Space Index (FSI)

These relationships show that early form decisions, including massing, articulation, glazing, and density, have lasting carbon impacts and must be evaluated against component-specific carbon budgets.

Form determines how efficiently material is distributed. Compact, repetitive geometries reduce carbon, while articulated, irregularity increase pressure on both structural and envelope budgets.

Total Mass Intensity and Efficiency



Mass intensity, defined as the total mass of materials per square metre of gross floor area, proved to be a strong predictor of embodied carbon. Across the dataset, mass intensity explained more than half of the variation in total ECI, with higher mass generally equating to higher embodied carbon. This positive correlation confirms that reducing the quantity of material used per square metre is one of the most direct strategies for lowering carbon.

Figure 24 - Scatter plot showing the relationship between mass intensity and total ECI

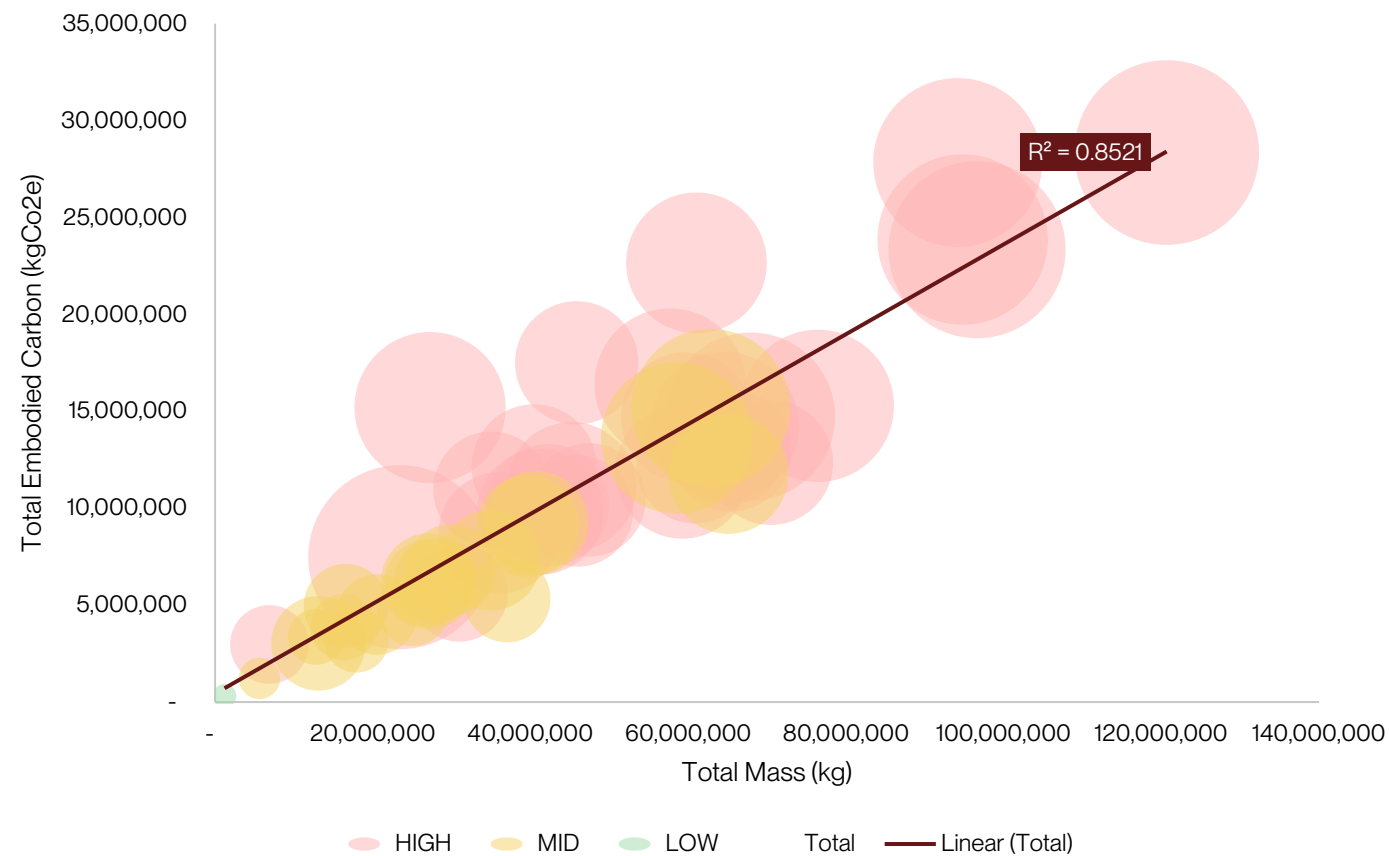


Figure 25 - Bubble chart showing total embodied carbon against total mass, with bubble size representing GFA and colour indicating typology.

Two additional patterns emerged. First, larger projects tend to carry higher total embodied carbon simply because they contain more material and more floor area. Yet on an intensity basis, repetition and scale can improve efficiency when structural systems and massing strategies are disciplined. Second, both mass intensity and total ECI have been trending downward over time in the portfolio, indicating that recent projects are becoming leaner and lower-carbon. This trend should be reinforced by setting clear carbon budgets at project inception and tracking mass intensity through design and construction.

Material quantity, mass, and embodied carbon describe the same relationship in different languages: architecture, engineering, and sustainability. Reducing mass intensity therefore provides a direct pathway to lowering total ECI.

Portfolio Trends over Time and Scale

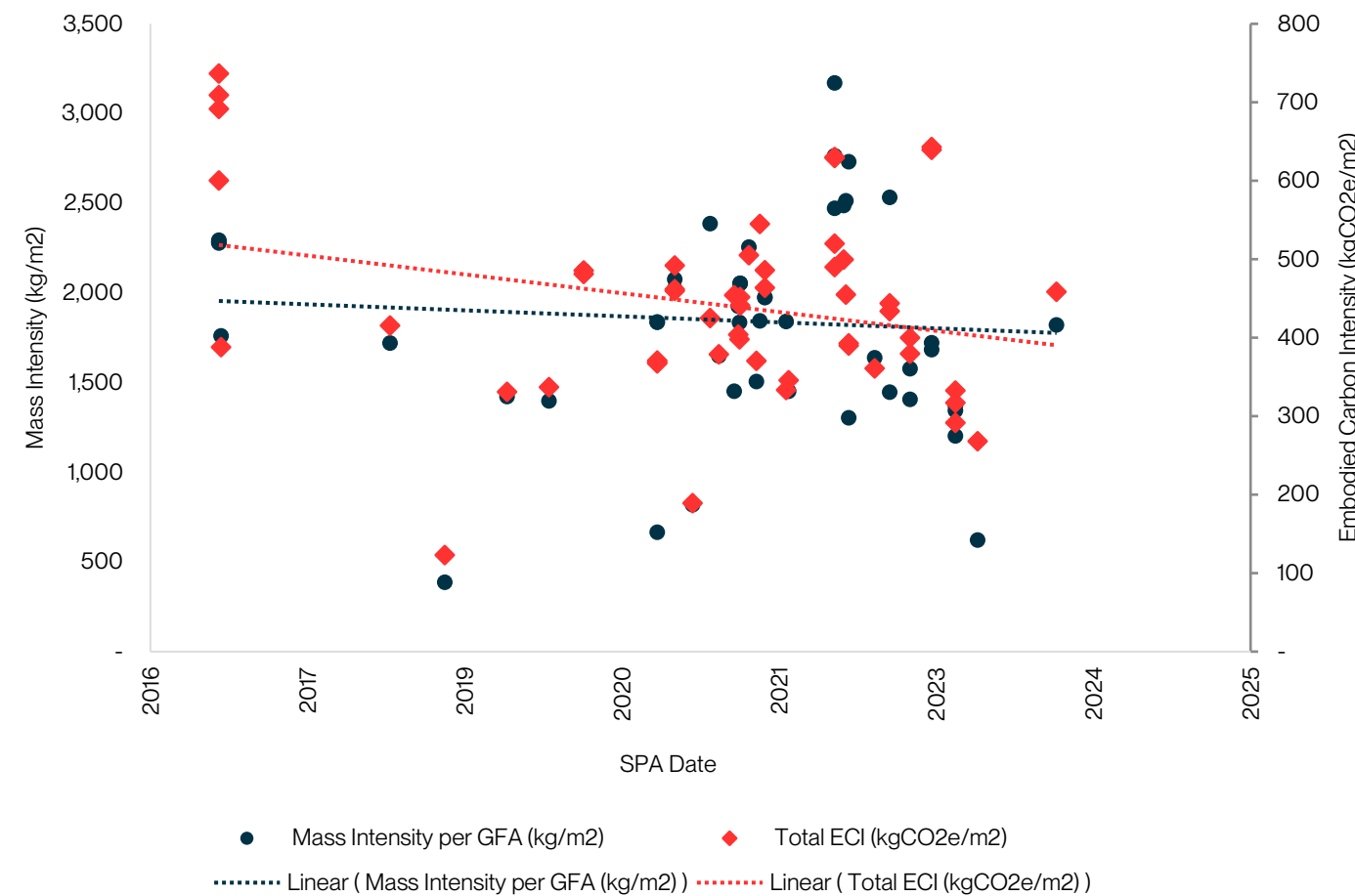


Figure 26 - Scatter plot showing total ECI over time by SPA date

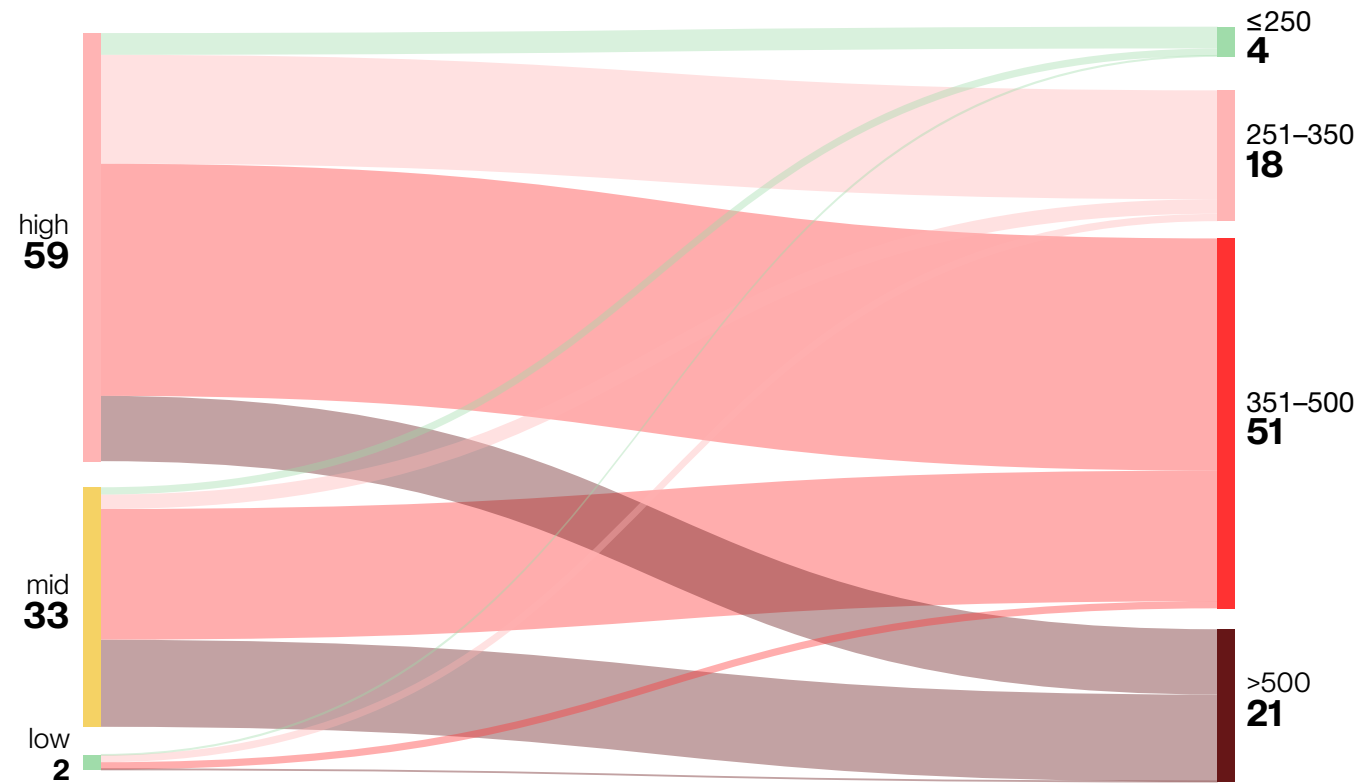
A temporal analysis of projects by Site Plan Approval date shows that both embodied carbon intensity and mass intensity have gradually decreased in more recent years. Early projects include several instances of mass intensities exceeding 2,200 kg/m², whereas projects approved more recently tend to sit closer to the 1,300–1,800 kg/m² range. Similarly, more recent projects often fall below the earlier median total ECI of 425 kgCO₂e/m², although most remain above the 350 kgCO₂e/m² threshold.

This downward trajectory reflects growing awareness and incremental improvements in structural efficiency, mass reduction and

envelope optimization. However, the wide spread in the data shows that project-specific conditions-such as below-grade requirements, transfer slabs, podium conditions and material choices-still cause significant variation. To continue driving the trend downward, carbon considerations must be embedded as early design constraints rather than late-stage checks.

The portfolio is trending toward lower ECI and lower mass intensity, showing that current practice is improving. To reach future targets, these gains need to become intentional, repeatable, and embedded in every project from the outset.

Portfolio Compliance



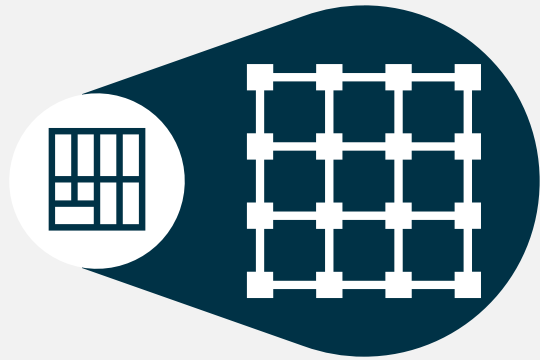
Of 94 residential projects, 22 projects, or 23%, meet the TGS Tier 2 threshold of 350 kgCO₂e/m². Four projects, or 4%, meet the TGS Tier

Figure 27 - Sankey chart showing target compliance by typology

3 threshold of 250 kgCO₂e/m². High-rise projects show the highest compliance rate with the 350 threshold, at approximately 30%, reflecting the structural efficiency benefits of height and repeated floor plates. Mid-rise projects show only 7% compliance with 350 and 3% compliance with 250, suggesting that mid-rise buildings may carry carbon penalties from podiums, transfers, articulation, or less efficient structural repetition. The two low-rise projects in the sample bracket the 350 threshold closely, with a median total ECI of approximately 358 kgCO₂e/m².

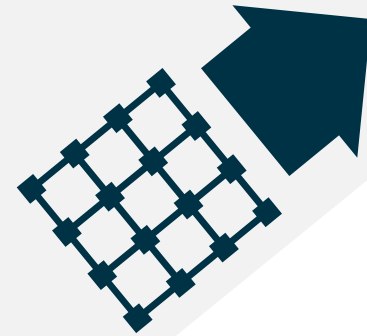
The 350 kgCO₂e/m² threshold appears within reach through disciplined improvements to current practice. The 250 kgCO₂e/m² target represents a step change, requiring structural efficiency, lower mass intensity, alternative structural systems, and retention opportunities to be considered from the outset.

Summary of Findings



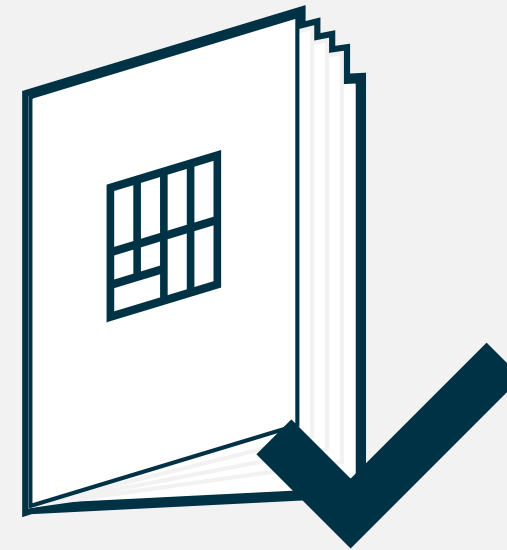
Scope Expansion from Envelope to Whole Building

This study expands embodied carbon research from an envelope-focused study to a whole-building carbon analysis. The previous study established that early design decisions, especially compact form, VFAR, WWR, and envelope material selection, strongly influence envelope embodied carbon. The 2025 study confirms that these design relationships still hold and adds the layer that structure is the dominant driver of upfront embodied carbon, accounting for approximately 76% of total embodied carbon across the residential dataset.



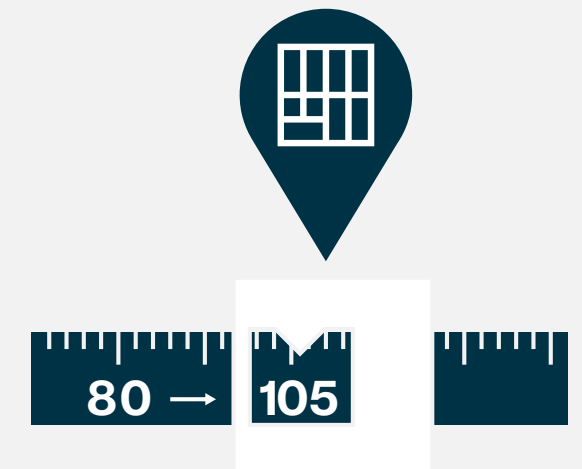
Structure Is the Dominant Carbon Driver

The central finding is that envelope optimization alone is not enough. Envelope design remains important because it is highly sensitive to architectural decisions, but the largest share of carbon sits in the structure. This changes the design challenge: at the 350 kgCO₂e/m² target, many projects can get close through improved business-as-usual practice, including better material selection, lower-carbon concrete, and envelope optimization; at the 250 kgCO₂e/m² target, incremental improvements are no longer enough.



Previous Envelope Findings Remain Valid

Several findings from the previous year remain consistent. Compact forms continue to perform better. VFAR should still be moderated, with 50% maintained as a useful early-stage reference point. WWR should continue to be controlled, with 40% remaining a useful design target for aluminum-heavy assemblies. The design direction from the previous study remains valid: reduce unnecessary envelope area, avoid excessive glazing, and make material decisions early enough to preserve the carbon budget.



Envelope Benchmarks Need Recalibration

What has changed is the scale and interpretation of the findings. The updated methodology shows that envelope ECI is higher than previously benchmarked. This does not reverse the earlier conclusion, but it does mean that internal benchmarks should be recalibrated. The result also highlights the sensitivity of LCA outcomes to EPDs, generic assumptions, and modelling methodology.



Scale and Repetition Influence Carbon Efficiency

As GFA increases, ECI generally decreases across total, envelope, and structure. This suggests that carbon efficiency can improve through repetition, compactness, and more efficient distribution of material across floor area. This should not be read as “bigger is always better.” Rather, the finding suggests that repetition and structural regularity can reduce ECI when scale is handled efficiently.



FSI Affects Structure and Envelope Differently

FSI shows that density affects structure and envelope differently. Low-FSI projects tend to be less efficient because material is spread across ECI, while very high density can introduce structural pressures. This reinforces that carbon-efficient density is not simply more density. It is density that is compact, repetitive, structurally rational, and materially efficient.



Mass Intensity Is a Primary Carbon Indicator

The mass analysis is one of the clearest additions to this year’s study. EC, GFA, and mass are strongly positively correlated, and mass intensity is meaningfully correlated with ECI. In the dataset reviewed, mass intensity explains the majority of the variation in embodied carbon intensity, confirming that material quantity is a primary driver of carbon outcomes. This finding turns structural efficiency into a direct carbon strategy: reducing mass per square metre is one of the most direct pathways to reducing upfront embodied carbon.



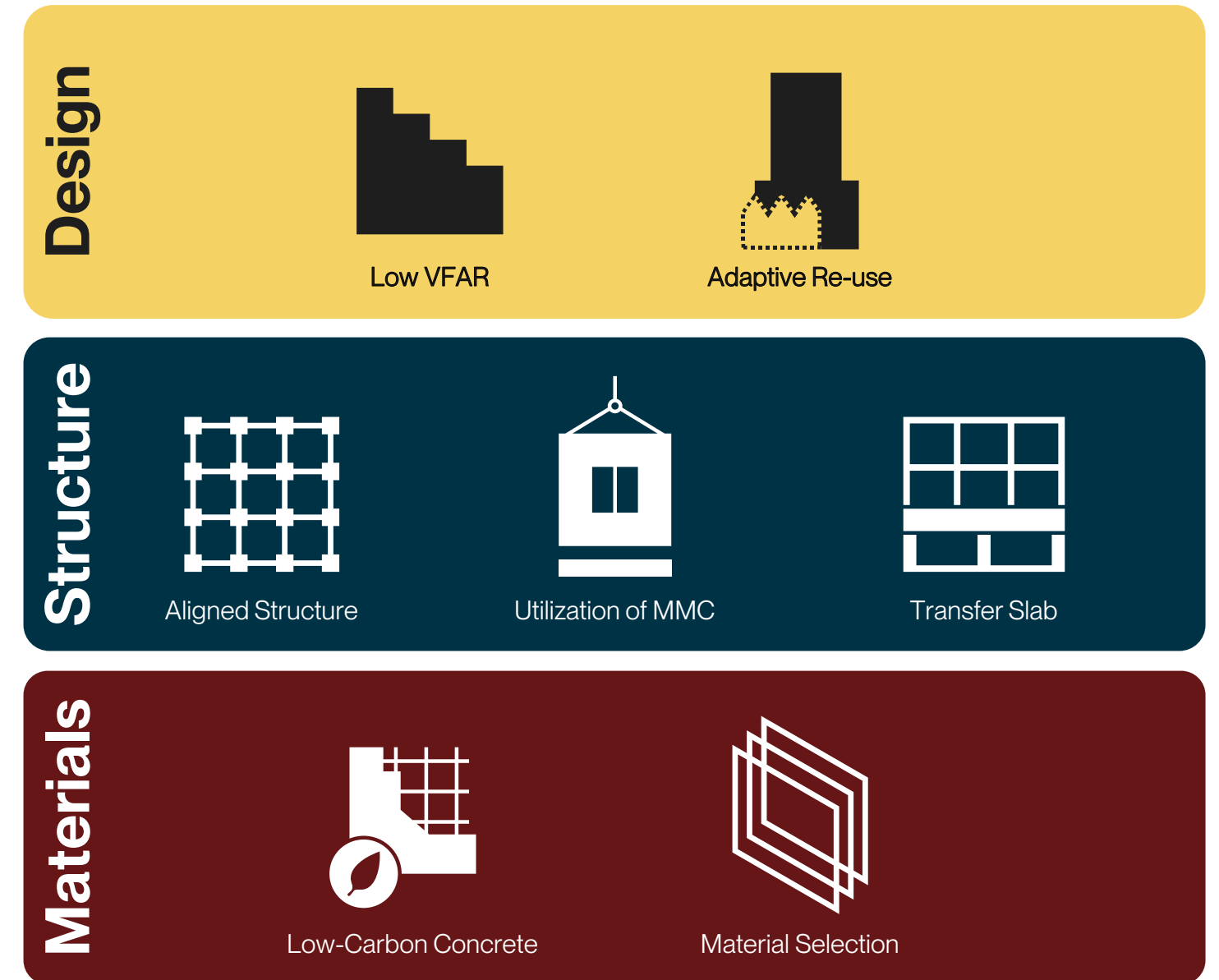
Portfolio Performance Is Trending Lower

The trend analysis suggests that both ECI and mass intensity have been coming down in more recent projects. This indicates that the portfolio is moving in a lower-carbon direction, likely through a combination of improved design awareness, better coordination, and more efficient use of material. These improvements should become intentional and repeatable through clearer carbon budgets, early structural review, and continuous LCA updates.

05

Case Studies

Icons



While not all strategies are represented equally across the dataset, the case studies illustrate a range of approaches observed in practice, including structural optimization, adaptive reuse, retention, MMC, and low-carbon material selection.

Figure 28 - Low-carbon strategy iconography

Valhalla Village



Figure 29 - Visualization of Valhalla Tower D

Number of Storeys
11

Number of Below Grade Storeys
1

GFA
15,474m²

Program
Residential

Unit Count
217

Structure Type
Precast Concrete

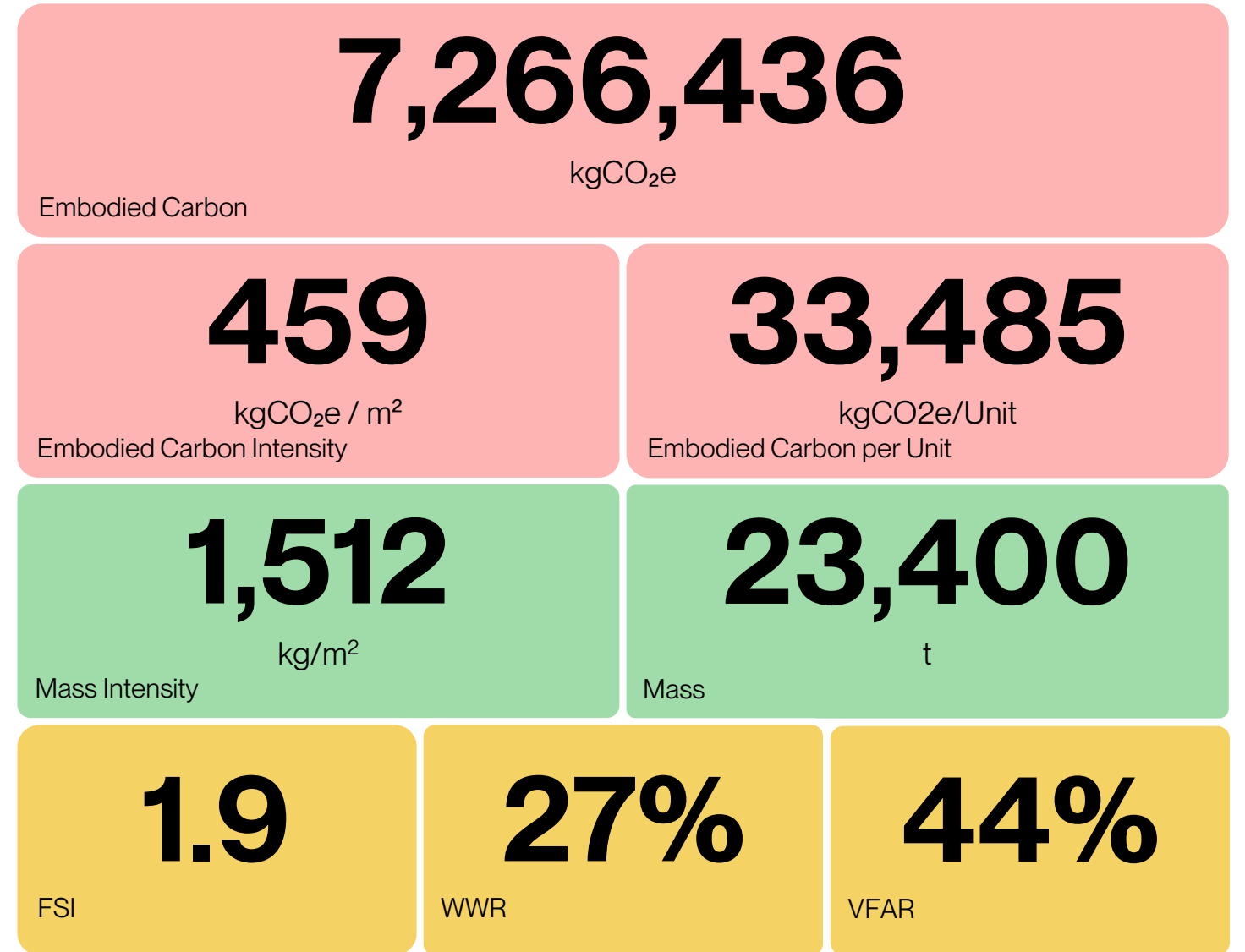
Foundation Type
Pier Foundation

SPA Year
2020

Status
In Construction

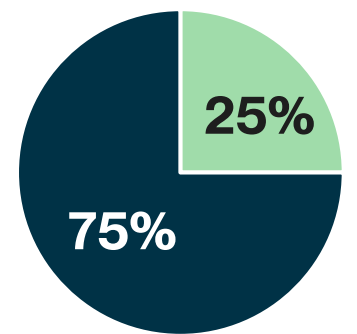
Project Description. Located in Etobicoke, Valhalla Village is a mixed-income rental community that transforms a former parking lot into affordable housing, retail space, a public park, and community-serving uses.

Carbon Performance Discussion. Valhalla Village achieves an embodied carbon intensity of 459 kgCO₂e/m², approximately 10% above the residential portfolio median. Despite its relatively compact form (VFAR 44%) and low window-to-wall ratio (27%), structural carbon remains the dominant contributor, accounting for 75% of total embodied carbon. The project utilizes a total modular precast concrete system, which project-specific LCA studies suggest can reduce transportation and construction-related emissions compared to a conventional cast-in-place alternative. The embodied carbon benefits are partially offset by the project's precast panels which, though less mass, include a layer of carbon intensive insulation. The



project also reported a 50% savings in winter heat due to enclosing each floor immediately. The case study is an outlier in the dataset and indicates that envelope optimization alone cannot achieve low embodied carbon outcomes. While Valhalla performs well from an envelope perspective, overall project performance remains strongly influenced by the structural system itself which is innovative and will require refinement with suppliers.

Key Lesson. Efficient building form and envelope design can help manage embodied carbon, but structural systems remain the primary drivers of overall project performance.



■ Envelope ■ Structure

89-101 Roehampton



Figure 30 - Photograph of 89-101 Roehampton

Number of Storeys
39

Number of Below Grade Storeys
2

GFA
27,908m²

Program
Residential

Unit Count
383

Structure Type
Cast-in-Place

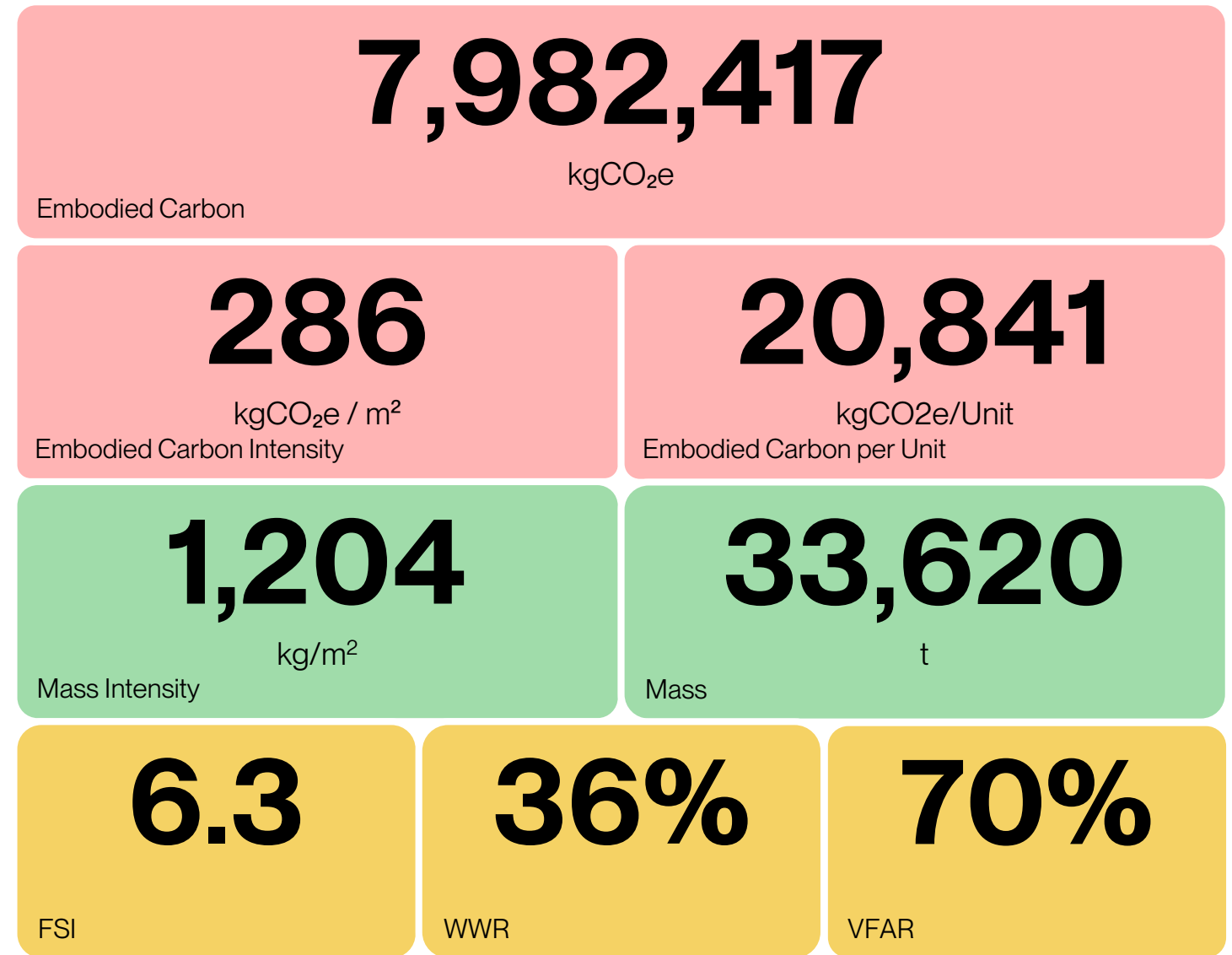
Foundation Type
Pier Foundation

SPA Year
2018

Status
Completed

Project Description. Located near Toronto's Yonge and Eglinton intersection, this 38-storey tower integrates directly with an existing 1970s apartment building, increasing density and connecting at the new lobby and amenity floors. It adds 255 new homes while preserving 128 units without displacing residents.

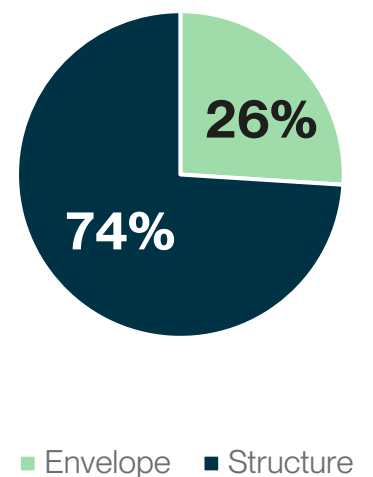
Carbon Performance Discussion. 89-101 Roehampton achieves an embodied carbon intensity of 286 kgCO₂e/m², approximately 33% below the residential portfolio median. A key contributor to this performance is the retention and integration of the existing residential building, which preserves a significant portion of the embodied carbon already invested in the structure while avoiding emissions associated with demolition and replacement. The project combines retained building elements with a new residential tower, demonstrating how intensification can be achieved while reducing the material demand typically associated with redevelopment.



Despite its high density (FSI 6.3) and substantial building mass, the project maintains a comparatively low embodied carbon intensity, highlighting the carbon benefits of retention and reuse strategies.

This case study demonstrates that adaptive reuse and overbuild approaches can support both urban intensification and embodied carbon reduction by treating existing buildings as carbon assets rather than liabilities.

Key Lesson. Retaining existing buildings and structures can significantly reduce upfront embodied carbon while supporting density, housing delivery, and community continuity.



400 King West



Figure 31 - Visualization of 400 King Street West

Number of Storeys
50

Number of Below Grade Storeys
3

GFA
40,239m²

Program
Residential

Unit Count
612

Structure Type
Cast-in-Place

Foundation Type
Pier Foundation

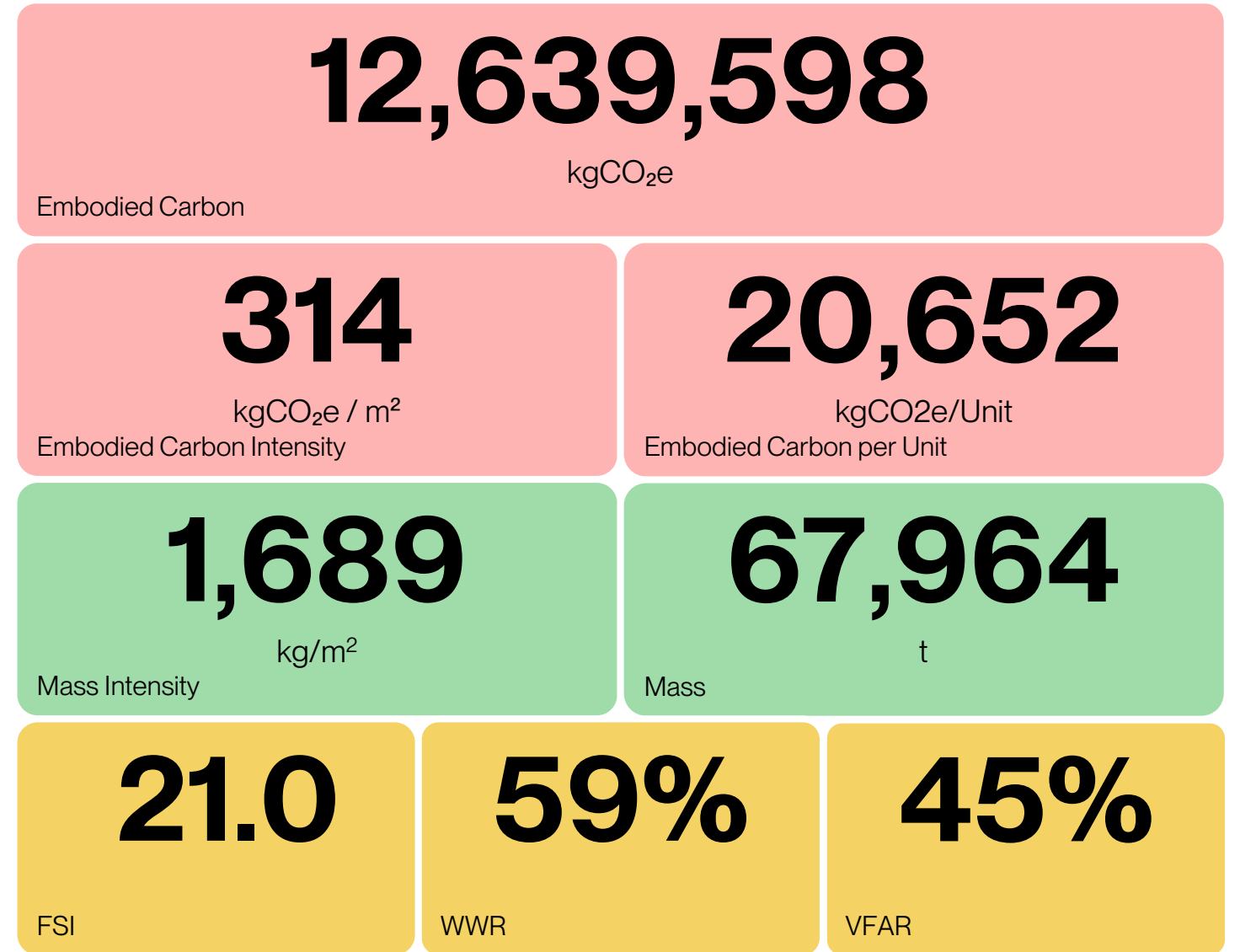
SPA Year
2019

Status
In Construction

Project Description. Located in downtown Toronto, 400 King West is a high-rise residential condominium. It features a distinctive brick and terracotta podium that complements the area's heritage context.

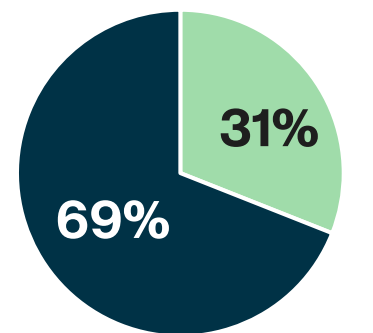
Carbon Performance Discussion. 400 King West achieves an embodied carbon intensity of 314 kgCO₂e/m², approximately 26% below the residential portfolio median despite its high density, extensive glazing, and three levels of below-grade construction. The project benefits from a highly efficient urban form, with an FSI of 21.0 and a relatively low mass intensity compared to many projects of similar scale. These characteristics allow a large amount of floor area to be delivered with comparatively low embodied carbon intensity.

In addition, the project retains existing shoring and caissons from the previous development. While these elements were not included within the project LCA and their carbon benefit was not quantified, the



favourable site conditions and reuse of existing substructure elements highlight an additional opportunity to reduce material demand and construction impacts on redevelopment sites.

Key Lesson. High-density development can achieve strong embodied carbon performance when efficient building form and structural design are combined with opportunities to retain existing site infrastructure.



■ Envelope ■ Structure

Indigenous Hub



Figure 32 - Photograph of Indigenous Hub

Number of Storeys
14

Number of Below Grade Storeys
1

GFA
41,160m²

Program
Residential

Unit Count
237

Structure Type
Cast-in-Place

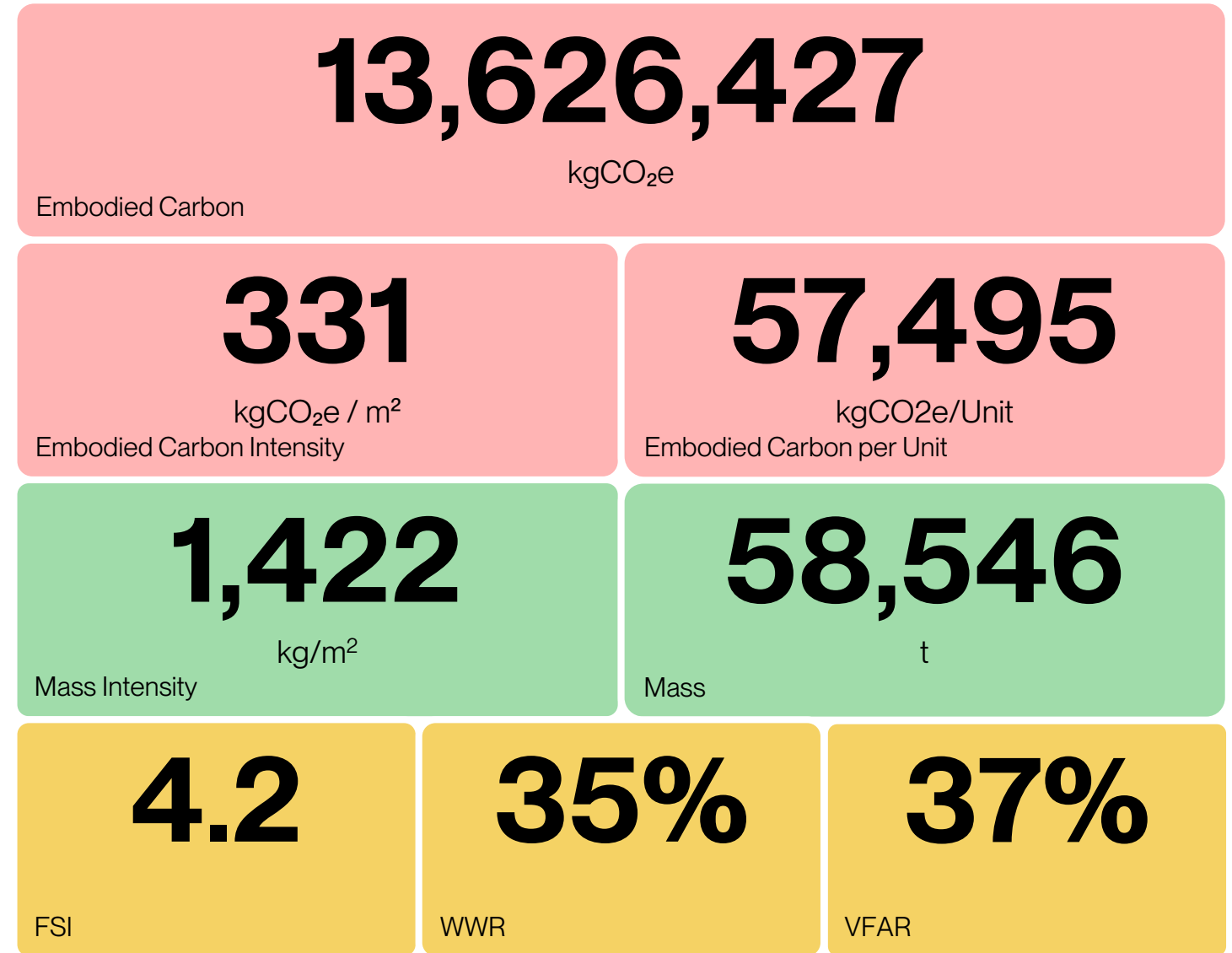
Foundation Type
Pier Foundation

SPA Year
2019

Status
Completed

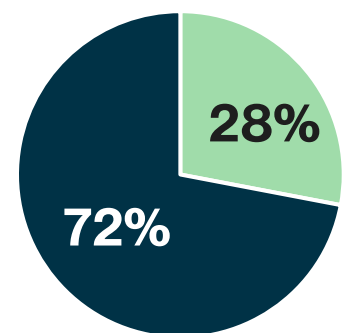
Project Description. The Indigenous Hub reclaims a long-vacant site to integrate a culturally grounded health centre, employment training, childcare, and residential buildings. Guided by the principle of "Two-Eyed Seeing," the design weaves Indigenous knowledge systems directly into its architecture.

Carbon Performance Discussion. The Indigenous Hub achieves an embodied carbon intensity of 331 kgCO₂e/m², approximately 22% below the residential portfolio median. Despite its mixed-use program and complex community-serving functions, the project maintains relatively low embodied carbon through efficient site utilization, compact massing, and coordinated structural design. A key contributor to performance was the careful management of below-grade construction and material quantities. The project minimized unnecessary structural complexity while accommodating cultural, community, and residential program requirements within a constrained urban site. Its relatively low window-to-wall ratio (35%) and



compact form further helped limit envelope-related embodied carbon. Rather than relying on a single low-carbon material or technology, the project demonstrates how integrated design decisions can collectively reduce embodied carbon. The case study highlights the value of balancing program requirements, site constraints, and structural efficiency to achieve strong carbon performance.

Key Lesson. Strong embodied carbon outcomes can be achieved through integrated design and material efficiency, even in complex mixed-use development.



■ Envelope ■ Structure

MV1 Condominium



Figure 33 - Photograph of MV1 Condominium

Number of Storeys
06

Number of Below Grade Storeys
2

GFA
15,989m²

Program
Residential

Unit Count
103

Structure Type
Panelized Wood

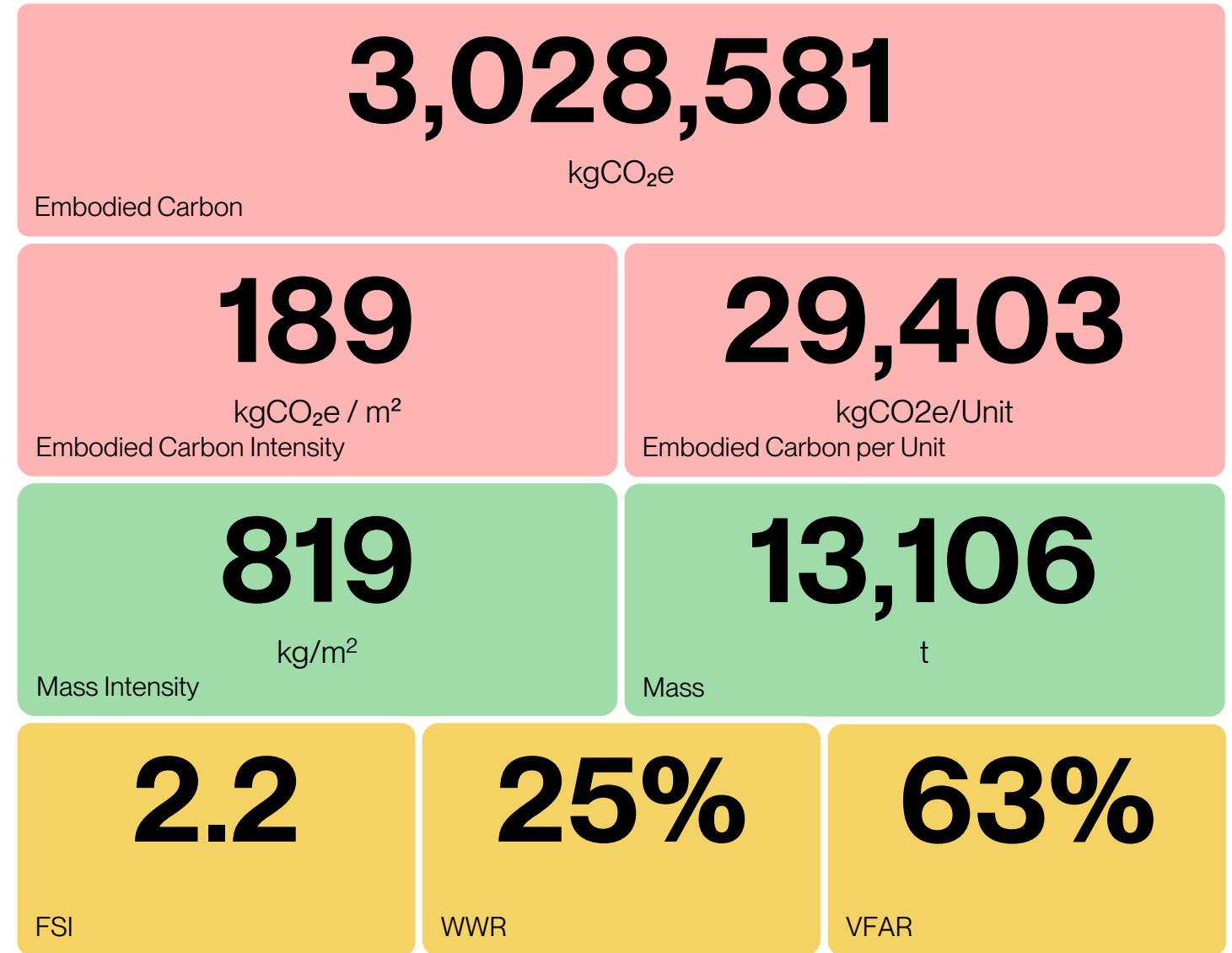
Foundation Type
Pier Foundation

SPA Year
2021

Status
Completed

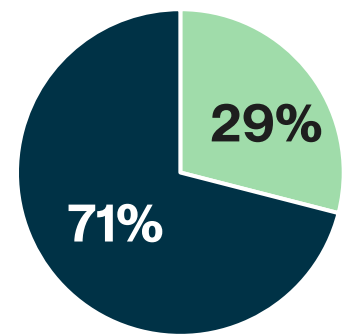
Project Description. MV1 Condominium is a six-storey, prefabricated wood-frame mid-rise in Milton. It serves as a suburban prototype, introducing compact, residential density and walkable amenities to an area traditionally dominated by single-family homes.

Carbon Performance Discussion. MV1 achieves an embodied carbon intensity of 189 kgCO₂e/m², approximately 55% below the residential portfolio median, making it one of the lowest-carbon projects in the study. The primary driver of this performance is the use of a panelized wood-frame structural system, which substantially reduces material demand and embodied carbon compared to conventional concrete construction. The project also benefits from a low window-to-wall ratio (25%), efficient building form, and relatively low mass intensity, helping to structural and envelope-related emissions. Prefabricated construction further improved material efficiency and reduced construction waste.



MV1 demonstrates the significant impact of early structural system selection on embodied carbon outcomes. While envelope optimization and material selection contributed to overall performance, the project's low embodied carbon intensity is primarily attributable to its lightweight structural system and efficient use of materials.

Key Lesson. Early structural system selection is one of the most influential embodied carbon decisions. MV1 demonstrates how lightweight, prefabricated construction can significantly reduce embodied carbon.



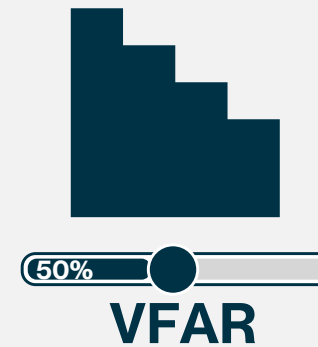
■ Envelope ■ Structure

06

Guidelines for Low-Carbon MURBs Design

The following guidelines are derived from observed relationships across the 100-project dataset. While project-specific conditions will vary, the findings consistently demonstrate that structural efficiency, material quantity, building form, and envelope design are the primary drivers of embodied carbon outcomes.

Envelope Form



01

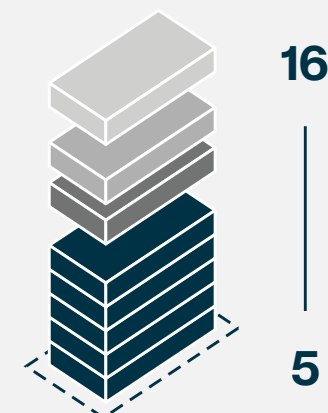
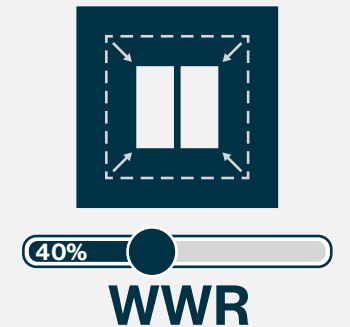
Keep VFAR below 50% wherever programmatic requirements allow.

Simplified, compact forms reduce envelope material demand and associated carbon.

02

Lock WWR at 40% as a baseline.

40% window-wall ratio is a good baseline target. If using low carbon envelope materials, a slightly higher ratio can be accommodated.



03

Target moderate-high FSI (6-15).

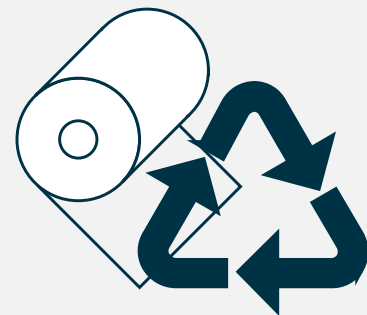
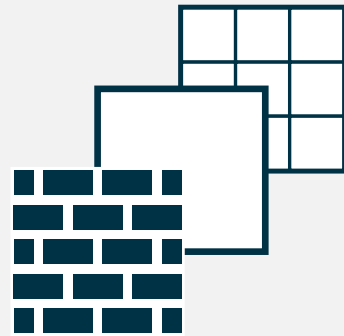
Avoid both under- and over-densification.

Envelope Materials

04

Prioritize brick, ceramic cladding, timber cladding and precast concrete as primary opaque assemblies where applicable.

These materials carry envelope ECI close to or below the TGS 350 envelope budget.



05

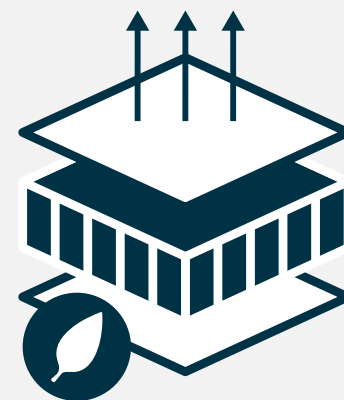
Where aluminum is used, specify post-consumer recycled content above 70%.

Specifying high post-consumer recycled content can reduce aluminum carbon factor by 60–75% vs. primary.

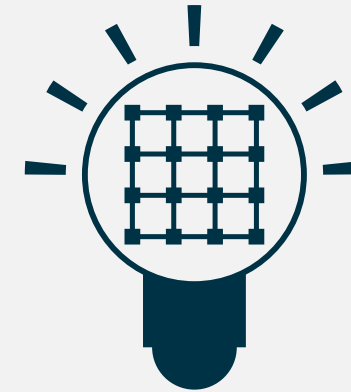
06

Coordinate insulation type with thermal envelope performance.

Insulation selection should consider embodied carbon alongside thermal performance, fire safety, durability, constructability, and code requirements. Where feasible, lower-carbon insulation options should be evaluated as part of the overall envelope strategy.



Structural Strategy



07

Align Structure, eliminate transfers slabs, and understand system and carbon.

Where longer spans are needed, compare PT/hollow-slab against composite timber-concrete and mass-timber options before selecting.

08

Consider all carbon reduction pathways early.

Evaluate opportunities to retain existing buildings, foundations, and structural elements where feasible.



09

Specify low-carbon cement wherever possible.

GUL / Portland-Limestone Cement reduces concrete embodied carbon by approximately 10%. Supplementary cementitious materials (slag, fly ash) reduce it further. Require EPDs with GWP ≤ 300 kgCO₂e/m³ for 30 MPa concrete.



Process and Governance

10

Establish component carbon budgets in the Project Intent.

Establish carbon budgets early, not a single total-ECl number. Track both structural and envelope budgets through DD, CD, and CA.



Note

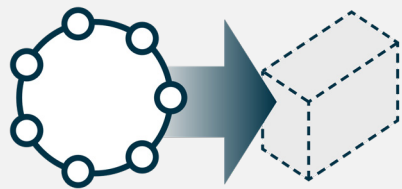
The 2024 envelope guidelines are preserved, re-ordered, and expanded with four structure-focused items from the 2025 analysis. These values should be treated as carbon budgets, not rigid design rules. Where site constraints require higher-impact design responses, such as mid-rise step backs increasing VFAR or poor soil conditions increasing structural demand, those impacts should be acknowledged and balanced through reductions elsewhere. The goal is to evaluate design options as a system, using trade-offs across structure, envelope, material selection, and form to reach the desired carbon target.

The guidelines translate the study's findings into a carbon budgeting framework for design. Structure, envelope, form, and material selection must be controlled together so that reductions in one area are not cancelled out by increases elsewhere.

11

Integrate High-Level LCA early.

LCA is often completed mid-to-late in the project, when key decisions have already been made, limiting opportunities for meaningful optimization. By adapting Carbon Flow, teams can make lower-carbon decisions before the design becomes fixed.



12

Iterate continuously through the design process.

Carbon performance is largely determined during early design decisions. Assess opportunities to optimize form, structure, material selection, retention of existing assets, and modern methods of construction (MMC).

