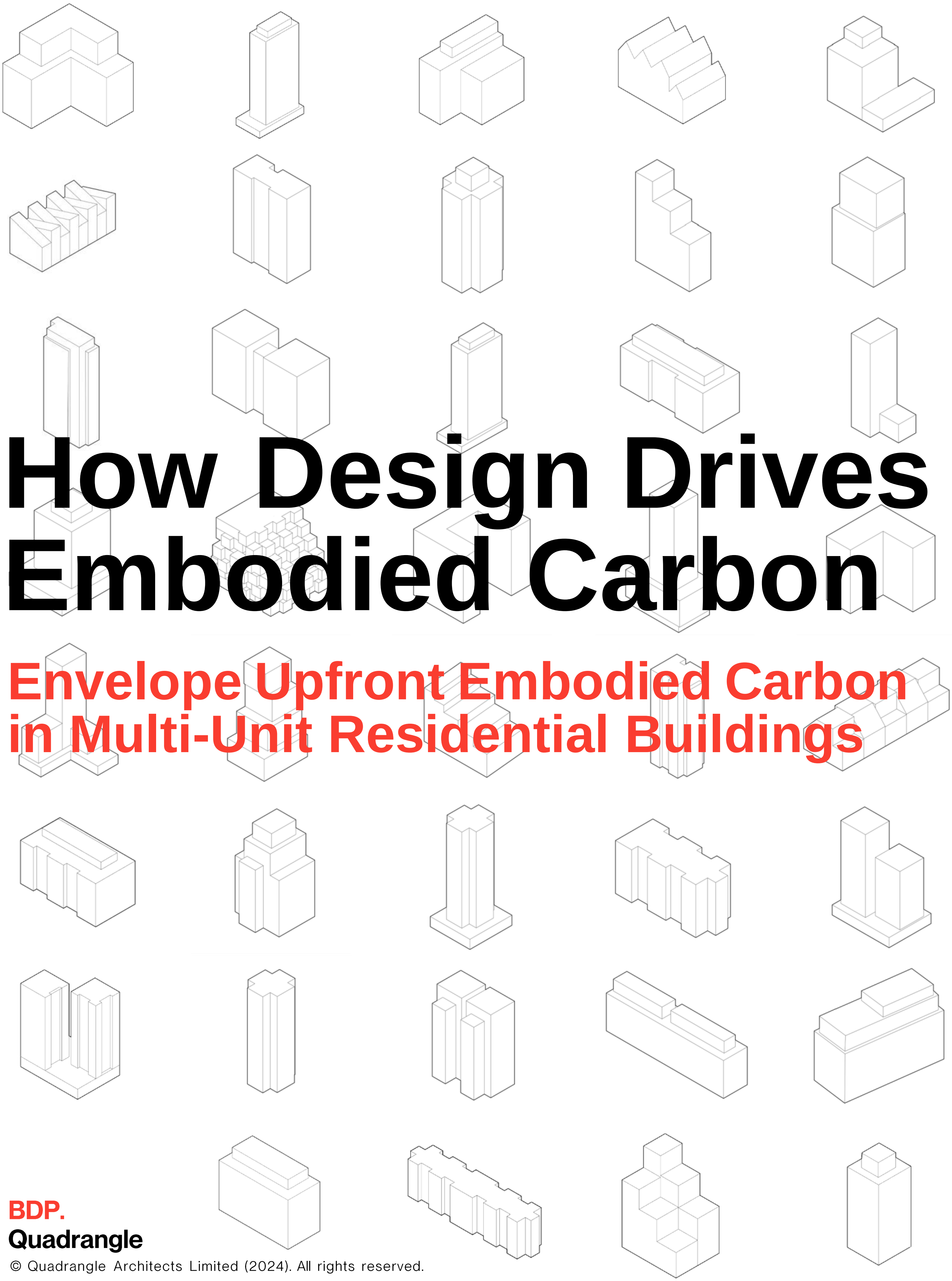

How Design Drives Embodied Carbon

Envelope Upfront Embodied Carbon in Multi-Unit Residential Buildings

BDP.
Quadrangle

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BDP.
Quadrangle

Introduction

Why embodied carbon?

Buildings contribute to approximately 40% of global carbon emissions, with 11% stemming from *embodied carbon* in material production, transportation, and assembly (UNEP & IEA, 2019).

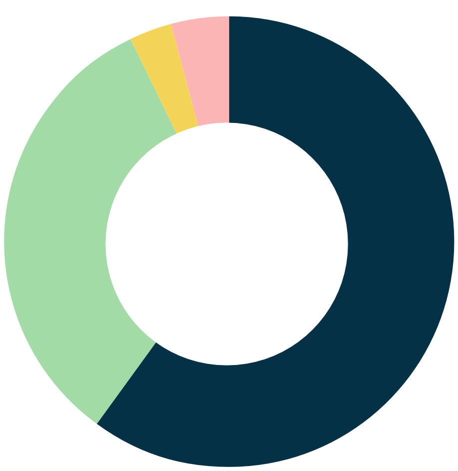


Fig. 1 Carbon Emission Inventory Report (TAF, 2023)

As urban development accelerates, addressing *embodied carbon* has become essential to reducing the environmental impact of new buildings.

City of Toronto

In 2022, building emissions accounted for 60% of Toronto's total greenhouse gas emissions, followed by transportation at 33%, industry at 3%, and waste at 4%. This distribution underscores the significant role of sustainable building practices in the city's climate strategy (TAF, 2022).

In a landmark move, Toronto became the first North American jurisdiction to implement *embodied carbon* limits for new buildings. As of May 2023, the TGS mandates that city-owned buildings limit upfront *embodied carbon* emissions (generated from material extraction, production, transportation, A1-A5) to 350 kgCO2e/m². For private developments, TGS Tier 2 and Tier 3 buildings are required to meet thresholds of 350 kgCO2e/m² and 250 kgCO2e/m², respectively (City of Toronto, 2023).

BDP Quadrangle

Aligned with these evolving standards, BDP Quadrangle has committed to designing net-zero carbon ready projects, targeting an *embodied carbon intensity* of 250 $kgCO_2e/m^2$ by 2030.

In 2024, BDP Quadrangle conducted an upfront assessment of *embodied carbon* emissions on 30% of its projects. 44 of these were multi-unit residential.

> ***This study was prepared to examine the upfront embodied carbon emissions of these multi-unit residential buildings, specifically focusing on the building envelope. It seeks to understand the impacts on embodied carbon intensity (ECI) from envelope expression, form, and material selection. It aims to provide design guidance for architects to make carbon-informed design decisions.***

Special thanks to Jablonsky Ast and Partners, RJC Engineering, Entuitive, Honeycomb, and Salas O'Brien 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.

Executive Summary

Optimizing Building Envelope

By analyzing *embodied carbon* assessments from 44 multi-unit residential projects in the GTA, we identified key metrics, quantified impacts, and developed actionable guidelines for architects.

This research aligns with existing industry insights on the impact of design decisions on *embodied carbon* emissions. The *embodied carbon* assessment is in alignment with the Toronto Green Standard Version 4 GHG 2.1 Low Embodied Emission materials, which references the CaGBC Zero Carbon Building Standard methodology for service life. Separate analyses were conducted for the envelope (by BDP Quadrangle) and structure (by contributing structural engineers).

Purpose

The primary objectives of this study are:

1. To assist designers in understanding the influence of early design decisions on *embodied carbon* emissions by providing data-driven insights.

2. To establish design guidelines for building envelopes, enabling architects to achieve measurable, sustainable outcomes to meet carbon reduction targets.

This dual focus ensures architects can effectively integrate carbon-conscious decisions into the design process.

Key Takeaways

Key findings reveal that compact building forms (Fig. 3), characterized by lower Vertical Floor Area Ratios (VFAR) and Window-to-Wall Ratios (WWR), provide a strong foundation for reducing the embodied carbon of building envelope, which accounts for 23% of a building's total embodied carbon.

These simplified forms minimize envelope material demands through reduced surface area, allowing greater flexibility in material selection to meet stringent carbon budgets like those outlined by the Toronto Green Standard (TGS). Conversely, complex forms with higher VFAR and WWR consume a significant portion of the embodied carbon budget early in the design process, constraining material options at later stages.

Material selection further amplifies or mitigates carbon impacts (Fig. 4). Brick, ceramic cladding, and precast concrete, all opaque wall materials, drive low carbon options. Aluminum-heavy assemblies*, driven by high glazing proportions drive up embodied carbon and require careful management of WWR.

Early-stage decisions on VFAR and WWR are crucial to aligning design with the embodied carbon budget.

*Note that the current process for manufacturing aluminum is very carbon intensive. It is understood that as the industry starts to decarbonize their manufacturing processes and use more post-consumer recycled materials, this relationship will change.

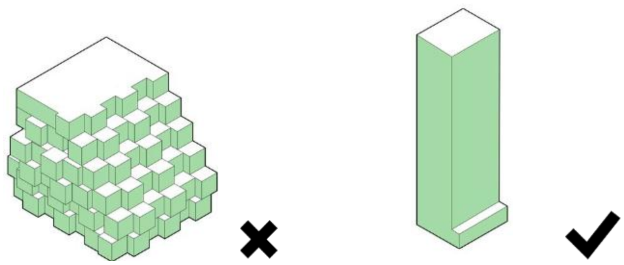


Fig. 3 Complex form (high *VFAR*) and compact form (low *VFAR*)

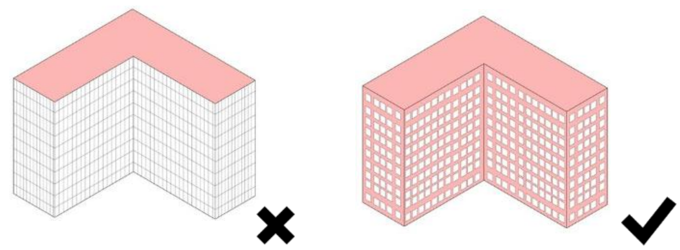


Fig. 4 High-carbon materials (high *WWR*) and low-carbon materials (low *WWR*)

As designers, the findings emphasize the importance of:

1. Establishing *embodied carbon* budgets early in the project lifecycle.

2. Coordinating with structural engineers and architects to ensure the envelope aligns design decisions with carbon goals.

3. Using BIM tools (Revit) to evaluate *VFAR, WWR*, and *ECI* during the schematic phase to optimize building forms and material selection.

Project teams can create compliant designs balancing carbon performance by focusing on simple forms, low-carbon materials, and early-stage carbon assessments. These strategies align with current market trends and set a benchmark for reducing the environmental footprint of multi-unit residential developments in Toronto.

Approach

The following approach was taken:

1. Conduct upfront *embodied carbon* studies looking at emissions generated from material extraction, production, transportation (A1-A5)
2. Determine the percentage of total *embodied carbon* attributed to the envelope.
3. Establish carbon budgets for building envelopes that align with *Toronto Green Standard (TGS)* target.
4. Assess the impact of building size on *embodied carbon*.

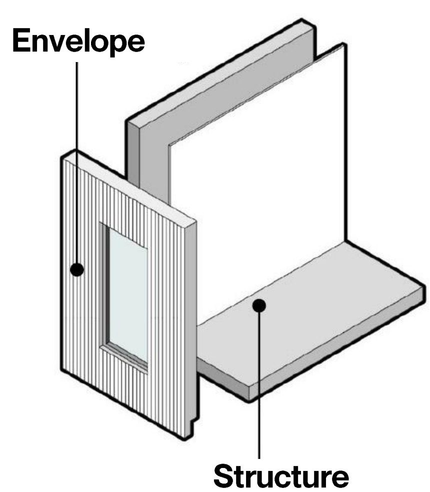


Fig. 2 Building envelope vs structure

5. Analyze how form characteristics influence *embodied carbon intensity*.
6. Understand the relative influence of design optimization versus material selection.

Method

The first step in the analysis identifies the portion of total *embodied carbon* attributed to the envelope, which allows for establishing a carbon budget for the envelope. The subsequent analysis explores the key design decisions—such as the *Vertical Floor Area Ratio (VFAR)*, *Window-to-Wall ratio (WWR)*, and material selection—that significantly influence the envelope's *embodied carbon*. Aligning with ECHO Reporting Schema standards (ECHO Project, 2024), this multi-dimensional approach provides a data-driven view framework for carbon-conscious envelope design.

Basis of Dataset

Sources, Tools and Scope

This study is based on Upfront Embodied Emissions Assessments for the structure and envelope of 44 multi-unit residential projects designed by BDP Quadrangle in the Greater Toronto Area (GTA). The projects in the dataset are predominantly in the Design Development and Construction Documentation phases.

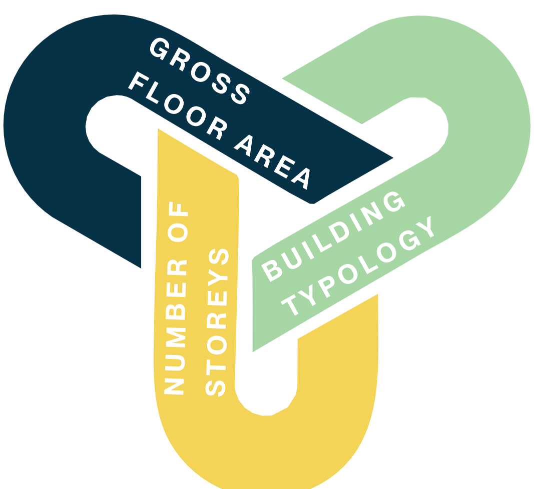


Fig. 5 Carbon Emission Inventory Report (TAF, 2023)

Project Typology Details

The dataset includes a mix of low-rise, mid-rise, and high-rise multi-unit residential buildings, representing the following:

- Low-rise (2 projects): GFA ranges from 3,522 m^2 to 5,389 m^2
- Mid-rise (12 projects): GFA ranges from 7,500 m^2 to 25,888 m^2
- High-rise (30 projects): GFA ranges from 8,249 m^2 to 61,103 m^2

Life-Cycle Stages

Following the Canada Green Building Council (CaGBC) Zero Carbon Building Standard, *embodied carbon* was calculated using the BS EN 15987 *embodied carbon* stages (Fig. 6). The *Toronto Green Standard* requires quantifying "upfront" impacts (Modules A1-A5) based on a 60-year life expectancy of the building. This is the scope that has been included for all projects broken down as follows:

A1-A3 (Product Stage): Includes emissions from raw material extraction, transport, and manufacturing, calculated using detailed *EPD* data.

A4-A5 (Construction): Incorporates transport-related emissions based on OneClick LCA's regional assumptions and material wasteage rates provided by OneClick LCA to capture impacts from on-site construction and installation practices.

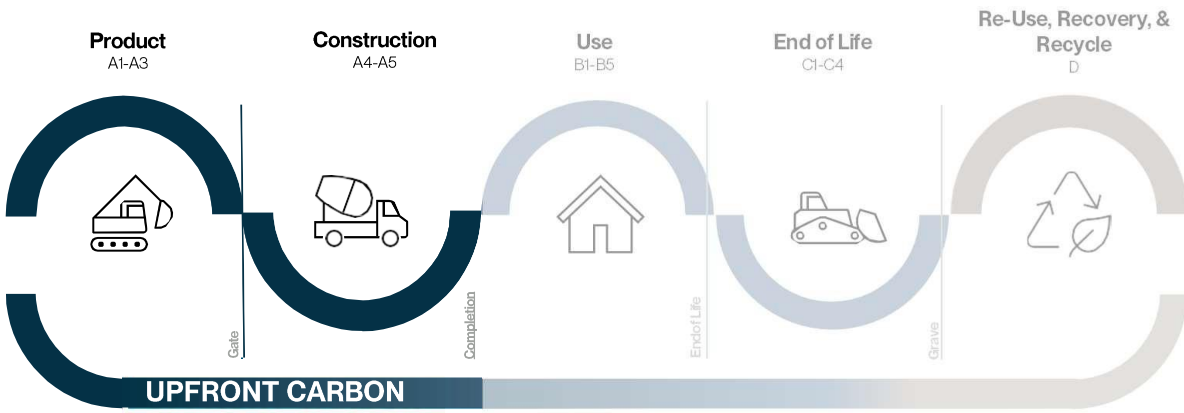


Fig. 6 Life Cycle Stages included in study include upfront emissions from stages A1-A5

Material Quantities

Material quantities were calculated using architectural Revit models where available and structural calculations as provided by the structural consultant.

The following elements were included in all assessments:
All permanently installed envelope and structural elements, including footings and foundations, complete structural wall assemblies (from cladding to interior finishes, including basement), structural floors and ceilings (not including finishes), roof assemblies, stairs, and parking structures.

The following elements were excluded from all assessments:
Excavation and other site developments, partitions, finishes, building services (electrical, mechanical, fire detection, alarm systems, elevators, etc.), fixtures and fitting, surface parking lots, and associated building site improvements.

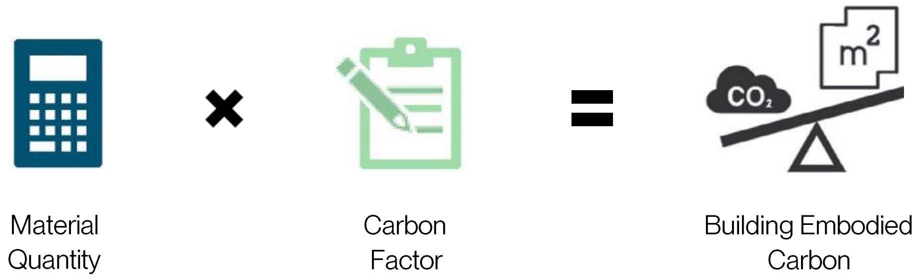


Fig. 7 Formula to calculate *embodied carbon* emissions

Data Sources

Environmental Data: *Embodied carbon* data was derived primarily from *Environmental Product Declarations (EPDs)* and calculated using OneClick LCA.

Software & Tools

Revit	Autodesk Revit was utilized to quantify material volumes accurately, ensuring alignment with each project's detailed design specifications. Revit models were meticulously cleaned and exported to generate material take-offs, establishing a reliable foundation for data analysis.
Excel	The exported material take-offs were processed in Excel, where the data was merged, organized, and refined for clarity and consistency. This step facilitated a seamless transition to subsequent stages of analysis.
Custom Analysis Tools	In-house-developed tools were employed to perform detailed analyses of building forms and systematically assign *Environmental Product Declarations (EPDs)* to relevant construction assemblies. These tools ensured that data inputs were tailored to project-specific parameters.
One Click LCA	The processed data and assigned *EPD*s were imported into One Click LCA, a leading life cycle assessment tool. This allowed for accurate embodied carbon calculation, producing actionable insights to inform carbon reduction strategies.

Area

Gross Floor Area (GFA) follows the *National Research Council of Canada (NRC)* defined in Appendix A of "National guidelines for whole-building life cycle assessment, 2022" as the reference unit. This definition includes the area from the external surface of walls and structures and includes the parking garage.

Key Data Collected

This document outlines the key data collected and calculated for all buildings within the dataset. It serves as a comprehensive guide to understanding the metrics used to assess the *embodied carbon (EC)* associated with various building components. The focus is on both the quantitative data collected and the calculations performed to derive insights into the buildings' environmental impact.

Key data collected for all buildings within the dataset included:

- *Gross Floor Area*
- Number of residential units
- Number of storeys
- Envelope Area
- *Window-to-Wall Ratio (WWR)*
- *Vertical Floor Area Ratio (VFAR)*
- Predominant building envelope cladding material

Key data calculated for all buildings within the dataset included:

- Total *EC*, kgCO2e
- Breakdown of total *EC* between structural and building envelope
- Total *embodied carbon intensity* per *GFA (ECI)* kgCO2e/m²
- Structural *embodied carbon intensity* per *GFA (ECI)* kgCO2e/m²
- Envelope *embodied carbon intensity* per *GFA (ECI)* kgCO2e/m²
- Total *embodied carbon* per unit kgCO2e/unit
- *Embodied carbon* of materials used in the wall assembly per square meter of assembly (*ECI* assembly) kgCO2e/m² assembly
- Envelope *Embodied carbon* intensity per square meter of envelope (*ECI* envelope) kgCO2e/m² envelope

This structured data collection and calculation approach enables a thorough analysis of the upfront *embodied carbon* emissions assessment.

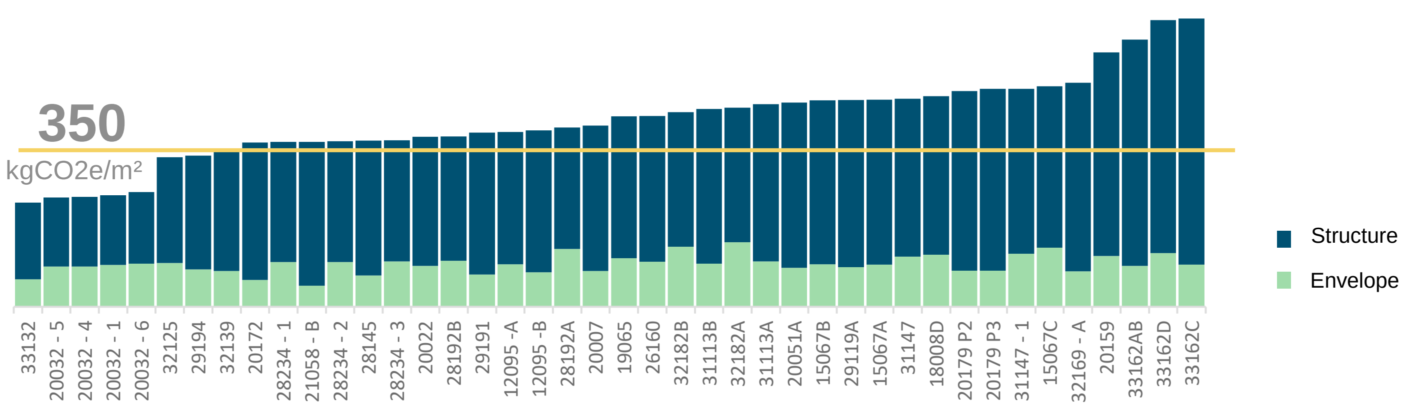


Fig. 8 Total *embodied carbon intensity (ECI)* of all buildings within the dataset broken down by a total *ECI* attributable to structure versus envelope compared to the *TGS ECI* target

Dataset Analysis

Factors and Correlations

The dataset was analyzed to determine the relative impact of envelope expression, form and material selection on *embodied carbon* emissions.

Factors examined include the ratio of *vertical surface area to floor area (VFAR),* the *ratio of window area to opaque wall assembly (WWR), the gross floor area (GFA)* and the material/wall assembly. The following methodology was incorporated to understand the correlations.

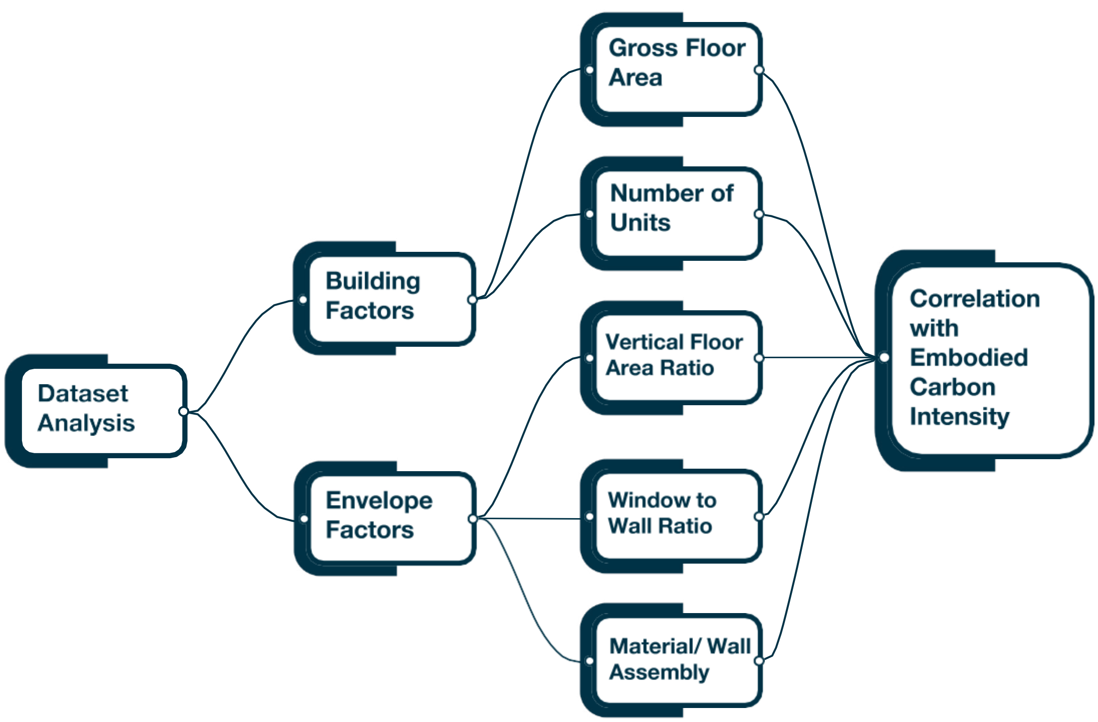


Fig. 9 Method of dataset analysis to determine correlations

Analytical Approach

The following steps outline the specific methods used to answer the study's questions:

1 **Breakdown of Total *Embodied Carbon***

Approach: Total *embodied carbon* was calculated for each project and broken down into structural and envelope components to determine their respective contributions. A range of values (minimum, maximum, and median) was then provided to establish typical project contributions.

2 ***ECI* Budget for Building Envelope Base on *TGS* Target**

Approach: With the *TGS* targeting a maximum of 350 kgCO2e/m², the average percentage *EC* value was multiplied by 350 kgCO2e to determine a reasonable *EC* budget for structure and building envelope.

3 **Impact of Building Size on Total *Embodied Carbon***

Approach: Regression and correlation analyses were performed to examine the relationship between building size *(Gross Floor Area)* and total *embodied carbon*. This relationship was visualized with scatter plots and heatmaps to highlight trends in how size impacts total and envelope EC.

4 **Impact of Form on *Embodied Carbon (VFAR, WWR)***

Approach: Analysis focused on the relationship between *VFAR, WWR,* and total *embodied carbon*. Projects were compared based on form factors to assess how *VFAR* and *WWR* influence carbon intensity.

5 **Relationship Between Form/Size and *ECI***

Approach: Multivariate analysis was conducted to evaluate how form (*VFAR, WWR*) and size (*GFA*) impact total and envelope *ECI*. This helped identify interactions between form and size that affect carbon outcomes.

6 **Comparing Impact of Building Size/Form with Material**

Approach: *Embodied carbon* reductions from form/size optimization were compared against reductions achieved through material selection. This analysis highlighted the relationship between form and material selection to understand the combined impact.

7 Correlation Between *Embodied Carbon* per m² Envelope vs. per m² *GFA*

Approach: Embodied carbon per m² of envelope and *GFA* was calculated for each project, followed by correlation analysis to assess the relationship between these metrics.

8 Summary of Insights (*VFAR, WWR,* Size)

Approach: Upon completing the analysis, key insights were summarized to highlight actionable requirements and recommendations related to *VFAR, WWR,* and building size.

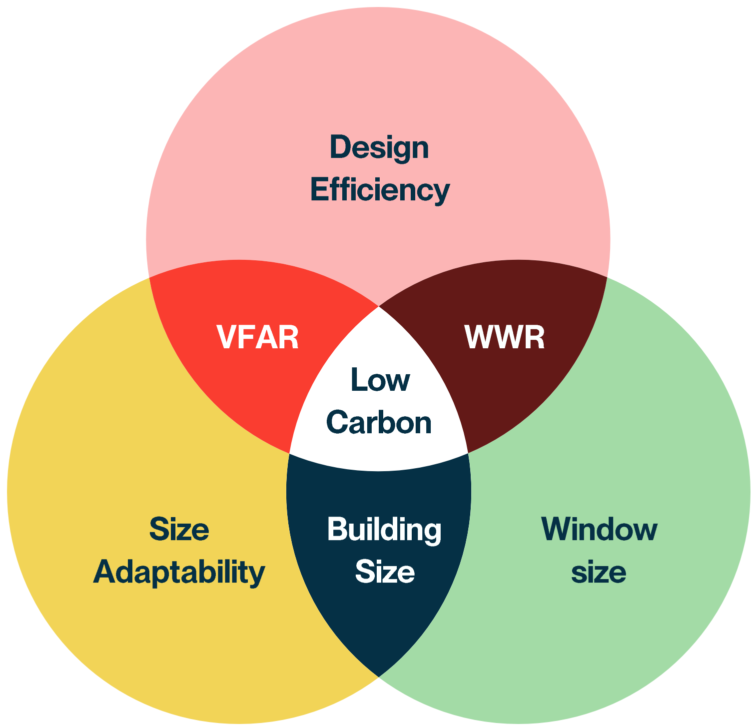


Fig. 10 Interplay of design factors on *embodied carbon*

Key Findings

Design and Embodied Carbon

In this study, we analyzed key factors influencing *embodied carbon* in multi-unit residential buildings, focusing on design characteristics and material selections.

The following insights and trends have been identified to help designers make informed decisions to minimize *embodied carbon*.

1 Breakdown of Total Embodied Carbon

The building envelope's *embodied carbon* contribution ranges from 15% to 38%, averaging 23% across all projects (Fig. 11). The percentage contribution establishes a baseline for understanding the envelope's contribution to total *embodied carbon*, and suggests and envelope carbon budget.

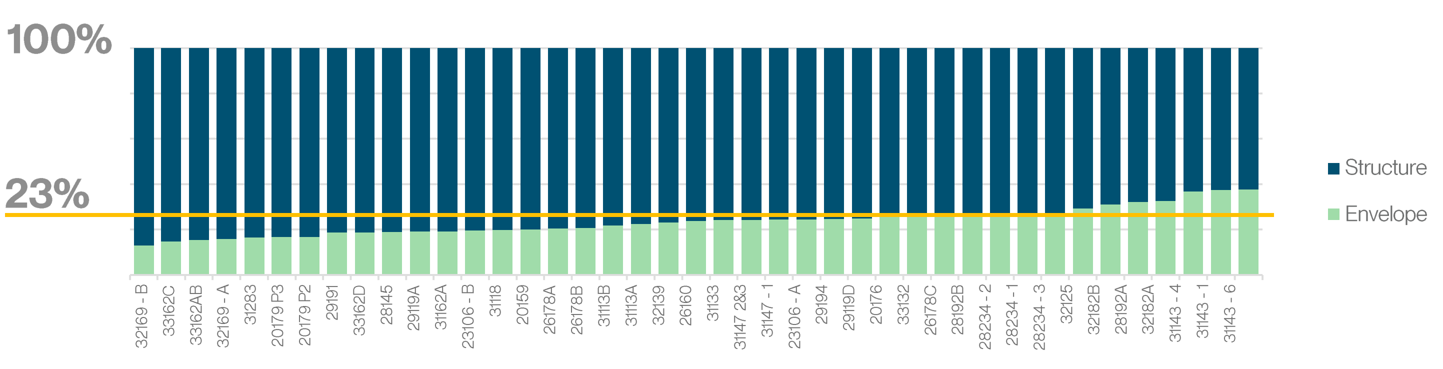


Fig. 11 Total *embodied carbon (EC)* of all buildings within the dataset broken down by percentage attributable to structure versus envelope

Building envelope makes up an average of 23% of the total Embodied Carbon Intensity

2 *ECI* for Building Envelope Based on TGS Target

The *Toronto Green Standard (TGS)* establishes a total *embodied carbon intensity (ECI)* target of 350 kgCO2e/m². The analysis indicates that the building envelope contributes approximately 23% of total *embodied carbon*, setting the envelope's carbon budget at 80.5 kgCO2e/m².

Among the 44 projects analyzed, 31% of the *upfront embodied emissions* assessments align with this carbon budget (Fig. 12).

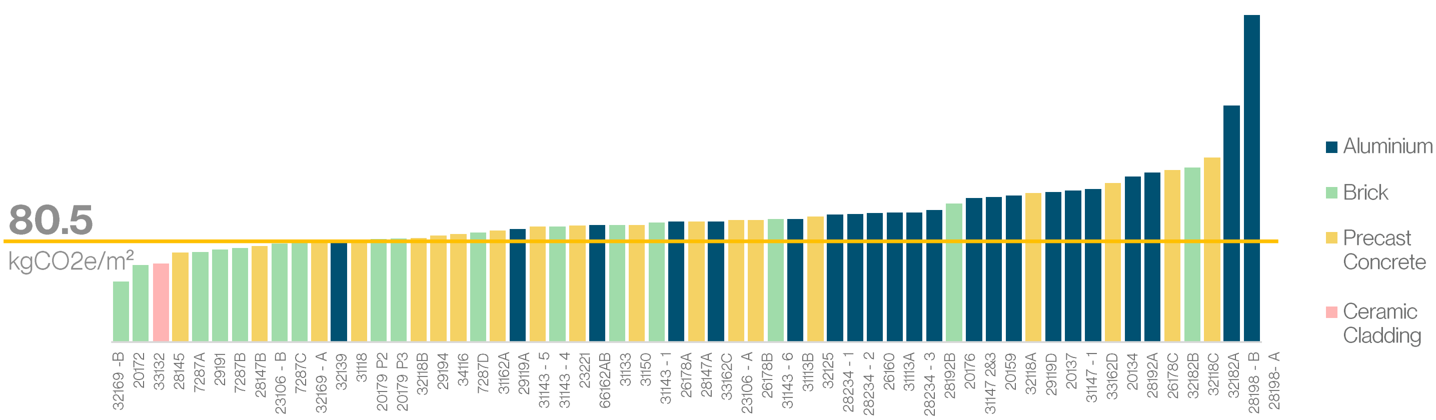


Fig. 12 *Embodied carbon intensity (ECI)* and primary assembly material of the envelope of all buildings within the dataset shown against the average envelope *ECI* budget to meet the *TGS ECI* target

To meet the TGS target of 350kgCO2e/m2, the average envelope ECI should not exceed 80.5 kgCO2e/m²

3 Impact of Building Size on Total EC

The study highlights the critical relationship between *Gross Floor Area (GFA)*, density, and envelope *embodied carbon*. Larger buildings inherently require more materials, leading to increased total *embodied carbon*. However, this impact can be mitigated through strategic design approaches that optimize density, unit mix, and layout efficiency. These factors directly influence how effectively *embodied carbon* is distributed across a project, enabling reductions in carbon intensity per unit or square meter of *GFA*.

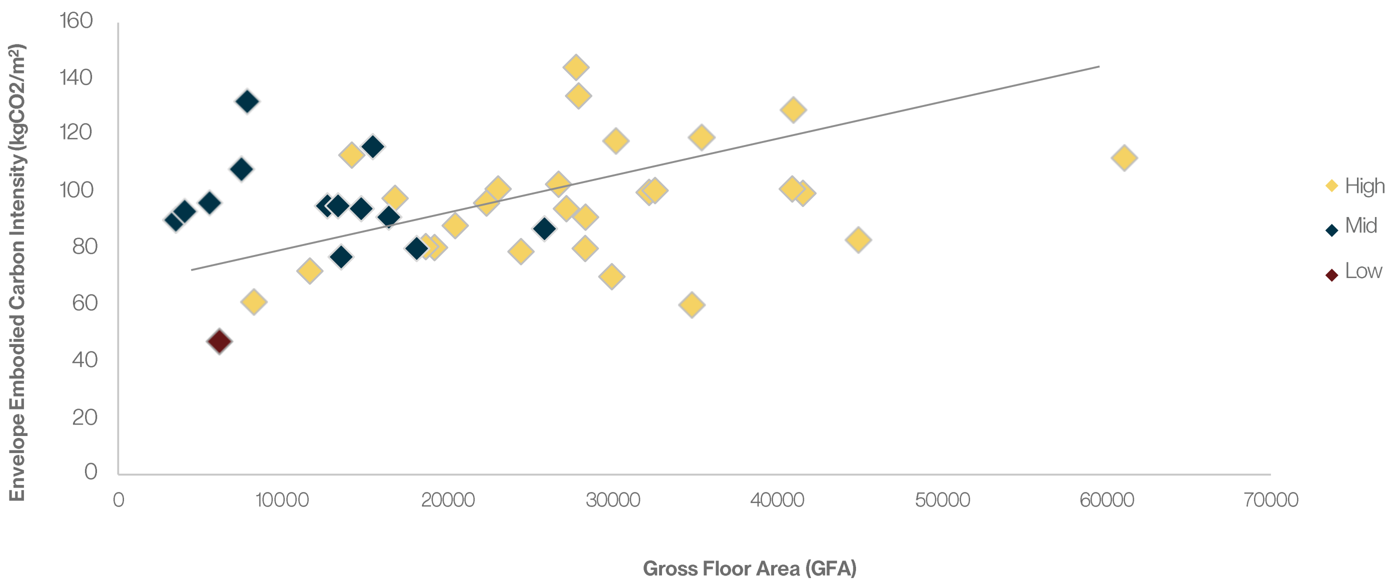


Fig. 13 Impact of building size total *GFA* on envelope *embodied carbon intensity*

Larger Buildings and Material Use:
As a building's *GFA* increases, the envelope embodied carbon intensity rises due to greater material demands.

FSI and *Embodied Carbon Intensity* of the Building Envelope:
As the building *FSI* increases, the envelope *embodied carbon intensity* increases.

Optimizing density, layout efficiency, and unit mix is the key to reducing embodied carbon in larger buildings

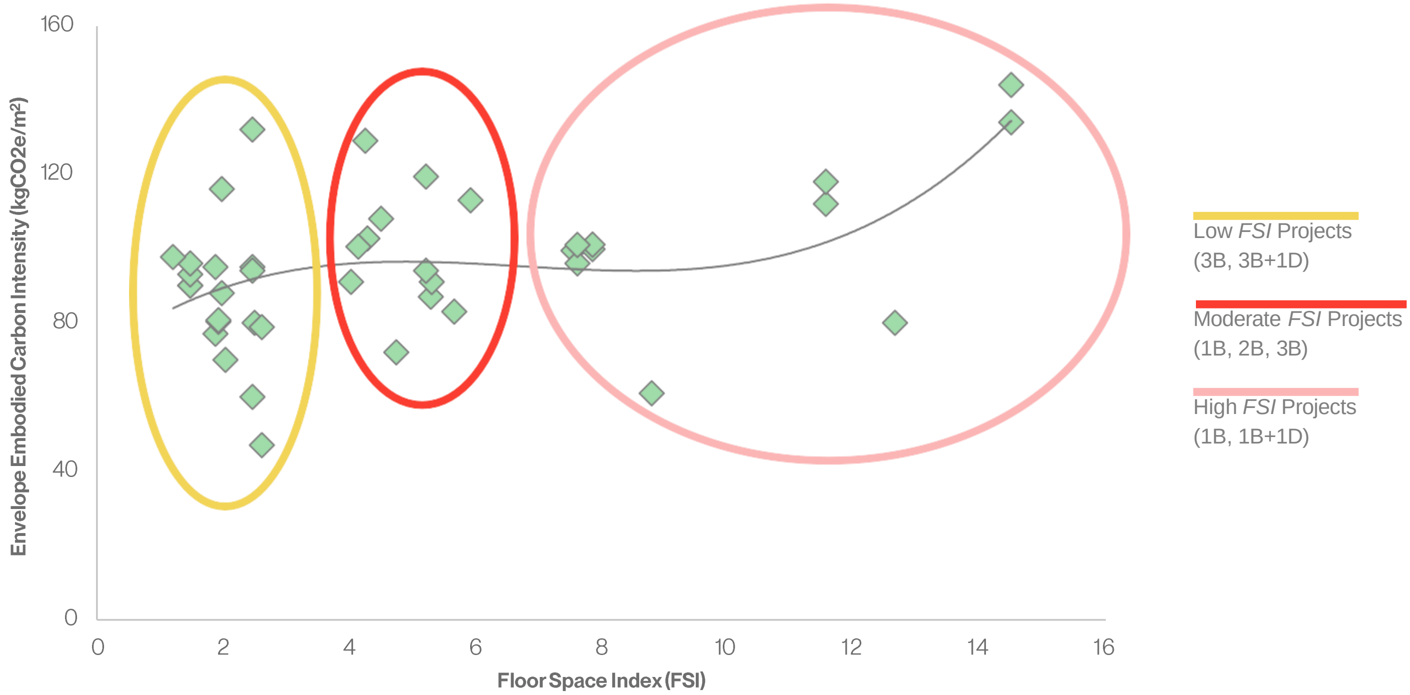


Fig. 14 *FSI* range and unit mix impact on *envelope embodied carbon intensity*

Key Finding: *FSI* and Envelope *Embodied Carbon Intensity*

- Low *FSI* (≤3): These developments often include larger units like 3-bedroom (3B) or 3-bedroom with a den (3B+1D). While their simpler building envelopes moderate carbon intensity, oversized units can significantly increase carbon impacts.

- Moderate *FSI* (3–6): Projects in this range are the most carbon-efficient. They balance a mix of unit types (1-bedroom, 2-bedroom, and some 3-bedroom units) with compact layouts that minimize material use and distribute *embodied carbon* effectively.

- High *FSI* (>6): High-density developments prioritize smaller units (1-bedroom and 1-bedroom with a den). Although material demands are higher, compact forms help control carbon intensity.

As unit numbers increase, the envelope *embodied carbon* tends to rise due to higher material demands. However, factors like unit size, material choices, and efficient design significantly impact carbon outcomes.

Balanced Density Configurations: Our analysis of unit sizes and mixes in relation to envelope *embodied carbon* optimization reveals that an average unit size of 75.4 m² effectively balances smaller and larger units, achieving optimal density to reduce envelope *embodied carbon*. Projects exceeding this optimal density range demonstrated diminishing carbon savings, indicating that over-densification does not necessarily result in further carbon reductions.

Strategic Density Optimization: Achieving optimal density reduces the embodied carbon impact per unit. Of the 44 projects analyzed, 21 fell within this optimal density range. As housing market trends shift toward smaller average unit sizes increasing density, architects must focus on optimizing building form characteristics and carefully selecting materials to ensure that the embodied carbon of the envelope remains within budget constraints.

Building Size and Density Strategies to Reduce Envelope *Embodied Carbon*

Optimize Density:
- Target moderate *FSI* ranges to balance density and material efficiency.
- Avoid over-densification, as excessively smaller divisions increase the number of windows, increasing both glazing and aluminum quantities, materials high in *embodied carbon*.
- Where high density is required, prioritize low *VFAR* and *WWR* and low carbon materials.

Right-Size Units:
- Mid-size units are optimal for managing envelope embodied carbon, balancing material use, and functional design.
- Minimize oversized units that disproportionately increase material demands.

Compact Layouts:
- Use efficient vertical forms and shared structural elements to reduce material intensity.
- Balance density with functional layouts to optimize material efficiency and carbon footprint.

4 Impact of Form on Envelope Embodied Carbon

Analysis of the dataset reveals a clear relationship between building form characteristics such as *Vertical Floor Area Ratio (VFAR)* and *Window-to-Wall Ratio (WWR)* and the *embodied carbon intensity* of building envelope. Compact, low *VFAR* designs consistently demonstrate lower *embodied carbon* intensity due to reduced vertical envelope areas relative to the building's floor area. Similarly, projects with lower *WWR* benefit from solid wall assemblies, resulting in lower envelope *embodied carbon intensity* than higher *WWR* projects, which feature more aluminum window wall systems, a common standard in Toronto's multi-unit residential market.

Vertical Floor Area Ratio (VFAR):
Compact buildings with lower *VFAR* (<50%) use materials more efficiently, reducing envelope *embodied carbon*. This impact is most significant in high-rise buildings, where compact forms optimize the envelope's surface area and structural systems. In contrast, higher *VFAR*s (>50%) increase carbon intensity due to larger vertical envelope areas requiring more materials and support.

Window-to-Wall Ratio (WWR):
Higher *WWR* (>40%) leads to increased *embodied carbon* due to the extensive use of aluminum windows, which have a higher carbon footprint than solid wall assemblies. Projects with balanced *WWR* benefit from reduced carbon intensity while maintaining operational performance. However, as the Ontario Building Code relaxes its requirements for non-combustable envelope materials, other lower carbon window materials such as fibreglass may become more prevalent.

Building Form Strategies to Reduce Envelope Embodied Carbon

1. ***Compact Designs: Keep VFAR < 50% to enhance material efficiency and reduce embodied carbon.***

2. ***Limit WWR: To minimize the carbon impact of glazing systems, maintain WWR at or below 40%.***

The dataset demonstrates that strategic adjustments to *VFAR* and *WWR* are critical for reducing *embodied carbon* in multi-unit residential projects.

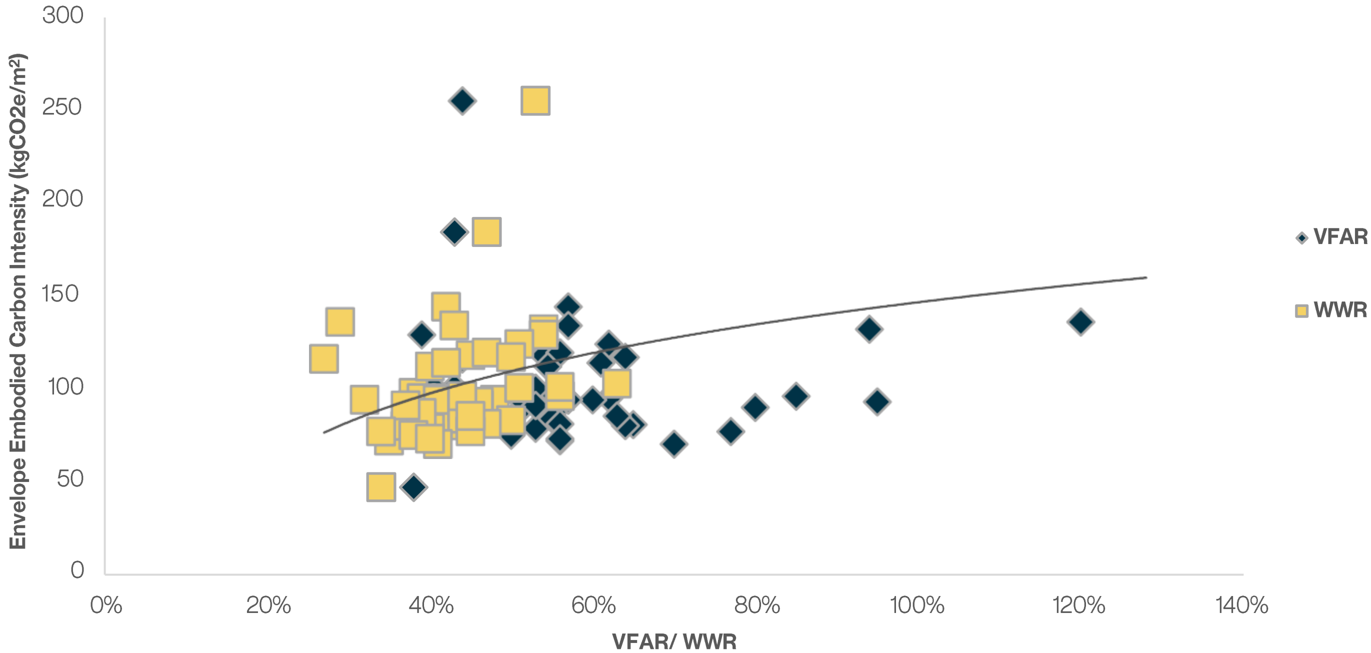


Fig. 15 Envelope *embodied carbon intensity* vs *VFAR* and *WWR*

5 Form/Size and *Embodied Carbon Intensity* of Envelope

Relationship Between Form/Size and Envelope *Embodied Carbon Intensity (ECI)*

The heatmap Fig. 16 reveals the impact of building size and form on envelope *embodied carbon intensity*. The factors are ranked from most to least impactful:

1. *Gross Floor Area (GFA)*: Larger buildings significantly increase embodied carbon due to higher material requirements. Reducing building size and optimizing material use (e.g., minimizing window walls with intense aluminum framing) can reduce carbon impacts.

2. *Vertical Floor Area Ratio (VFAR)*: Compact building forms reduce embodied carbon by decreasing the envelope's surface area and minimizing material use.

3. *Floor Space Index (FSI)*: A balanced *FSI* optimizes *embodied carbon* by efficiently distributing materials. However, excessive densification does not lead to further reductions in *embodied carbon*, emphasizing the need for strategic density management.

4. *Window-to-Wall Ratio (WWR)*: Higher *WWR* increases *embodied carbon* due to the reliance on aluminum windows, which are more carbon-intensive than solid walls. In this case, limiting *WWR* helps control carbon.

This analysis highlights the importance of optimizing building size and form to achieve the most efficient balance in embodied carbon performance.

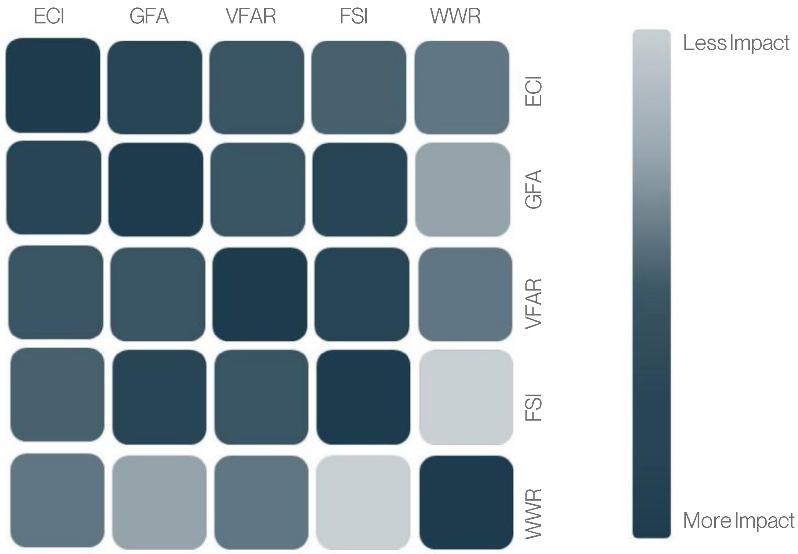


Fig. 16 The heatmap displays the relationship among key variables, including *WWR*, *FSI*, *GFA*, Envelope *ECI*, and *VFAR*.

6 Impact of Building Size/Form and Material Selection

This analysis, based on 44 multi-unit residential projects, highlights how building size, form, and material selection impact envelope embodied carbon. Compact forms, efficient wall assemblies, and strategic material choices are key factors for achieving low-carbon outcomes.

Prevalence of Concrete and Aluminum (Fig. 17)

- Precast concrete and aluminum are Toronto's most commonly used wall assembly materials, reflecting industry trends.

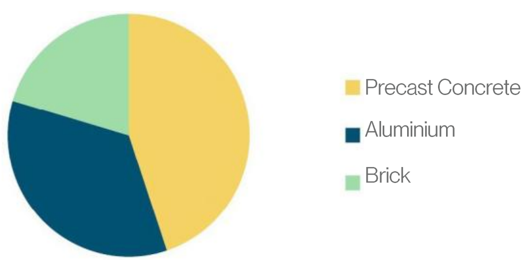


Fig. 17 Wall assembly composition between projects in the dataset

Average *ECI* by Main Wall Assembly (Fig. 18)

- Brick and ceramic cladding align with the *Toronto Green Standard (TGS)* envelope carbon budget, making them effective low-carbon options.
- Precast concrete is close to the *TGS* budget and can comply with low-carbon cement.
- Aluminum, exceeding the *TGS* budget by 50%, significantly increases *embodied carbon* and requires careful attention to form, *WWR*, and density.

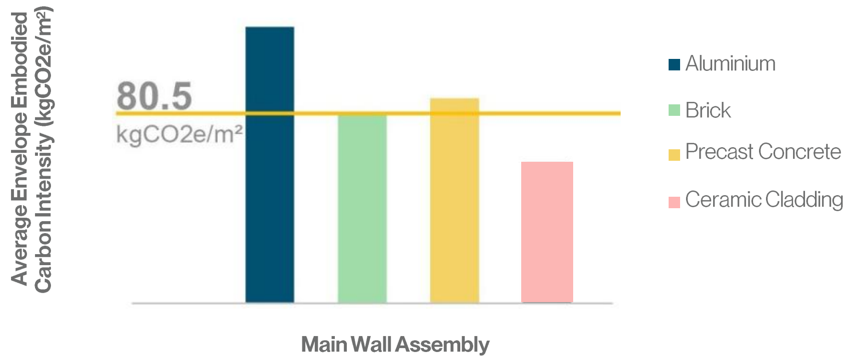


Fig. 18 The average *ECI* of the main wall assemblies compared to the *ECI* average budget required to meet the *TGS ECI* target

Relationship Between *VFAR, WWR,* and Envelope *Embodied Carbon Intensity*

- Compact forms with lower *VFAR (Vertical Floor Area Ratio)* and lower *WWR (Window-to-Wall Ratio)* reduce *embodied carbon* by minimizing material demands.
- Material selection enhances reductions with low-carbon alternatives like recycled pre-cast concrete or brick.
- Complex forms with higher *VFAR* and *WWR* consume more carbon budget, limiting material flexibility and increasing *embodied carbon*.

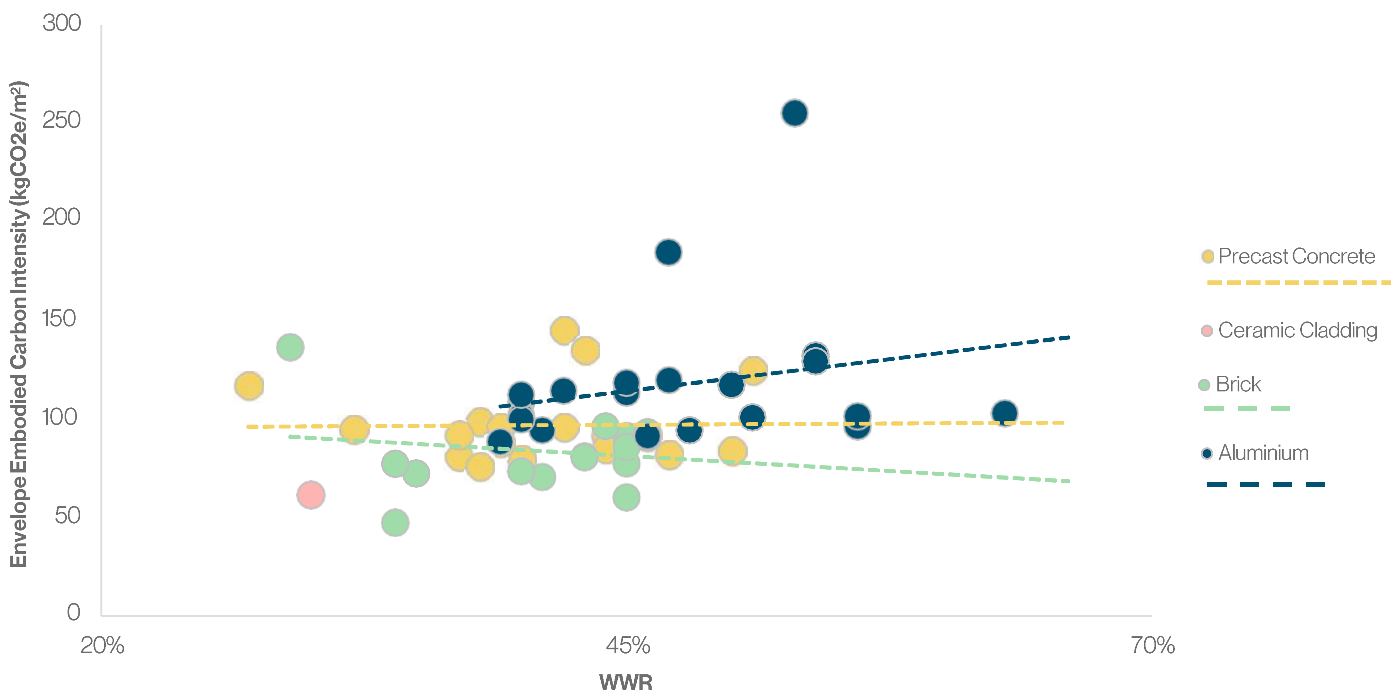


Fig. 19 Demonstrates the relationship between *WWR* and envelope *embodied carbon intensity*, with differences by wall assembly material

Material Selection and Design

- High-Carbon Materials: Aluminum framing and large glass areas drive higher *embodied carbon* due to energy-intensive production.
- Low-Carbon Alternatives: Brick and precast concrete with recycled content significantly lower *embodied carbon*, especially when paired with balanced designs of solid walls and limited glazing.
- Variability in *Embodied Carbon*: Wall assembly choice heavily influences *embodied carbon*, even for similarly sized buildings. Efficient material use and careful design are essential to achieving low-carbon outcomes.

Compact forms with lower VFAR and WWR provide a foundation for reducing embodied carbon, opening-up material options, and optimizing flexibility. Conversely, complex forms decrease material opportunities and require low-carbon options as designs progress. Early-stage decisions on VFAR and WWR are crucial to aligning design with the embodied carbon budget.

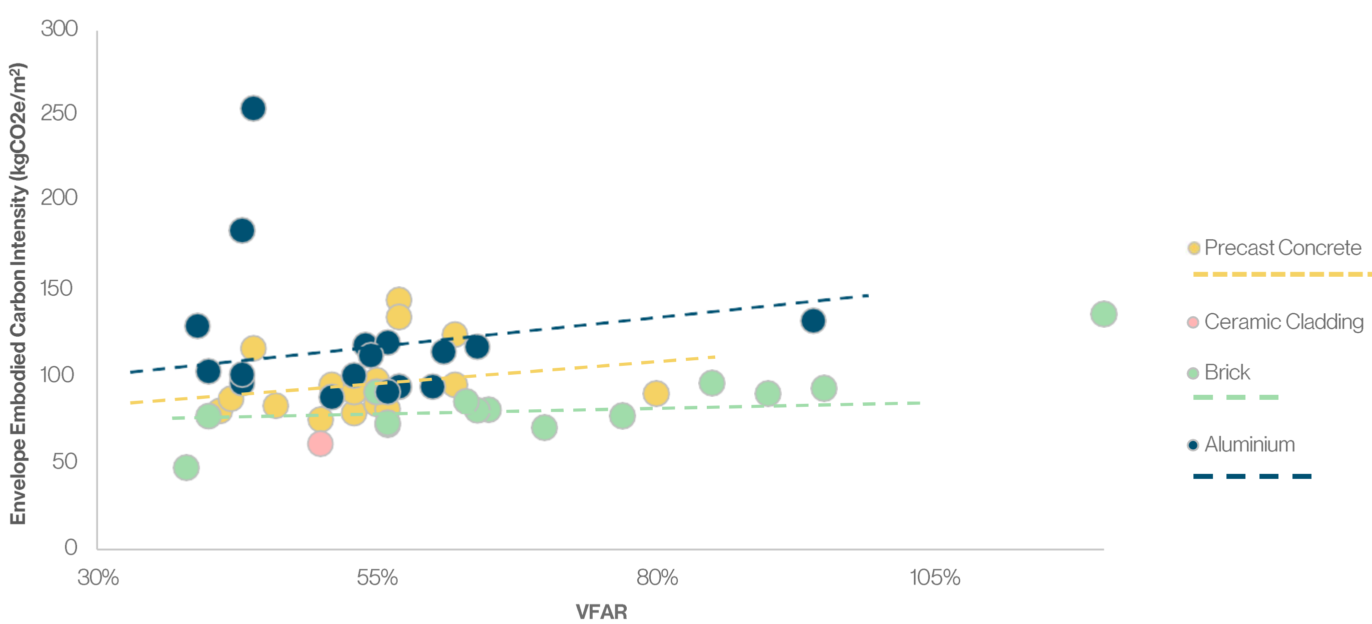


Fig. 20 Envelope *embodied carbon intensity* trends comparing *VFAR* and predominant envelope material

7 Correlation Between ECI $_{(Envelope)}$ and ECI $_{(Assembly)}$

To understand material impact on *embodied carbon,* most studies to date provide *embodied carbon intensity* of building envelope assemblies in *ECI* per square meter of the facade which is very helpful for comparative purposes. For reporting purposes, *ECI* is expressed as *ECI* per square meter of *gross floor area*. To understand how the *ECI* of an assembly translates into the *ECI* of the building envelope, we provide the following formula:

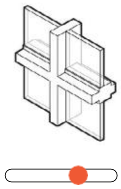
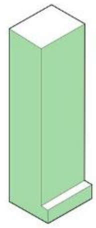
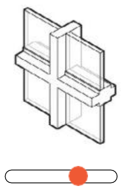
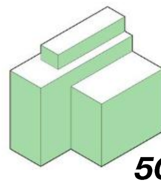
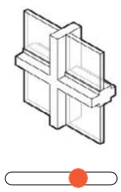
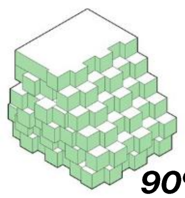
$$\text{Total ECI}_{(Envelope)} = \text{ECI}_{(Assembly)} \times \text{VFAR}$$

ECI (Assembly): The carbon intensity of the materials used in the wall assembly, expressed per square meter of the building envelope.
VFAR (Vertical Floor Area Ratio): The ratio of the vertical envelope area to the building's *GFA*, reflecting the building's form and material use.

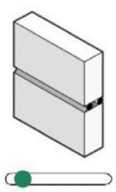
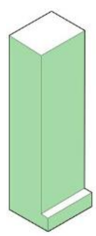
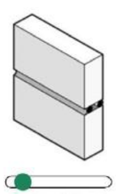
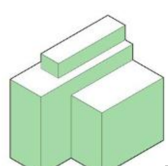
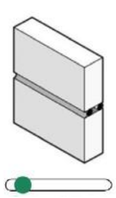
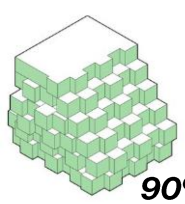
The following formula illustrates how the building form and material choices interact to define the overall carbon intensity of the envelope, providing a measurable framework for meeting *embodied carbon* targets such as the T*oronto Green Standard (TGS)* envelope carbon budget.

Total ECI *(Assembly)* × *VFAR* = *ECI* *(Envelope)*

Window Wall System

Total ECI (Assembly)		VFAR		ECI (Envelope)
 147.7 kgCO2e/m²	×	 39%	=	**58** kgCO2e/m²
 147.7 kgCO2e/m²	×	 50%	=	**74** kgCO2e/m²
 147.7 kgCO2e/m²	×	 90%	=	**133** kgCO2e/m²

Precast Concrete Cladding

Total ECI (Assembly)		VFAR		ECI (Envelope)
 37.0 kgCO2e/m²	×	 39%	=	**14** kgCO2e/m²
 37.0 kgCO2e/m²	×	 50%	=	**19** kgCO2e/m²
 37.0 kgCO2e/m²	×	 90%	=	**33** kgCO2e/m²

Design Process Strategies

1 Set an *Embodied Carbon* Budget

Establish an *embodied carbon* budget for the project and coordinate with the structural engineer to ensure alignment for the building envelope.

2 Aim for Optimal Density

Avoid under- or over-densification. Optimal density balances material efficiency and carbon performance.

3 Key Factors Driving Envelope *Embodied Carbon (EC)*:

Embodied carbon is influenced by the *Vertical Floor Area Ratio (VFAR)*, *Window-to-Wall Ratio (WWR)*, and material selection.
Prioritize the building form (*VFAR* and *WWR*) first, then select materials within the *EC* budget.

4 Design Strategies for Low-Carbon Envelopes:

Building Form:

- Opt for simple forms to minimize *VFAR*.
- Keep *WWR* below 40%, as aluminum framing and large glass areas increase carbon intensity compared to opaque walls.

Material Selection:

- Use low-carbon materials that balance carbon savings with design flexibility.

5 Early Design Optimization:

Set up massing models in BIM early to calculate *VFAR* and *WWR*.
This helps optimize the building form and understand the *ECI* budget for cladding and envelope materials during the project's earliest stages.

By following these strategies, project teams can effectively balance design ambitions with carbon performance, ensuring sustainable and compliant outcomes.

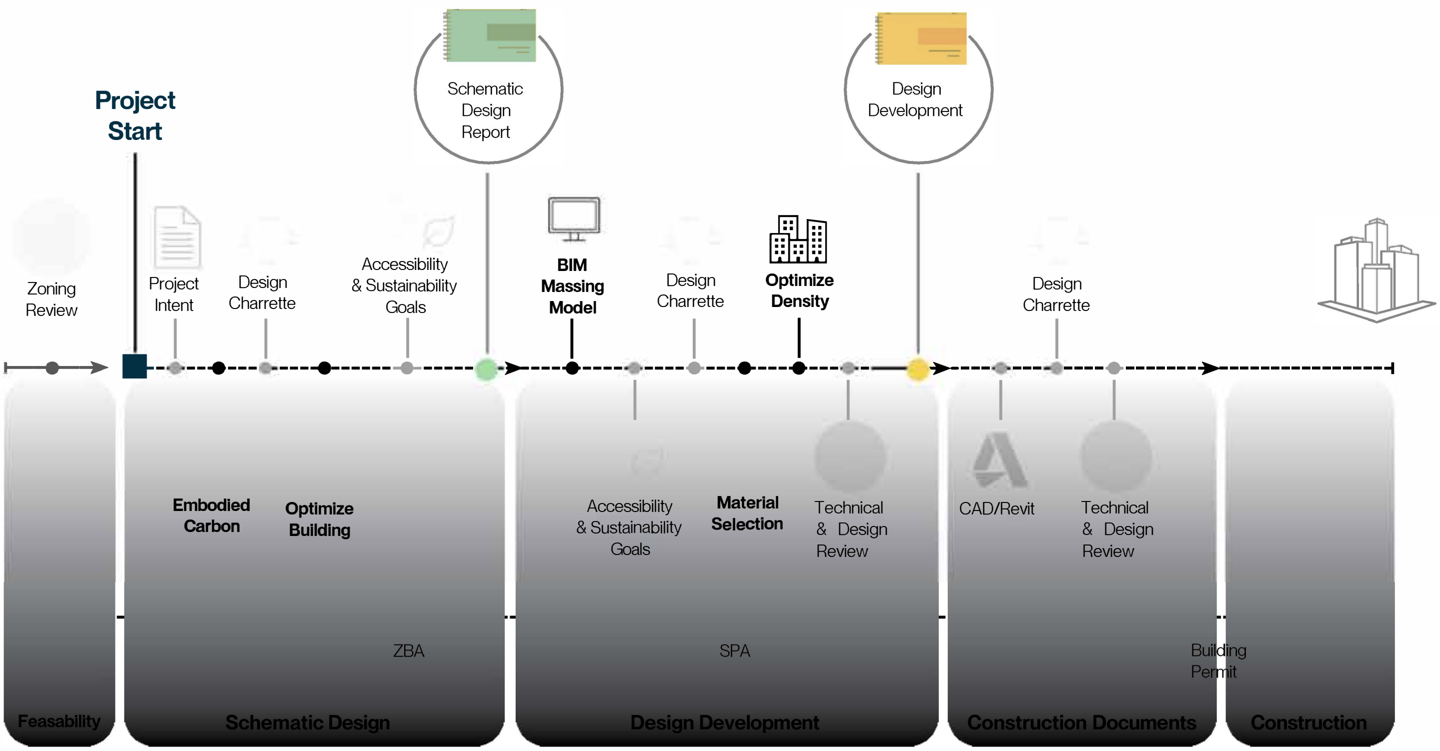


Fig. 21 Timeline for the implementation of these insights throughout the design phases

Appendix

- Glossary
- Project Carbon Facts
- Guidelines
- Key References

Glossary

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 ($kgCO_2e/m^2$). It allows for assessing and comparing the carbon footprint of building materials and construction processes.

Environmental Product Declaration (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)

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)

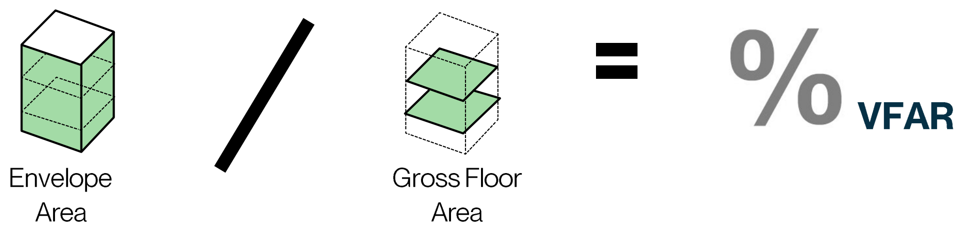
The total floor area of a building. GFA calculations are based on the outside face of enclosing walls for each floor, excluding parking, with no deductions for openings. This provides a consistent and reliable basis for comparing carbon performance across various projects, ensuring that carbon emissions are consistently reported per square meter of building area.

National Research Council (NRC)

Canada's 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.

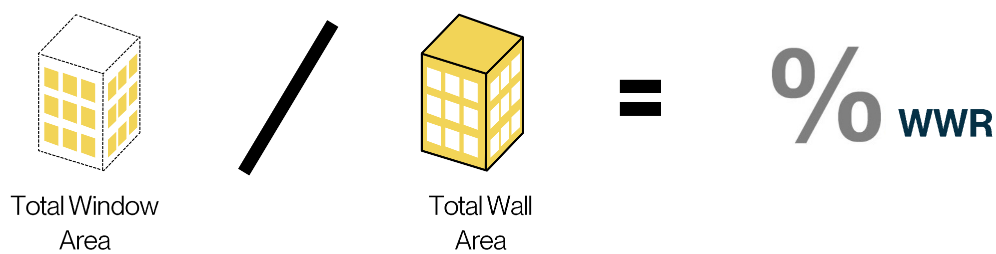
Vertical Floor Area Ratio (VFAR)

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.



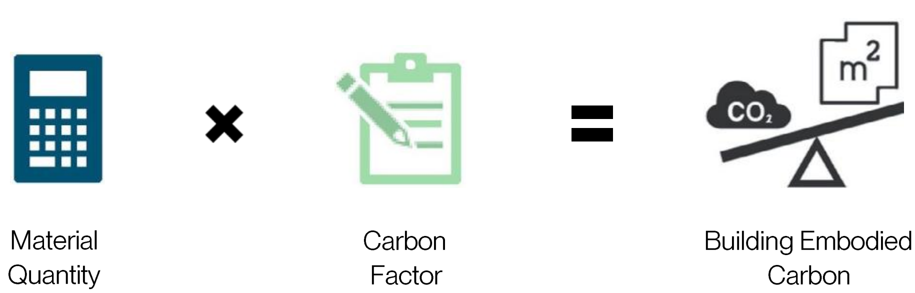
Window to Wall Area Ratio (WWR)

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



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).



Project Carbon Facts

BDP Quadrangle completed embodied carbon studies for 44 projects this year, marking a major milestone toward our net-zero carbon-ready goal by 2030. These projects span various phases, from Design Development to Construction Documentation, allowing us to gather a comprehensive dataset.

To extend the analysis, we created Project Carbon Facts, which combine both embodied and operational carbon data. This provides a holistic view of each project's total carbon impact, helping us evaluate the full lifecycle carbon footprint.

This integrated approach enables us to make smarter, data-driven decisions. By understanding the total carbon impact, we can optimize material choices, improve energy efficiency, and set clear benchmarks for carbon performance across future projects.

Notes

**Carbon Total (EC) is embodied carbon total; is calculated using OneClickLCA using EDPs. Material quantities are derived from Revit models. Calculation stages are A1-A5, assumed OneClickLCA default scenarios. The calculation method is intended for only as a guidance, not an absolute calculation.*

***Values derived from Energy Reports per project. If reports do not exist, field will state "N/A".*

Carbon Facts

Project Number	33132	
Suites per Building	91	
Building Size (GFA)	8249	m^2
Carbon Total*	**232**	
Envelope Facts	61	kgCO$_2$e/m^2
Wall Assembly	Ceramic Cladding	Type
VFAR	N/A	%
WWR	30%	%
Envelope R-value**	15	
Structural Facts	171	kgCO$_2$e/m^2
Structure System	Mass Timber	Type
Operational Facts**		
EUI	92	kWh/m^2/Year
GHGI	2.8	kgCO$_2$e/Year
TEDI	27.3	kWh/m^2/Year
Thermal Facts		
RSI Walls	2.64	m^2.K/W
RSI Roof	N/A	m^2.K/W
U-value Windows	0.35	BTU/h*ft^2*°F

Carbon Facts

Project Number	31143 - 5	
Suites per Building	38	
Building Size (GFA)	3525	m^2
Carbon Total*	**244**	
Envelope Facts	90	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	80%	%
WWR	46%	%
Envelope R-value**	9.1	
Structural Facts	154	kgCO$_2$e/m^2
Structure System	Concrete Hollow Slab	Type
Operational Facts**		
EUI	220.5	kWh/m^2/Year
GHGI	20.9	kgCO$_2$e/Year
TEDI	44.9	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.61	m^2.K/W
RSI Roof	6.16	m^2.K/W
U-value Windows	0.25	BTU/h*ft^2*°F

Carbon Facts

Project Number	31143 - 4	
Suites per Building	39	
Building Size (GFA)	3522	m^2
Carbon Total*	**245**	
Envelope Facts	90	kgCO$_2$e/m^2
Wall Assembly	Brick	Type
VFAR	90%	%
WWR	46%	%
Envelope R-value**	9.1	
Structural Facts	155	kgCO$_2$e/m^2
Structure System	Concrete Hollow Slab	Type
Operational Facts**		
EUI	217.3	kWh/m^2/Year
GHGI	21.4	kgCO$_2$e/Year
TEDI	49.4	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.61	m^2.K/W
RSI Roof	6.16	m^2.K/W
U-value Windows	0.25	BTU/h*ft^2*°F

Carbon Facts

Project Number	31143 - 1	
Suites per Building	45	
Building Size (GFA)	4051	m^2
Carbon Total*	**249**	
Envelope Facts	93	kgCO$_2$e/m^2
Wall Assembly	Brick	Type
VFAR	95%	%
WWR	46%	%
Envelope R-value**	9.1	
Structural Facts	156	kgCO$_2$e/m^2
Structure System	Concrete Hollow Slab	Type
Operational Facts**		
EUI	214.6	kWh/m^2/Year
GHGI	21.3	kgCO$_2$e/Year
TEDI	50	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.61	m^2.K/W
RSI Roof	6.16	m^2.K/W
U-value Windows	0.25	BTU/h*ft^2*°F

Carbon Facts

Project Number	31143 - 6	
Suites per Building	61	
Building Size (GFA)	5561	m^2
Carbon Total*	**256**	
Envelope Facts	96	kgCO$_2$e/m^2
Wall Assembly	Brick	Type
VFAR	85%	%
WWR	44%	%
Envelope R-value**	9.1	
Structural Facts	160	kgCO$_2$e/m^2
Structure System	Concrete Hollow Slab	Type
Operational Facts**		
EUI	212.4	kWh/m^2/Year
GHGI	20.8	kgCO$_2$e/Year
TEDI	47.5	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.61	m^2.K/W
RSI Roof	6.16	m^2.K/W
U-value Windows	0.25	BTU/h*ft^2*°F

Carbon Facts

Project Number	23221	
Suites per Building	263	
Building Size (GFA)	21478	m^2
Carbon Total*	**311**	
Envelope Facts	91	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	55%	%
WWR	44%	%
Envelope R-value**	17.9	
Structural Facts	146	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	191.4	kWh/m^2/Year
GHGI	23.3	kgCO$_2$e/Year
TEDI	75.9	kWh/m^2/Year
Thermal Facts		
RSI Walls	3.15	m^2.K/W
RSI Roof	5.28	m^2.K/W
U-value Windows	0.33	BTU/h*ft^2*°F

Carbon Facts

Project Number	32125	
Suites per Building	239	
Building Size (GFA)	16826	m^2
Carbon Total*	**334**	
Envelope Facts	98	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	55%	%
WWR	38%	%
Envelope R-value**	7.9	
Structural Facts	236	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	130.8	kWh/m^2/Year
GHGI	10.9	kgCO$_2$e/Year
TEDI	68.2	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.39	m^2.K/W
RSI Roof	5.7	m^2.K/W
U-value Windows	0.36	BTU/h*ft^2*°F

Carbon Facts

Project Number	29194	
Suites per Building	578	
Building Size (GFA)	44973	m^2
Carbon Total*	**337**	
Envelope Facts	83	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	46%	%
WWR	50%	%
Envelope R-value**	16.8	
Structural Facts	254	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	188.4	kWh/m^2/Year
GHGI	25.2	kgCO$_2$e/Year
TEDI	81.2	kWh/m^2/Year
Thermal Facts		
RSI Walls	3	m^2.K/W
RSI Roof	6.4	m^2.K/W
U-value Windows	0.38	BTU/h*ft^2*°F

Carbon Facts

Project Number	32139	
Suites per Building	345	
Building Size (GFA)	28363	m^2
Carbon Total*	**346**	
Envelope Facts	80	kgCO$_2$e/m^2
Wall Assembly	Aluminium	Type
VFAR	N/A	%
WWR	N/A	%
Envelope R-value**	N/A	
Structural Facts	266	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	kWh/m^2/Year
GHGI	N/A	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	N/A	m^2.K/W
RSI Roof	N/A	m^2.K/W
U-value Windows	N/A	BTU/h*ft^2*°F

Carbon Facts

Project Number	32118A	
Suites per Building	390	
Building Size (GFA)	26276	m^2
Carbon Total*	**361**	
Envelope Facts	114	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	61%	%
WWR	42%	%
Envelope R-value**	7.7	
Structural Facts	174	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	$kWh/m^2/Year$
GHGI	N/A	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.36	$m^2.K/W$
RSI Roof	5.69	$m^2.K/W$
U-value Windows	0.32	BTU/h*ft²*°F

Carbon Facts

Project Number	20172	
Suites per Building	139	
Building Size (GFA)	34857	m^2
Carbon Total*	**366**	
Envelope Facts	60	$kgCO_2e/m^2$
Wall Assembly	Stone	Type
VFAR	N/A	%
WWR	45%	%
Envelope R-value**	10	
Structural Facts	306	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	136	$kWh/m^2/Year$
GHGI	15	$kgCO_2e/Year$
TEDI	47	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.76	$m^2.K/W$
RSI Roof	7	$m^2.K/W$
U-value Windows	0.35	BTU/h*ft²*°F

Carbon Facts

Project Number	28234 - 1	
Suites per Building	407	
Building Size (GFA)	41592	m^2
Carbon Total*	**367**	
Envelope Facts	99	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	N/A	%
WWR	40	%
Envelope R-value**	8	
Structural Facts	268	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	155	$kWh/m^2/Year$
GHGI	19.8	$kgCO_2e/Year$
TEDI	62.8	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.4	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.33	BTU/h*ft²*°F

Carbon Facts

Project Number	21058B	
Suites per Building	46	
Building Size (GFA)	6179	m^2
Carbon Total*	**368**	
Envelope Facts	47	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	38%	%
WWR	34%	%
Envelope R-value**	18.5	
Structural Facts	321	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	106	$kWh/m^2/Year$
GHGI	6	$kgCO_2e/Year$
TEDI	49	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	3.26	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.35	BTU/h*ft²*°F

Carbon Facts

Project Number	28234 - 2	
Suites per Building	420	
Building Size (GFA)	32240	m^2
Carbon Total*	**369**	
Envelope Facts	100	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	N/A	%
WWR	40%	%
Envelope R-value**	8	
Structural Facts	269	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	144.4	$kWh/m^2/Year$
GHGI	18.4	$kgCO_2e/Year$
TEDI	59.6	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.4	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.33	BTU/h*ft²*°F

Carbon Facts

Project Number	28145	
Suites per Building	196	
Building Size (GFA)	29993	m^2
Carbon Total*	**370**	
Envelope Facts	70	$kgCO_2e/m^2$
Wall Assembly	Precast Concrete	Type
VFAR	N/A	%
WWR	N/A	%
Envelope R-value**	29.3	
Structural Facts	300	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	$kWh/m^2/Year$
GHGI	N/A	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	5.16	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	N/A	BTU/h*ft²*°F

Carbon Facts

Project Number	28234 - 3	
Suites per Building	458	
Building Size (GFA)	40945	m^2
Carbon Total*	**371**	
Envelope Facts	101	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	N/A	%
WWR	40%	%
Envelope R-value**	8.5	
Structural Facts	270	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	141.3	$kWh/m^2/Year$
GHGI	18	$kgCO_2e/Year$
TEDI	60.2	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.5	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.33	BTU/h*ft²*°F

Carbon Facts

Project Number	31133	
Suites per Building	196	
Building Size (GFA)	16451	m^2
Carbon Total*	**379**	
Envelope Facts	91	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	55%	%
WWR	45%	%
Envelope R-value**	9.2	
Structural Facts	288	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	138.4	$kWh/m^2/Year$
GHGI	13	$kgCO_2e/Year$
TEDI	68.5	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.62	$m^2.K/W$
RSI Roof	5.21	$m^2.K/W$
U-value Windows	0.34	BTU/h*ft²*°F

Carbon Facts

Project Number	28192B	
Suites per Building	375	
Building Size (GFA)	26753	m^2
Carbon Total*	**380**	
Envelope Facts	103	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	40%	%
WWR	63%	%
Envelope R-value**	25	
Structural Facts	277	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	$kWh/m^2/Year$
GHGI	N/A	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	4.43	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.78	BTU/h*ft²*°F

Carbon Facts

Project Number	29191	
Suites per Building	116	
Building Size (GFA)	11651	m²
Carbon Total*	**388**	
Envelope Facts	72	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	56%	%
WWR	35%	%
Envelope R-value**	18	
Structural Facts	316	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	197.6	kWh/m²/Year
GHGI	N/A	$kgCO_2e$/Year
TEDI	N/A	kWh/m²/Year
Thermal Facts		
RSI Walls	3.17	m².K/W
RSI Roof	5.28	m².K/W
U-value Windows	0.35	BTU/h*ft²*°F

Carbon Facts

Project Number	23106A	
Suites per Building	134	
Building Size (GFA)	12710	m²
Carbon Total*	**390**	
Envelope Facts	95	$kgCO_2e/m^2$
Wall Assembly	Precast Concrete	Type
VFAR	51%	%
WWR	39%	%
Envelope R-value**	N/A	
Structural Facts	295	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	kWh/m²/Year
GHGI	N/A	$kgCO_2e$/Year
TEDI	N/A	kWh/m²/Year
Thermal Facts		
RSI Walls	N/A	m².K/W
RSI Roof	N/A	m².K/W
U-value Windows	N/A	BTU/h*ft²*°F

Carbon Facts

Project Number	23106B	
Suites per Building	149	
Building Size (GFA)	13550	m²
Carbon Total*	**393**	
Envelope Facts	77	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	40%	%
WWR	34%	%
Envelope R-value**	12.9	
Structural Facts	316	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	147.4	kWh/m²/Year
GHGI	18.1	$kgCO_2e$/Year
TEDI	43.1	kWh/m²/Year
Thermal Facts		
RSI Walls	2.27	m².K/W
RSI Roof	5.64	m².K/W
U-value Windows	0.3	BTU/h*ft²*°F

Carbon Facts

Project Number	28192A	
Suites per Building	188	
Building Size (GFA)	41010	m²
Carbon Total*	**400**	
Envelope Facts	129	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	39%	%
WWR	54%	%
Envelope R-value**	25	
Structural Facts	271	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	167.9	kWh/m²/Year
GHGI	18.1	$kgCO_2e$/Year
TEDI	N/A	kWh/m²/Year
Thermal Facts		
RSI Walls	4.43	m².K/W
RSI Roof	5.28	m².K/W
U-value Windows	0.78	BTU/h*ft²*°F

Carbon Facts

Project Number	31118	
Suites per Building	227	
Building Size (GFA)	18128	m²
Carbon Total*	**404**	
Envelope Facts	80	$kgCO_2e/m^2$
Wall Assembly	Precast Concrete	Type
VFAR	41%	%
WWR	37%	%
Envelope R-value**	15.7	
Structural Facts	324	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	198.8	kWh/m²/Year
GHGI	27.8	$kgCO_2e$/Year
TEDI	87.6	kWh/m²/Year
Thermal Facts		
RSI Walls	2.76	m².K/W
RSI Roof	5.88	m².K/W
U-value Windows	0.35	BTU/h*ft²*°F

Carbon Facts

Project Number	20176	
Suites per Building	13	
Building Size (GFA)	7501	m²
Carbon Total*	**425**	
Envelope Facts	108	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	N/A	%
WWR	40%	%
Envelope R-value**	20	
Structural Facts	317	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	131.4	kWh/m²/Year
GHGI	9.2	$kgCO_2e$/Year
TEDI	67.4	kWh/m²/Year
Thermal Facts		
RSI Walls	3.52	m².K/W
RSI Roof	6.16	m².K/W
U-value Windows	0.33	BTU/h*ft²*°F

Carbon Facts

Project Number	26160	
Suites per Building	407	
Building Size (GFA)	32604	m²
Carbon Total*	**425**	
Envelope Facts	100	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	53%	%
WWR	51%	%
Envelope R-value**	6.8	
Structural Facts	325	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	204.8	kWh/m²/Year
GHGI	24.3	$kgCO_2e$/Year
TEDI	60.2	kWh/m²/Year
Thermal Facts		
RSI Walls	1.2	m².K/W
RSI Roof	5.53	m².K/W
U-value Windows	0.35	BTU/h*ft²*°F

Carbon Facts

Project Number	32182B	
Suites per Building	430	
Building Size (GFA)	27972	m²
Carbon Total*	**434**	
Envelope Facts	134	$kgCO_2e/m^2$
Wall Assembly	Precast Concrete	Type
VFAR	57%	%
WWR	43%	%
Envelope R-value**	9.1	
Structural Facts	300	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	127	kWh/m²/Year
GHGI	N/A	$kgCO_2e$/Year
TEDI	N/A	kWh/m²/Year
Thermal Facts		
RSI Walls	1.6	m².K/W
RSI Roof	5.34	m².K/W
U-value Windows	0.34	BTU/h*ft²*°F

Carbon Facts

Project Number	31113B	
Suites per Building	355	
Building Size (GFA)	22378	m²
Carbon Total*	**441**	
Envelope Facts	96	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	43%	%
WWR	56%	%
Envelope R-value**	15.6	
Structural Facts	345	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	245	kWh/m²/Year
GHGI	25	$kgCO_2e$/Year
TEDI	N/A	kWh/m²/Year
Thermal Facts		
RSI Walls	2.75	m².K/W
RSI Roof	3.32	m².K/W
U-value Windows	0.36	BTU/h*ft²*°F

Carbon Facts

Project Number	32182A	
Suites per Building	429	
Building Size (GFA)	27821	m^2
Carbon Total*	**444**	
Envelope Facts	144	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	57%	%
WWR	42%	%
Envelope R-value**	9.1	
Structural Facts	300	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	128	kWh/m^2/Year
GHGI	N/A	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.6	m^2.K/W
RSI Roof	5.34	m^2.K/W
U-value Windows	0.34	BTU/h*ft^2*°F

Carbon Facts

Project Number	31113A	
Suites per Building	367	
Building Size (GFA)	23078	m^2
Carbon Total*	**452**	
Envelope Facts	101	kgCO$_2$e/m^2
Wall Assembly	Aluminium	Type
VFAR	43%	%
WWR	56%	%
Envelope R-value**	15.6	
Structural Facts	351	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	229	kWh/m^2/Year
GHGI	27	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	2.75	m^2.K/W
RSI Roof	3.32	m^2.K/W
U-value Windows	0.36	BTU/h*ft^2*°F

Carbon Facts

Project Number	31162A	
Suites per Building	361	
Building Size (GFA)	25888	m^2
Carbon Total*	**455**	
Envelope Facts	87	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	42%	%
WWR	39%	%
Envelope R-value**	5.2	
Structural Facts	368	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	133.7	kWh/m^2/Year
GHGI	10.4	kgCO$_2$e/Year
TEDI	38.4	kWh/m^2/Year
Thermal Facts		
RSI Walls	0.92	m^2.K/W
RSI Roof	N/A	m^2.K/W
U-value Windows	N/A	BTU/h*ft^2*°F

Carbon Facts

Project Number	26178	
Suites per Building	158	
Building Size (GFA)	13357	m^2
Carbon Total*	**460**	
Envelope Facts	95	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	62%	%
WWR	42%	%
Envelope R-value**	17.8	
Structural Facts	365	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	203.5	kWh/m^2/Year
GHGI	26.1	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	3.14	m^2.K/W
RSI Roof	5.21	m^2.K/W
U-value Windows	N/A	BTU/h*ft^2*°F

Carbon Facts

Project Number	29119A	
Suites per Building	277	
Building Size (GFA)	20468	m^2
Carbon Total*	**461**	
Envelope Facts	88	kgCO$_2$e/m^2
Wall Assembly	Aluminium	Type
VFAR	51%	%
WWR	39%	%
Envelope R-value**	6.8	
Structural Facts	373	kgCO$_2$e/m^2
Structure System	Concrete, Steel	Type
Operational Facts**		
EUI	83.4	kWh/m^2/Year
GHGI	2.2	kgCO$_2$e/Year
TEDI	52.8	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.2	m^2.K/W
RSI Roof	4.4	m^2.K/W
U-value Windows	0.33	BTU/h*ft^2*°F

Carbon Facts

Project Number	26178A	
Suites per Building	182	
Building Size (GFA)	14775	m^2
Carbon Total*	**462**	
Envelope Facts	94	kgCO$_2$e/m^2
Wall Assembly	Aluminium	Type
VFAR	58%	%
WWR	41%	%
Envelope R-value**	16.8	
Structural Facts	368	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	216.9	kWh/m^2/Year
GHGI	29	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	2.96	m^2.K/W
RSI Roof	5.21	m^2.K/W
U-value Windows	N/A	BTU/h*ft^2*°F

Carbon Facts

Project Number	31147 - 2&3	
Suites per Building	294	
Building Size (GFA)	61103	m^2
Carbon Total*	**464**	
Envelope Facts	112	kgCO$_2$e/m^2
Wall Assembly	Aluminium	Type
VFAR	55%	%
WWR	40%	%
Envelope R-value**	8.4	
Structural Facts	352	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	118	kWh/m^2/Year
GHGI	10	kgCO$_2$e/Year
TEDI	55.2	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.29	m^2.K/W
RSI Roof	5.28	m^2.K/W
U-value Windows	0.38	BTU/h*ft^2*°F

Carbon Facts

Project Number	29119D	
Suites per Building	217	
Building Size (GFA)	15474	m^2
Carbon Total*	**470**	
Envelope Facts	116	kgCO$_2$e/m^2
Wall Assembly	Precast Concrete	Type
VFAR	44%	%
WWR	27%	%
Envelope R-value**	11	
Structural Facts	354	kgCO$_2$e/m^2
Structure System	Precast Concrete	Type
Operational Facts**		
EUI	83.4	kWh/m^2/Year
GHGI	2.2	kgCO$_2$e/Year
TEDI	49.7	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.94	m^2.K/W
RSI Roof	4.4	m^2.K/W
U-value Windows	0.39	BTU/h*ft^2*°F

Carbon Facts

Project Number	20179 P2	
Suites per Building	185	
Building Size (GFA)	19210	m^2
Carbon Total*	**481**	
Envelope Facts	80	kgCO$_2$e/m^2
Wall Assembly	Brick	Type
VFAR	64%	%
WWR	43%	%
Envelope R-value**	7.4	
Structural Facts	401	kgCO$_2$e/m^2
Structure System	Concrete	Type
Operational Facts**		
EUI	201.5	kWh/m^2/Year
GHGI	24.7	kgCO$_2$e/Year
TEDI	N/A	kWh/m^2/Year
Thermal Facts		
RSI Walls	1.3	m^2.K/W
RSI Roof	5.21	m^2.K/W
U-value Windows	0.53	BTU/h*ft^2*°F

Carbon Facts

Project Number	20179 P3	
Suites per Building	191	
Building Size (GFA)	18692	m^2
Carbon Total*	**486**	
Envelope Facts	81	$kgCO_2e/m^2$
Wall Assembly	Brick	Type
VFAR	65%	%
WWR	43%	%
Envelope R-value**	7.4	
Structural Facts	405	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	201.5	$kWh/m^2/Year$
GHGI	24.7	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.3	$m^2.K/W$
RSI Roof	5.21	$m^2.K/W$
U-value Windows	0.53	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	31147 - 1	
Suites per Building	454	
Building Size (GFA)	30233.7	m^2
Carbon Total*	**486**	
Envelope Facts	118	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	54%	%
WWR	45%	%
Envelope R-value**	9.5	
Structural Facts	368	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	152.3	$kWh/m^2/Year$
GHGI	16.2	$kgCO_2e/Year$
TEDI	57.8	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.29	$m^2.K/W$
RSI Roof	5.28	$m^2.K/W$
U-value Windows	0.38	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	26178C	
Suites per Building	91	
Building Size (GFA)	7852	m^2
Carbon Total*	**492**	
Envelope Facts	132	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	94%	%
WWR	54%	%
Envelope R-value**	17.3	
Structural Facts	360	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	252.9	$kWh/m^2/Year$
GHGI	31	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	3.04	$m^2.K/W$
RSI Roof	5.21	$m^2.K/W$
U-value Windows	N/A	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	32169A	
Suites per Building	375	
Building Size (GFA)	24466	m^2
Carbon Total*	**500**	
Envelope Facts	79	$kgCO_2e/m^2$
Wall Assembly	Precast Concrete	Type
VFAR	53%	%
WWR	40%	%
Envelope R-value**	6.6	
Structural Facts	421	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	106	$kWh/m^2/Year$
GHGI	6	$kgCO_2e/Year$
TEDI	49	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.16	$m^2.K/W$
RSI Roof	5.1	$m^2.K/W$
U-value Windows	0.35	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	20159	
Suites per Building	234	
Building Size (GFA)	14190	m^2
Carbon Total*	**567**	
Envelope Facts	113	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	N/A	%
WWR	45%	%
Envelope R-value**	N/A	
Structural Facts	454	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	N/A	$kWh/m^2/Year$
GHGI	N/A	$kgCO_2e/Year$
TEDI	N/A	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	N/A	$m^2.K/W$
RSI Roof	N/A	$m^2.K/W$
U-value Windows	N/A	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	33162AB	
Suites per Building	382	
Building Size (GFA)	28391	m^2
Carbon Total*	**596**	
Envelope Facts	91	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	56%	%
WWR	46%	%
Envelope R-value**	8.4	
Structural Facts	505	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	118.4	$kWh/m^2/Year$
GHGI	3.6	$kgCO_2e/Year$
TEDI	49.7	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.48	$m^2.K/W$
RSI Roof	7.04	$m^2.K/W$
U-value Windows	0.35	$BTU/h*ft^2*°F$

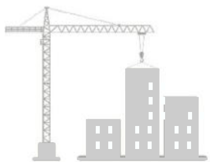
Carbon Facts

Project Number	33162D	
Suites per Building	552	
Building Size (GFA)	35443	m^2
Carbon Total*	**639**	
Envelope Facts	119	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	56%	%
WWR	47%	%
Envelope R-value**	9.1	
Structural Facts	520	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	118.4	$kWh/m^2/Year$
GHGI	3.6	$kgCO_2e/Year$
TEDI	44.8	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.6	$m^2.K/W$
RSI Roof	7.04	$m^2.K/W$
U-value Windows	0.35	$BTU/h*ft^2*°F$

Carbon Facts

Project Number	33162C	
Suites per Building	404	
Building Size (GFA)	27219	m^2
Carbon Total*	**643**	
Envelope Facts	94	$kgCO_2e/m^2$
Wall Assembly	Aluminium	Type
VFAR	60%	%
WWR	48%	%
Envelope R-value**	9.1	
Structural Facts	549	$kgCO_2e/m^2$
Structure System	Concrete	Type
Operational Facts**		
EUI	116.5	$kWh/m^2/Year$
GHGI	3.5	$kgCO_2e/Year$
TEDI	45.8	$kWh/m^2/Year$
Thermal Facts		
RSI Walls	1.6	$m^2.K/W$
RSI Roof	7.04	$m^2.K/W$
U-value Windows	0.35	$BTU/h*ft^2*°F$

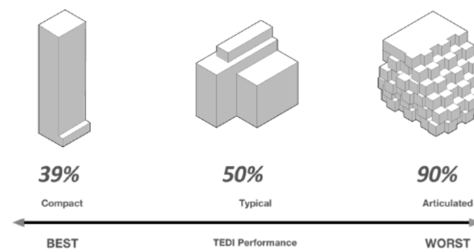
Envelope Guidelines



01

Set A Carbon Budget

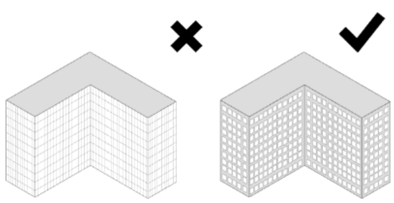
Establish an *embodied carbon* budget early and coordinate it with structural and envelope engineers.



02

Simplify Building Forms

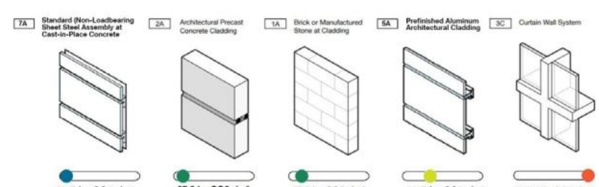
Use compact forms with low *VFAR* to minimize material demands.



03

Limit Glazing

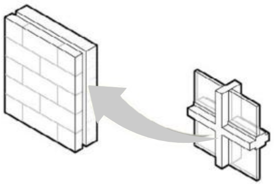
Keep *WWR* below 40% to reduce reliance on carbon-intensive materials like aluminum.



04

Choose Low-Carbon Materials

Opt for brick, ceramic cladding, and precast concrete with low-carbon cement.



05

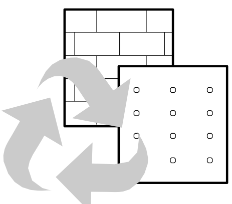
Avoid High-Carbon Assemblies

Limit aluminum and large glass areas to control carbon intensity.

06

Optimize Density

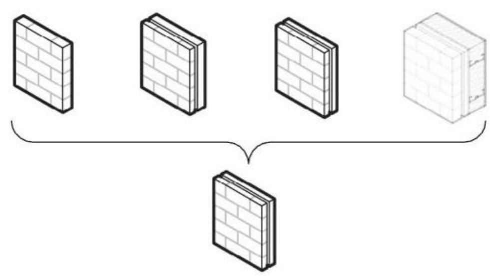
Achieve optimal density by avoiding under- or over-densification.



07

Focus on Material Efficiency

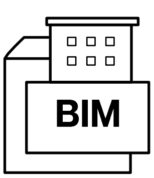
Incorporate recycled and low-carbon materials into the envelope design.



08

Collaborate Across Disciplines

Work with engineers and consultants to align form and material decisions with carbon goals.



09

Leverage BIM Tools

Use BIM in early design phases to calculate *VFAR*, *WWR*, and *ECI*.

Key References

This study aligns with findings from current research on *embodied carbon*, reinforcing the relevance and applicability of established industry standards and methodologies. Key alignments include:

1. ECHO Reporting Schema (ECHO Project, 2024)

Our analysis confirms alignment with the ECHO framework, which standardizes the reporting and evaluation of *embodied carbon* metrics. This congruence underscores the importance of a structured approach to assessing carbon impacts in the built environment.

2. TMU x RDH Building Science Study (2024)

Aligning with the findings from the TMU x RDH study funded by The Atmospheric Fund (TAF), our study highlights the critical role of material performance in reducing *embodied carbon*, particularly in multi-unit residential projects.

3. Centre for Window and Cladding Technology (CWCT, 2022)

This study's emphasis on envelope carbon assessments corroborates CWCT methodologies, particularly regarding the significant impact of *Vertical Floor Area Ratio (VFAR)* and envelope *embodied carbon intensity.*

4. Toronto's Part 3 Building Embodied Carbon Benchmarking Report (Half, 2022)

Our benchmarking data align with Toronto's regulatory framework, which sets a precedent for embodied emissions reduction in multi-unit residential buildings. This ensures our findings are applicable within the local context.

5. City of Toronto Urban Design Guidelines (Half, 2024)

Consistent with these guidelines, our study supports strategies that emphasizing reductions in *embodied carbon* for multi-unit residential buildings.

These alignments validate the study's findings and recommendations, confirming their foundation in and consistency with established industry practices and research. This ensures their relevance and practical applicability for architects and designers.

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