BUILDINGS & CITIES

SPECIAL COLLECTION: MAINSTREAMING BUILDING COMPONENT REUSE

RESEARCH

Capturing circular value for building sector actors

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ABSTRACT

Environmental and life-cycle cost assessments of two renovation case studies in Montreal, Canada—a single-detached house and a triplex—investigated three different renovation scenarios: business-as-usual, recycling, and reuse. Results indicate that incorporating circular reuse principles offers the highest potential to reduce environmental impacts while lowering costs. Higher upfront costs and labour requirements for selective deconstruction are subsequently offset by savings via the use of secondary materials. As contractors typically prioritise initial budget considerations within project-based delivery frameworks, these redistributed gains may remain insufficiently visible at the decision-making stage, leaving longer term economic and environmental benefits partially obscured for contractors and clients. A structural mismatch exists between academic evaluations (often framed from cradle to cradle) and industry perspectives focused on project completion. Addressing this misalignment requires rethinking how value is assessed in the building sector, moving beyond upfront costs towards incorporating longer term environmental and economic considerations. By grounding life-cycle assessments in real renovation contexts and translating them into contractor-focused guidance, this study contributes practice-based evidence to support circular renovation decision-making and policy discussions.

PRACTICE RELEVANCE

This study outlines how circular renovation of a single-detached house and a triplex can achieve economic and environmental reductions if fully implemented. This includes a two-phase construction process: phase 1 (selective deconstruction) and phase 2 (renovation with secondary materials). If only phase 1 is followed, costs for the project rise as this phase is more costly than demolition. However, when both construction phases are followed, net negative greenhouse gas emissions can be achieved, representing a 123% reduction relative to a linear renovation (demolition and the use of primary materials). This significant reduction is due to the avoided burden approach which generates environmental credits that exceed gross impacts, resulting in negative net emissions. Project costs can also be reduced by up to 19%. A deconstruction guide produced for contractors showcases the best practices in selective deconstruction and reuse, and highlights the potential environmental and economic savings.

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1. INTRODUCTION

The building sector significantly contributes to resource use and its associated global greenhouse gas (GHG) emissions. Circular economy (CE) principles have emerged as a framework to tackle these issues, particularly by extending the life of materials and components through practices such as reuse. However, the implementation of circular practices in construction, especially in renovation contexts, remains limited. A key challenge lies in how circular value is understood and implemented within the construction sector. This issue, combined with existing implementation gaps and the misalignment between academic evaluation frameworks and contractor-level decision-making, highlights the need for more practice-based and collaborative approaches.

1.1 A GAP BETWEEN EVALUATION AND VALUE CAPTURE

In linear construction models, value is primarily defined by short-term outcomes within the budgetary, time, and quality constraints of the construction project scope (Devlieger & Vande Capelle 2024; Hosseini *et al.* 2024; Osobajo *et al.* 2022). Contractor decision-making is shaped by risk aversion, timelines, and financial conditions (Oo *et al.* 2022), reinforcing practices that prioritise on-time delivery over long-term considerations such as environmental impacts (Abu Oda *et al.* 2022; Rondinel-Oviedo 2021; Sadliwala & Gogate 2022). In addition, building sector pressures of labour shortages, supply chain disruptions, and material cost volatility contribute to tightened margins, reinforcing a focus on speed and cost efficiency (Meisels *et al.* 2026). Procurement models and contractual arrangements reinforce this dynamic by prioritizing short-term cost efficiency over long-term value creation (Huuhka *et al.* 2023). Consequently, demolition is often favored over circular practices such as deconstruction and material recovery, which typically involve multiple barriers such as higher upfront costs, additional coordination, and fragmented supply chains (Ababio & Lu 2023; Munaro & Tavares 2023).

Within a linear construction paradigm, circular strategies that generate value over extended timeframes are disadvantaged, as their benefits are not captured within the temporal and financial boundaries of construction projects (Ababio & Lu 2023; Shahidi Hamedani *et al.* 2025). However, the linear paradigm is increasingly unsustainable in the Canadian context, as is similar in many countries worldwide, given the dual pressures to meet climate targets (*i.e.* reducing GHG emissions by 40–45% below 2005 levels by 2030 and achieving net-zero emissions by 2050), and housing demand (*i.e.* 2.3 million new homes required by 2030) (CMHC 2023; Government of Canada 2022). Building material production and use is central to these challenges, contributing up to 97% of life-cycle emissions in Quebec housing (SURCY *et al.* 2025) and 34% of the province's material footprint (Circle Economy 2021). Circular models propose a shift toward long-term, system-level value, emphasizing building and material preservation across multiple life-cycles (Alaux *et al.* 2025; Bauhaus Earth *et al.* 2025; Wuni 2023). This reconceptualization distinguishes between functional value, maintained through reuse, and created value, encompassing broader environmental, economic, and social impacts (Vulsteke *et al.* 2024). Reuse strategies, a primary pillar of the '10Rs' hierarchy within the Circular Economy 3.0 framework, exemplify this dual value by extending material lifetimes and avoiding impacts associated with material extraction and disposal (Reike *et al.* 2022; Devlieger & Vande Capelle 2024). Reuse practices are supported by approaches such as selective deconstruction (SD), design for disassembly, and urban mining (Durmisevic & Yeang 2009; Ghyoot *et al.* 2018; Gorgolewski 2018; Yang *et al.* 2022).

In circular construction systems, functional and created value frequently extends beyond the analytical boundaries of conventional life-cycle evaluation, as benefits accrue to multiple users, beyond the initial user, and are therefore only partially captured, reflecting the distributed and multi-actor nature of such systems (Alvarenga *et al.* 2020). This limitation is particularly pronounced in renovation contexts, where decision-making persistently demonstrates trade-offs between multiple objectives such as decarbonization, material circularity, and cost-effectiveness (Rajala *et al.* 2022; Zhang *et al.* 2025). These objectives are rarely evaluated in an integrated manner, limiting the visibility of life-cycle benefits. As a result, the economic and socio-ecological value of reuse is not consistently captured at the project level (Enciso-Alfaro & García-Sánchez 2023).

Life-cycle assessment (LCA) and life-cycle cost assessment (LCCA) provide established methods to quantify environmental and economic impacts (Barbhuiya & Das 2023; Vella *et al.* 2026). Nevertheless, their reliance on generalised datasets, extended system boundaries, and long-term horizons creates misalignment with project-level decision-making (Lueddeckens *et al.* 2020; Olanrewaju *et al.* 2024; Trofimenko *et al.* 2025). As a result, despite identifying long-term benefits, these frameworks often fail to translate circular value into actionable project decision-making and outcomes, reinforcing the gap between evaluation and value capture in practice.

1.2 CIRCULARITY CHALLENGES IN THE BUILDING SECTOR

The limited capture of circular value described above is reflected in current practice across Canada and Quebec. Canada's circularity rate remains low at 6.1%, while Quebec reports 3.5%, alongside more than 1.6 million tonnes of construction, renovation, and demolition (CRD) waste sent to disposal in 2023 (Jagou & Raufflet 2025; RECYC-QUÉBEC 2023, 2025). Given Canada's 16.5 million dwellings, renovation represents a key intervention and a promising catalyst to promote circularity (Keena *et al.* 2025a). Expenditures frequently exceed home purchases, with strong homeowner intent to renovate (Buckley 2019; CMHC 2025; EspaceProprio & APCHQ 2024). However, renovations are primarily driven by functional and economic objectives rather than circularity. Despite significant potential to extend material life-cycles and reduce impacts, the environmental and economic value of circular strategies remains insufficiently captured in practice towards initiating ubiquitous circular construction.

1.3 BRIDGING THE GAP THROUGH ACADEMIA–INDUSTRY COLLABORATION

Efforts to promote circularity through policy and guidelines have increased, yet their implementation at the project level remains constrained. Contractors, homeowners, and professionals face practical obstacles to integrating deconstruction and reuse, including fragmented and difficult-to-interpret information on recoverable materials, its limited adaptation to construction contexts, and operational uncertainty that constrains reuse within projects (Keena *et al.* 2025b).

A shift to circularity is particularly slow among small-scale contractors, firms with fewer than four employees which are prevalent in Quebec (IDQ 2025). Despite the development of CE guidelines at regional or city level (CELC 2023; CELC & CIC 2025; Circle Economy 2024; City of Toronto 2026), these offer strategic frameworks for circular practices, rather than detailed construction-level guidance for deconstruction, handling, and reinstallation. Additionally, while CE guidelines reference LCA and LCCA as evaluation tools, they do not specify how these methods should be applied within the time, cost, and data constraints typical of construction projects, limiting their practical utility for contractor decision-making (Shahidi Hamedani *et al.* 2025).

This limitation reflects the misalignment identified in previous sections. While evaluation frameworks generate knowledge about the potential value of circular strategies, this knowledge is not effectively translated into tools that inform contractor decision-making. More detailed, practice-oriented information is therefore needed to bridge the gap between long-term assessments and project-level decision-making. In this context, academia–industry collaboration is increasingly recognised as a way to bridge knowledge production and practical implementation (P6 Technologies 2025). By integrating academic methods with practice-based insights (Currall 2025; Walker 2025), such collaboration can support the development of tools and guidelines aligned with circular evaluation and construction constraints.

1.4 RESEARCH OBJECTIVES AND CONTRIBUTION

This aim is to demonstrate how academia–industry collaboration can bridge the gap of circular knowledge transfer from theory to practice. Two renovation case studies demonstrate how results from context-specific LCA (environmental) and LCCA (economic) can be translated into a contractor-oriented deconstruction guide that supports the capture of circular value at the project level. The case studies are a triplex (a multi-unit residential building, typically two to three storeys, specific to Montreal) and a single-detached house.

The assessments reflect the real-world economic conditions of implementing circular renovation within the current circular infrastructure and construction sector in Montreal. This includes the emerging reuse market, where salvaged material prices, deconstruction labour costs, and limited supplier networks shape circular renovation feasibility. Environmental and economic savings are observed within the early stages of Montreal's circular building ecology. The study uses a collaborative academia–industry model that bridges evaluation and implementation, supporting industry decision-making and informing policy discussions on circular renovation.

2. METHODS

The study adopts a collaborative methodological approach combining academic tools with empirical input from construction industry actors. Previous research on circular construction, LCA, and CRD management in Montreal and Quebec provides the empirical foundation for this study (Keena *et al.* 2022, 2023a, 2023b, 2024, 2025a, 2025b; Rondinel-Oviedo *et al.* 2024); including datasets, system boundaries, and methodological protocols for environmental impact assessment in the Quebec residential context. This study extends that work through direct collaboration with industry actors, translating LCA and LCCA into contractor-oriented deconstruction guidelines.

The methodology includes four stages (Figure 1). First, an academia–industry collaborative framework was established to define the actors, the collaboration scope, and shared research objectives. Second, case studies, linear versus circular renovation scenarios, and construction phases, were collaboratively defined to reflect realistic construction practices and decision-making contexts. Third, the cases were evaluated through LCA and LCCA, conducted by the academic research team and informed by empirical data and technical input from industry partners. Fourth, results informed contractor-oriented deconstruction guidelines to support the implementation of circular strategies in renovation projects.

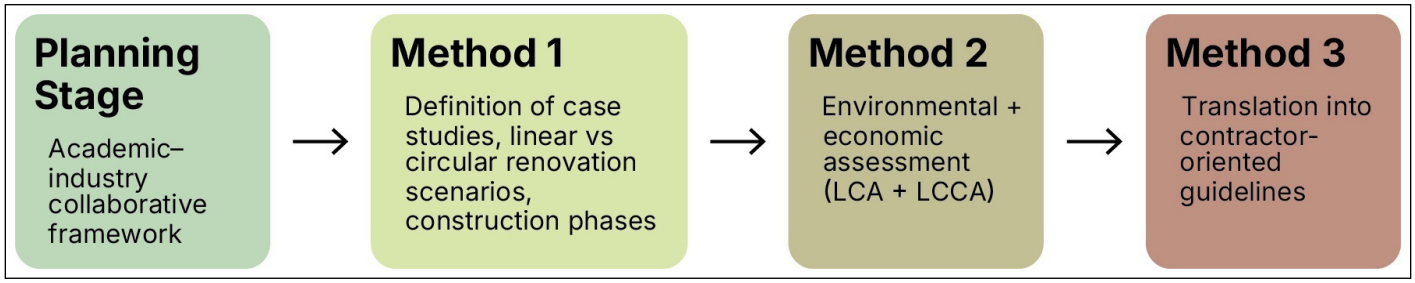


Figure 1: Overview of the four-stage methodological process.

2.1 INTRODUCING AN ACADEMIA–INDUSTRY COLLABORATIVE FRAMEWORK

This research emerged from a shared need between industry and academia. Industry actors require analytical tools and evidence-based approaches to support circular design and construction decision-making in residential renovation, while academic researchers benefit from access to real project data. On the industry side, the collaboration involved SURCY, a Montreal-based social enterprise, and the Association of Construction and Housing Professionals of Quebec (APCHQ). The academic collaborator was TRACE Lab, an interdisciplinary research group on the CE in the building sector. The research was supported by government organizations Société d'habitation Québec and Mitacs, a Canadian national not-for-profit organization that drives innovation by co-funding collaborative research projects between academia and private sectors, non-profits, or municipal organizations.

The research project ran for 10-months, with primary coordination conducted by the research team through weekly meetings and shared milestones meetings involving all relevant partners. To identify renovation projects and gather industry expertise on circular renovation practices, an open call was distributed through the APCHQ network, soliciting both case study projects for the LCA and LCCA and contractor participants for interviews. The research team conducted semi-structured interviews with seven contractors, each lasting between around 1 hour. The interviews were recorded, transcribed, and analysed by the authors. The questions were designed to collect

data on material handling, cost estimation, and labour practices that informed the LCA and LCCA inputs (see data file 1 in the supplemental data online). After data collection, the research team systematised the interview results by deriving average cost and time factors, which informed initial estimation schedules for the guide. These factors capture the cost and time implications of SD relative to demolition in phase 1, available market pathways for recovered materials in phase 2, and the overheads and contingencies for all scenarios. A final review with APCHQ led to the inclusion of an uncertainty factor to reflect variability in labour and cost estimates, as deconstruction costs remain an emerging area.

2.2 LINEAR VERSUS CIRCULAR RENOVATION SCENARIOS

Case study selection followed a two-stage process. First, Montreal's housing typologies with high renovation frequency were reviewed to establish typological representativeness, identifying the triplex and single-detached house as the most relevant building types for the Quebec residential renovation context. Second, two renovation projects were selected through an open call led by SURCY. These were chosen collaboratively by all project partners during the planning stage, based on typological fit and data availability.

The case studies had distinct renovation scopes. The triplex involves a full interior remodel with facade modifications, representing the maximum extent of intervention possible without requiring a demolition permit. The single-detached house focuses on common interventions: the kitchen, bathroom, and exterior patio or terrace.

After the selection, three renovation design scenarios comparing linear and circular construction approaches were defined namely: (S1) business-as-usual (BAU), (S2) recycling, and (S3) reuse. For each renovation scenario, two construction phases were identified: construction phase 1 (phase 1) demolition or SD, and construction phase 2 (phase 2) material procurement and installation. By investigating these two construction phases, the life-cycle analyses outlined in stage 3 highlighted, for each scenario, the environmental and economic impacts across these phases, allowing for a comparison in real-world renovation contexts. These three scenarios were justified as a means to study current market conditions in Quebec. The linear and circular renovation scenarios were defined across the system boundary, from the potential end-of-life (EoL) stage to the construction of the renovation phase, including and excluding specific processes as outlined below:

- S1 outlines a current, linear approach to renovating an existing building. In phase 1, it includes demolition and transport of discarded materials to landfill. In phase 2, new materials are procured from suppliers, transported to the project site, and installed to replace the removed components.
- S2 presents a recycling-oriented approach involving SD in phase 1, where used materials are dismantled from the existing building, and a portion is diverted to recycling facilities. The remaining materials are transported to landfill sites. In phase 2, new materials are procured and installed as in S1.
- S3 outlines an integrated approach combining SD, reuse, and recycling. The process initiates with SD in phase 1, wherein existing components are dismantled to maximise material integrity. A portion of these salvaged materials is repurposed on-site, while others are sold to reuse material marketplaces. The remaining recoverable fractions are sent to recycling facilities, with only non-recoverable waste diverted to landfill. Phase 2 prioritises the procurement, transportation, and installation of reused materials whenever feasible; when specific elements cannot be sourced through secondary markets, they are replaced with new materials. Transport distances for reused materials sourced from secondary markets were estimated based on average distances within the Montreal metropolitan area.

2.3 ENVIRONMENTAL (LCA) AND ECONOMIC (LCCA) ASSESSMENT METHODS

2.3.1 Goal and scope

The goal of the assessment was to compare the environmental and economic performance of linear (demolition, landfill, and replacement) and circular (deconstruction, reuse, and recycling)

renovation approaches for single-detached homes and triplexes in Montreal. The functional unit was established separately for each case study: (1) the renovation of one representative Montreal single-detached house, and (2) the renovation of one representative Montreal triplex. LCA and LCCA were used to identify environmental and economic hotspots, respectively, within the renovation process and assess potential trade-offs, and capture how reuse generates both functional and created value in circular renovation. The scope is defined by the life-cycle phases included in the renovation timeframe. Three renovation scenarios were compared for both case studies (see Section 2.2). Figure 2 shows the scope of each scenario, evaluated at the assembly and phase levels for each functional unit.

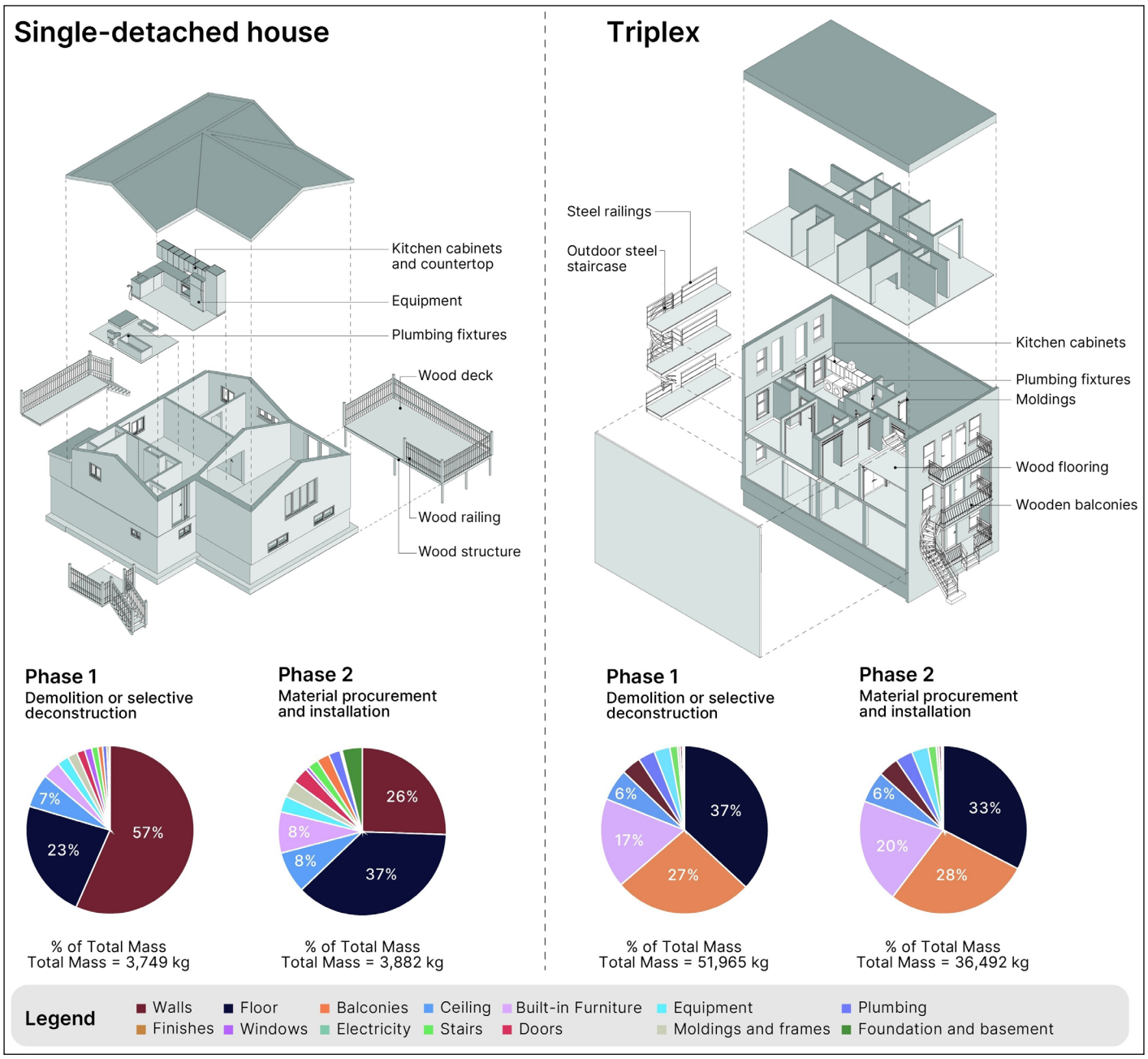


Figure 2: System boundaries for renovation scenarios applied to both single-detached and triplex case studies.

2.3.2 Life-cycle inventory for the LCA

Two representative models of average Montreal dwelling units were developed as building information models (BIM). These include walls, floors, ceilings, stairs, balconies, finishes, doors, plumbing, equipment, built-in furniture, moldings, frames, and electricity. The bill of materials (BOM) was calculated by building assembly, construction material, mass, and unit of measurement (*e.g.* kg). Assemblies and materials were classified into construction phases 1 and 2. Three Excel spreadsheets were created for each scenario (*i.e.* S1, S2, and S3) to support comparative analysis. Figure 3 illustrates the percentage of total mass of the building assemblies included in construction phases 1 and 2.

Figure 3: Representative model of a single-detached house and triplex.



An LCA model was constructed using OpenLCA (GreenDelta 2024). All background processes were modelled using the Ecoinvent V3 (ecoinvent Association 2023) life-cycle impact (LCI) database. The closest available local processes were selected, prioritizing Quebec. The three scenarios (*i.e.* S1–S3), as defined in Section 2.2, each representing an alternative EoL cycle phase, were modelled to assess the benefits of reuse and recycling.

To model the EoL allocation in phase 1, the avoided burden approach was applied across all scenarios, assigning environmental credits to reused and recycled materials assuming that they displace equivalent quantities of virgin materials (Obrecht *et al.* 2021). This approach was selected over the cut-off method to evaluate the substitution value of recovered materials from a system-wide perspective. This makes it more appropriate for comparing circular and linear scenarios, in which the displacement of virgin material production is the key mechanism providing environmental benefits. This approach influences the reported credits, including results where net emissions become negative.

To ensure realistic estimates of displaced primary production, a quality ratio was incorporated into the environmental credit calculations (Figure 4). This ratio adjusts the environmental credit to reflect the degree to which a reused or recycled material substitutes for virgin production, accounting for quality loss and the technological feasibility of diversion. Following previous applications (Keena *et al.* 2023b; Sarmiento-Pastor *et al.* 2025), the recyclability and reusability index expressed in numerical factors was assigned to evaluate the feasibility of diverting CRD waste materials from landfills. Diversion categories are assigned quality factors (1.0, 0.75, 0.50, < 0.25) to quantify value retention in the avoided burden approach. High-value categories (1.0) retain original material quality, while simple (0.75), complex (0.50), and limited (< 0.25) options reflect increasing degrees of downcycling, accounting for both quality loss and technological feasibility of diversion from landfill. These factors operationalise varying levels of downcycling, whereby a material is recycled into a secondary product of lower quality and value. This enables the calculation of environmental credits that reflect both the technical and economic viability of material recovery.

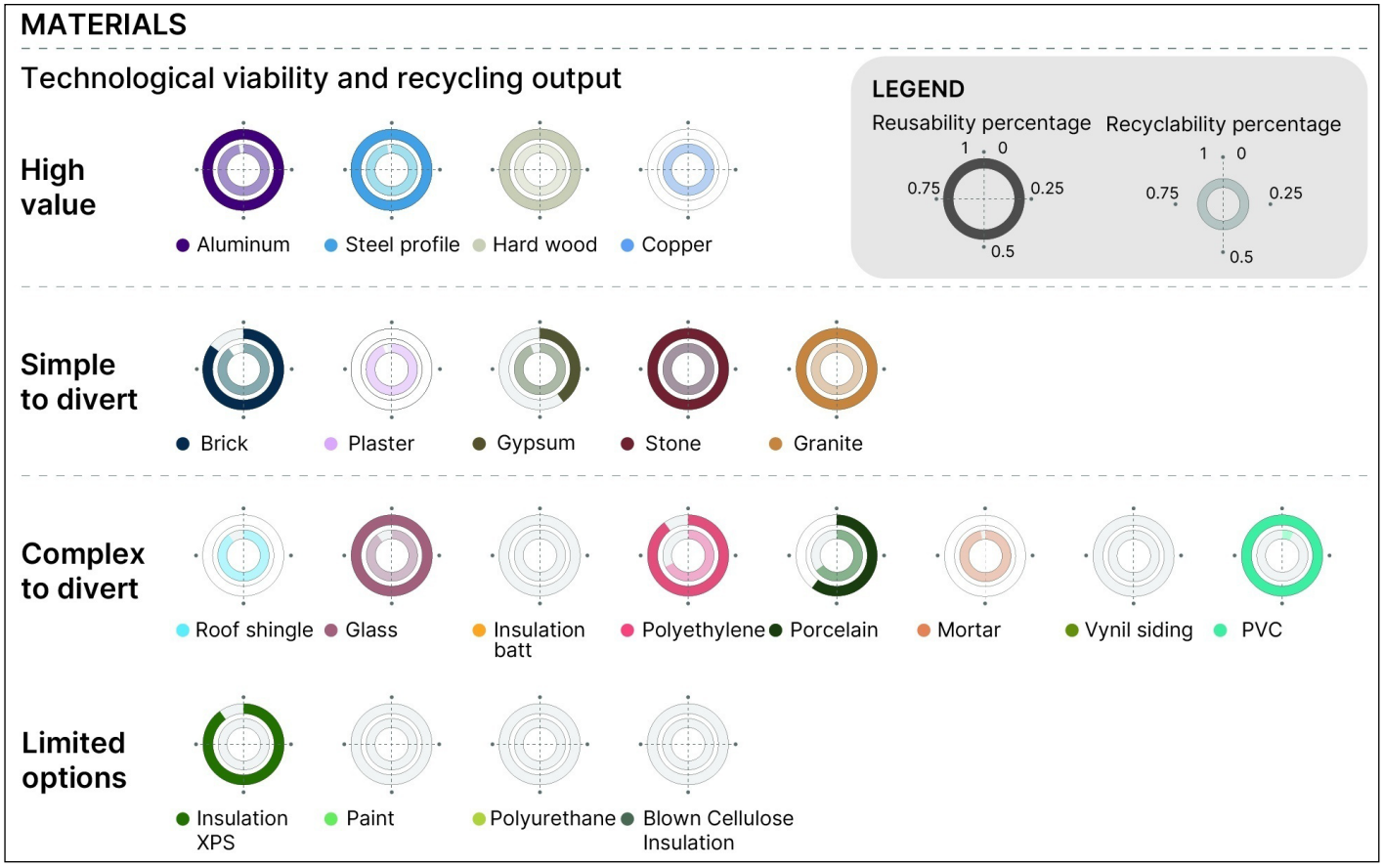


Figure 4: Recyclability and reusability index.

Note: Quality factors assigned to construction, renovation, and demolition (CRD) waste materials.

Sources: Adapted from Keena *et al.* (2023b) and CCME (2019).

2.3.3 LCI for the LCCA

The economic inventory was developed using a hybrid data-sourcing approach reflecting Montreal market conditions in 2025. Although a comprehensive LCCA usually considers life-cycle revenues and residual values, this study focuses on the renovation costs. Cost inputs and multipliers

were validated through SURCY's industry expertise and the contractor interviews described in Section 2.1, including verification of reclaimed material market rates, labour time estimates, and the feasibility of SD under current market conditions.

For phase 1, the inventory was modelled to account for labour-intensive material removal. Costs were compiled in Excel and organised as follows: material name and demolition or SD unit, with direct costs categorised as material-specific labour, equipment, and transportation. The model incorporates EoL costs, including landfill tipping charges and sorting for recycled materials.

For phase 2, the inventory covers material procurement and installation. An Excel spreadsheet was organised according to material name and procurement unit, with costs differentiated between virgin retail prices and reclaimed market rates, as well as transportation, equipment rates, and installation labour. In this phase, labour costs incorporate difficulty multipliers for specialised on-site recovery, ensuring realistic construction conditions for material reuse in S3, as greater time investment is required compared with new installations. Therefore, time-consuming factors were applied to specific materials (Table 1). For example, the reinstallation of on-site metal staircases and balcony railings incurred a cost multiplier of 5, whereas moldings and frames were adjusted by a factor of 2.5.

Data sections 4.5 and 4.6 in the supplemental data online include a template of the Excel file referenced above to support methodological replicability; cost data are excluded due to commercial sensitivity.

ASSEMBLIES AND MATERIALS	UNIT	PHASE 1		PHASE 2			DEGREE OF UNCERTAINTY
		COST	TIME	REUSE	DONATION	RESALE	
Floors							
Plywood	ft²	$$	◷◷	○			3
Wood finish	ft²	$$$	◷◷◷		○		3
Softwood	ft²	$	◷		○		4
Ceramic	ft²	$	◷			○	1
Walls							
Brick	ft²	$$	=	●	●	●	1
Rigid insulation	ft²	$$$	◷◷	●	●		4
Batt insulation	ft²	=	◷◷	●			5
Gypsum	ft²	$$	◷◷	○			1
Wood studs	ft²	$$	◷	○			3
Ceiling							
Softwood	ft²	$	◷		○		4
Gypsum	ft²	$$	◷◷	○			1
Balconies							
Wood structure	ft	$$	◷◷	○	○		4
Decking	ft²	$	◷◷	○			1
Wood railings	ft	$	◷	○			3
Stairs							
Exterior metal staircase	pc	$$$	◷◷	●	●		2
Wood stringer	pc	$	◷	○			4
Wood step	pc	$	◷	○			4

(Contd.)

Table 1: Deconstruction labour considerations and reuse marketplace availabilities by material assembly.

Note: Phase 1 presents the cost and time implications of selective deconstruction relative to demolition, expressed as multipliers of current demolition costs (CAN$) and time (◷). In phase 2, ● = available market pathways for recovered materials: reuse, donation and resale; and ○ = pathway implemented in the study. Values under phase 1 (cost and time) are multipliers of standard demolition effort: ◷ = one to two times baseline; ◷◷ = two to four times baseline; and ◷◷◷ = more than four times baseline. The degree of uncertainty refers to the ability to assess the feasibility of demolition or the potential for reuse of a material before construction. It also reflects the stability and level of development of the reuse market and the availability of outlets for that material. MDF = medium-density fiberboard; pc = piece.

Source: Authors' experience and interviews with contractors.

ASSEMBLIES AND MATERIALS	UNIT	PHASE 1		PHASE 2			DEGREE OF UNCERTAINTY
		COST	TIME	REUSE	DONATION	RESALE	
Built-in furniture							
Kitchen cabinets	ft	$$	◷◷		○	○	2
Granite	ft	=	◷◷		○	○	2
Integrated carpentry	ft	$$	◷◷			○	2
Doors							
Interior hinged doors	pc	$$	◷◷		○	○	1
Moldings and frames							
MDF moldings and frames	ft	$$	◷◷◷	○			1
Equipment							
Dishwasher	pc	=	=		○	○	1
Clothing washing machine	pc	=	=		○	○	1
Clothing dryer	pc	=	=		○	○	1
Electric oven	pc	=	=		○	○	1
Refrigerator	pc	=	=		○	○	1
Lighting fixtures	pc	$$	◷◷		○	○	1
Plumbing							
Sinks and faucets	pc	$	◷◷		○	○	1
Toilets	pc	$	◷		○	○	1
Sinks and vanities	pc	$	◷		○	○	1
Bathtub	pc	$	◷		○	○	1
Shower	pc	$	◷		○	○	1
Faucets	pc	$	◷◷		○	○	1

Primary cost data, including material costs, labour, and equipment, were sourced from the RSMeans database 2018 (RSMeans Online n.d.). Quebec construction contractors use this database as a standard cost-estimation reference and as the primary pricing tool employed in practice within the construction industry in North America. To ensure the reliability of the data, Montreal-specific location factors embedded within the RSMeans database were selected to adjust base costs to the Quebec context. Labour costs from RSMeans were updated to 2025 values using the Construction Union wage rate index (Statistics Canada 2024: tab. 18-10-0140-01). Material and equipment costs were adjusted using Montreal-specific construction price indices and inflation factors for the period 2018–25 (Bank of Canada n.d.). Data for some new material procurements were collected directly from local retail suppliers in Montreal.

For S3, empirical data were gathered from local second-hand platforms (*e.g.* Kijiji and Marketplace) and specialised Montreal resale centers: RECO, a 10,000-ft^2 (930 m^2) reclaimed construction materials center, and Ecodepot, a 14,000-ft^2 (1300 m^2) salvaged furniture and appliances warehouse. Materials were selected based on expert judgement of fitness for purpose and availability in the Montreal market at the time of data collection, reflecting real-world procurement conditions that depend on current inventory rather than standardised pricing. Availability and pricing in the secondary market are subject to supply and demand fluctuations, introducing uncertainty in S3 cost estimates, which is addressed through contingency rates.

To account for this, a contingency of 10% was applied to all scenarios to account for unforeseen conditions. Management overheads were set at 15% for S1 and S2. For S3, a rate of 30% was assigned to the single-detached house to reflect the labour intensity and coordination required for

SD and installation of existing materials. In the case of the triplex, for S3 this rate was reduced to 20% due to the larger overall project scale, where deconstruction and reuse represent a smaller share of total costs. All percentages were based on empirical data collected by the research team through contractor input and validated by APCHQ against current Quebec construction market conditions (Table 1).

2.3.4 LCI assessment

For the LCA, the environmental impacts were evaluated using the Environmental Footprint 3.0 (EF 3.0) method. Given that GHG emissions are identified as a primary contributor to environmental degradation in the built environment (UNEP 2023), the EF 3.0 aggregated indicator for climate change was utilised, which accounts for fossil, biogenic, and land use/land use change (LULUC) emissions, expressed in kilograms of carbon dioxide equivalent (kg CO_2-eq). Other EF 3.0 impact categories were excluded to align with the research priorities of the APCHQ and with Montreal's regulatory mandate to disclose GHG emissions from buildings, including multi-unit residential dwellings (City of Montreal 2021). For the LCCA, the economic costs were assessed by calculating the renovation cost per scenario in Canadian dollars (CAD$) in present-value terms.

2.4 DECONSTRUCTION GUIDE DEVELOPMENT METHODOLOGY

The guide was developed by converting analytical results into practical tools that support contractor decision-making during phases 1 and 2, when key decisions regarding demolition, SD, and material sourcing are made. First, materials with reuse potential were identified based on assessments and represented in a diagram to provide contractors with a clear overview of priorities. Second, carbon and cost results were structured to compare the three renovation scenarios, highlighting differences in labour and material cost. Third, these results were translated into operational formats, including decision trees and deconstruction sequences for on-site planning, as well as material-specific tools such as tables (cost, labour, time, uncertainty, and reuse streams) and recommendations derived from the collaborative research. Throughout this process, continuous feedback from contractors and industry partners (including APCHQ) informed the guide's structure, content, and presentation. The content was further refined to ensure usability under typical site conditions, timelines, and contractor constraints.

3. RESULTS

Results from both case studies indicate that S3 achieves the greatest reductions in environmental impacts while lowering costs (for disaggregated results, see supplemental data files 3 and 4 in the supplemental data online). The single-detached house achieves greater relative reductions (up to 123% in GHG emissions due to credits and 19% in costs), while the triplex shows more moderate gains (39% reduction in emissions and 6% in costs). In both cases, higher labour in phase 1 (up to 15% of total costs) is offset by savings in phase 2 through material reuse. While hotspots differ, the results highlight that material-intensive assemblies are the main driver of both costs and emissions.

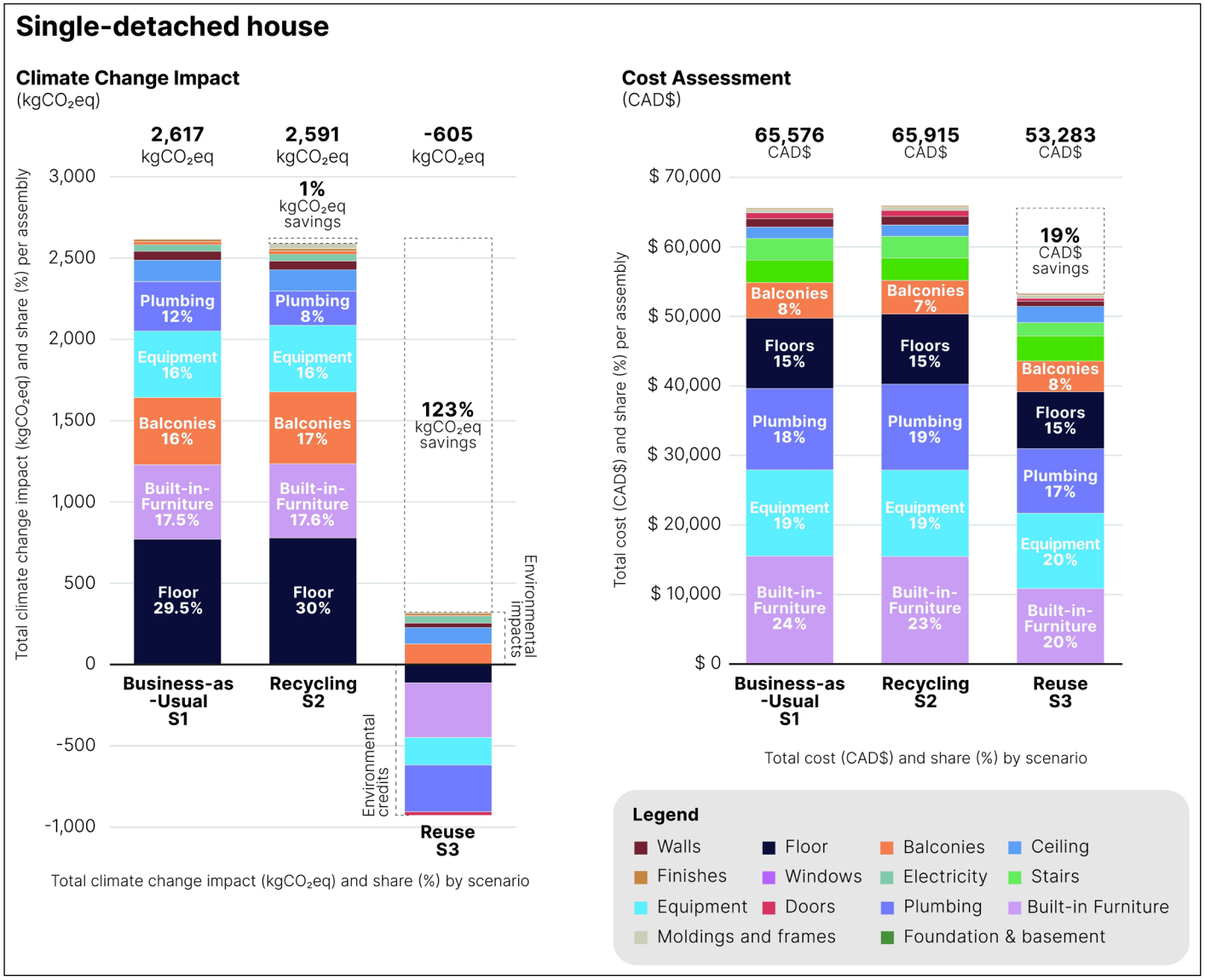
3.1 ENVIRONMENTAL AND ECONOMIC IMPACTS OF THE SINGLE-DETACHED HOUSE

The GHG reduction in S2 compared with S1 is 1% (Figure 5). This 1% difference is found in plumbing, where some plumbing fixtures could be recycled, but currently are not, such as toilets. The small reduction in GHG emissions reflected in S2 is also a consequence of the fact that recycling of engineered wood (*e.g.* medium-density fiberboard (MDF) used in the moldings and frames, balconies and floors) led to greater GHG emissions than landfilling it. This finding is in line with the literature (Keena *et al.* 2023b; Farjana *et al.* 2023). In contrast, S3 demonstrated greater environmental performance, reducing GHG emissions by 87.7% relative to S1. When environmental credits generated through the avoided burden approach are incorporated, whereby reused materials displace the production and transportation of equivalent virgin materials, net emissions become

negative. This yields a total GHG reduction of 123% relative to S1, which exceeds 100% because the credits associated with avoided primary material production outweigh the gross emissions of the renovation process itself. The most significant contributors to this reduction are floors, built-in furniture, equipment, plumbing, and doors (see data section 3.1 in the supplemental data online). Of the total renovated mass, 15.78% was reused on-site, generating the largest share of avoided emission credits by eliminating both production and transportation stages.

In all scenarios, the primary cost drivers are built-in furniture (19% in S1 and S2, and 15% in S3), equipment (15% in S1 and S2, and 14% in S3), plumbing (14% in S1, 15% in S2, and 12% in S3) and flooring (12% in S1 and S2, and 11% in S3), collectively accounting for over 50% of total costs (Figure 5) (see data section 4.1 in the supplemental data online). Despite higher labour requirements associated with SD, S3 remains the most cost-effective scenario. The phase-based analysis reveals that while phase 1 represents 9–10% of total costs in S1 and S2, it rises to 15% in S3, reflecting the higher labour intensity of material recovery. However, in S3, this upfront increase is offset by savings in phase 2, which are driven by the procurement of reused materials, resulting in lower overall costs compared with S1 and S2 (see data section 4.2 online).

Figure 5: Climate change impact and cost assessment divided by assemblies in the single-detached house across the three scenarios studied: S1 (business-as-usual—BAU), S2 (recycling), and S3 (reuse).



In S3, built-in furniture, equipment, and plumbing are the primary drivers of environmental performance, generating net credits of −335.7, −169.4, and −288.4 kg CO_2-eq, respectively, while reducing costs by 30%, 21%, and 21% relative to S1 (Figure 6). Floors and doors further contribute environmental credits of −112.4 and −21.6 kg CO_2-eq, alongside cost reductions of 19% and 51%.

These assemblies collectively drive S3's total net emissions to –691.1 kg CO_2-eq compared with S1's gross emissions of 2621.8 kg CO_2-eq. The selection of LCA and LCCA as methodological tools was appropriate for this study, as both methods captured how reuse generates functional and created value. Functional value is generated through reduced material procurement costs and the extension of the life-cycle for these secondary materials, while created value is generated through avoided GHG emissions that extend beyond the project boundary. However, not all assemblies present favorable trade-offs: balconies and ceilings present the largest GHG emissions in S3 (126.9 and 100.9 kg CO_2-eq, respectively) and generated cost increases relative to S1, representing assemblies where reuse potential is technically limited.

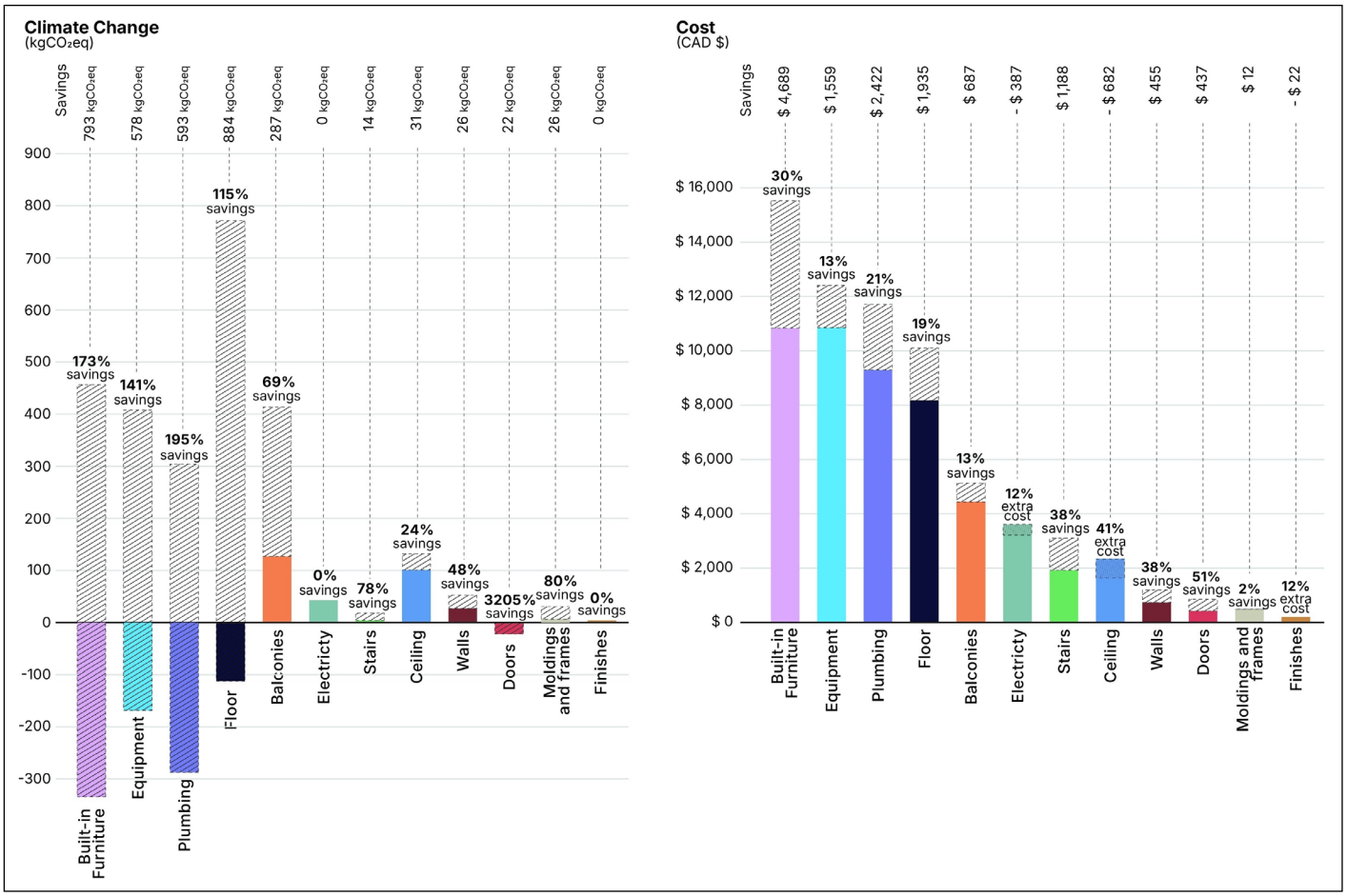


Figure 6: Potential reduction, or increase, in greenhouse gas (GHG) emissions and monetary costs by implementing reuse (S3) as opposed to a business-as-usual (BAU) approach (S1) across all assembly types in the single-detached house.

Note: GHG emission reductions are achieved based on environmental credits; cost savings are achieved based on lower costs for reused materials.

3.2 ENVIRONMENTAL AND ECONOMIC IMPACTS OF THE TRIPLEX

The GHG reduction in S2 relative to S1 is 2.5%, reflecting, as in the single-detached house, the limited environmental benefit of recycling alone within the current Montreal construction context. In contrast, S3 achieves a gross GHG reduction of 31% relative to S1, driven primarily by floors and equipment, which are reduced through reuse procurement (Figure 7). Walls, however, increase their relative emissions share to 24% in S3, reflecting the limited reuse potential of wood-based materials. When avoided burden credits are incorporated, net GHG savings increase to 38.8% relative to S1, with stairs (–1441 kg CO_2-eq) and doors (–919 kg CO_2-eq) generating the largest credits, followed by built-in furniture (–286 kg CO_2-eq) (see data section 3.2 in the supplemental data online). Across all scenarios, emissions are concentrated in phase 2, accounting for 94%, 96%, and 99% of total GHG in S1, S2, and S3, respectively, confirming material procurement and installation as the dominant environmental hotspot. Within S3, phase 2 emissions are reduced by 36% relative to S1, demonstrating the significant mitigation potential of reuse procurement from salvage markets and on-site material recovery.

The total project costs are CAN$740,749 in S1, CAN$740,885 in S2, and CAN$696,166 in S3. This represents a 6% reduction in costs through reuse (Figure 7). Floors, built-in furniture, and walls collectively account for around half of the total expenditure across all scenarios (see data section 4.3 in the supplemental data online). The phase-based analysis reveals that while phase 1 costs increase from CAN$68,098 in S1 to CAN$102,846 in S3, a 51% rise reflecting the higher labour intensity of SD, phase 2 costs decrease from CAN$672,651 to CAN$593,320, a 12% reduction driven by lower material procurement costs for reused components. This confirms that the economic case for reuse in the triplex relies on phase 2 savings offsetting the initial labour costs of phase 1 (see data section 4.4 online).

When interpreted through the functional and created value framework (Figure 8), stairs and doors demonstrate the most favorable trade-offs in S3, contributing 54% and 35% of total environmental credits, respectively, while representing only 7% of total project costs. This indicates a high created value return, through avoided emissions, at relatively low functional cost. By contrast, walls and floors account for 30% of economic costs yet retain 37% of remaining gross GHG emissions in S3, representing assemblies where reuse potential is structurally limited and created value remains difficult to capture at the project level.

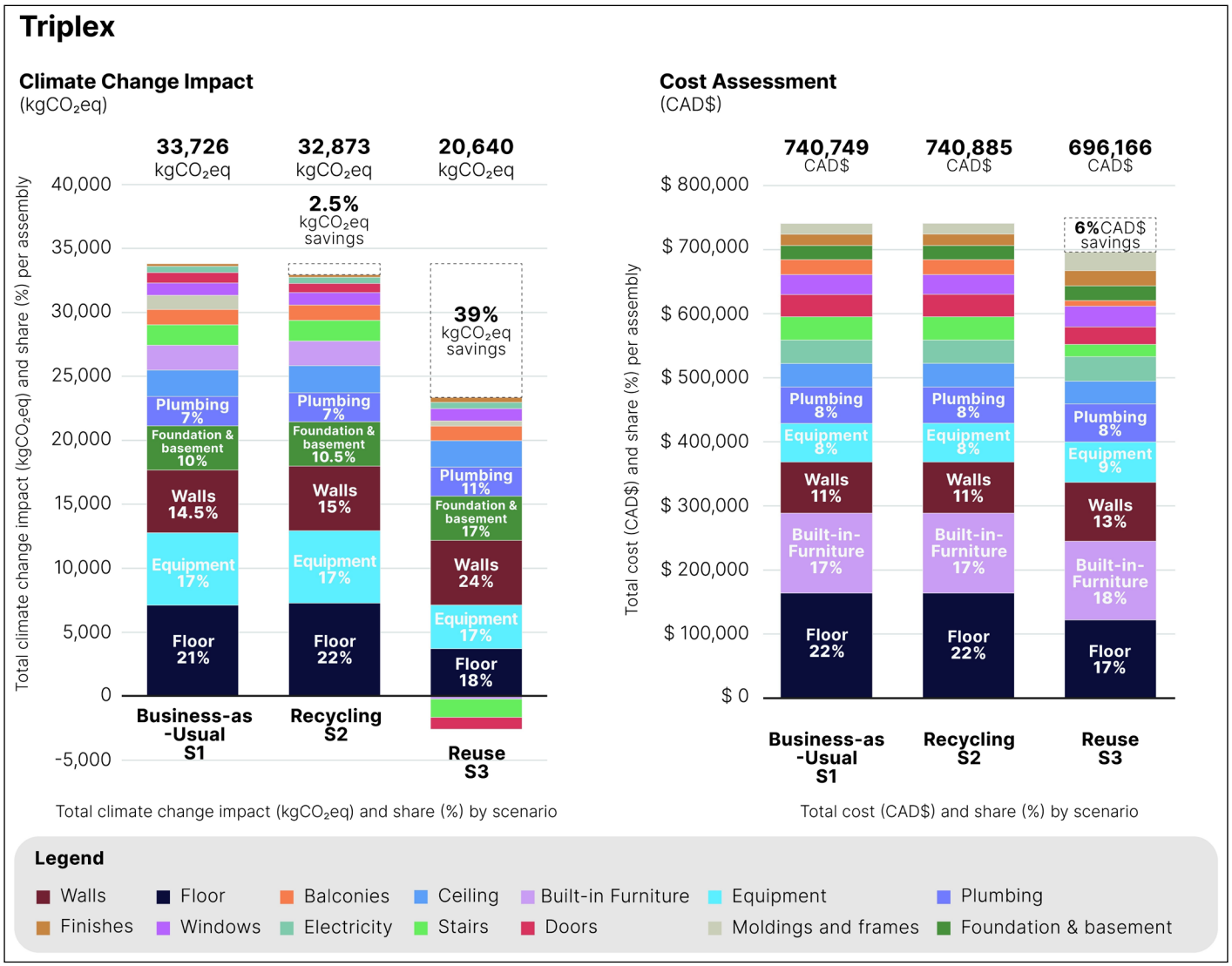


Figure 7: Climate change impact and cost assessment divided by assemblies in the triplex across the three scenarios studied: S1 (business-as-usual—BAU), S2 (recycling), and S3 (reuse).

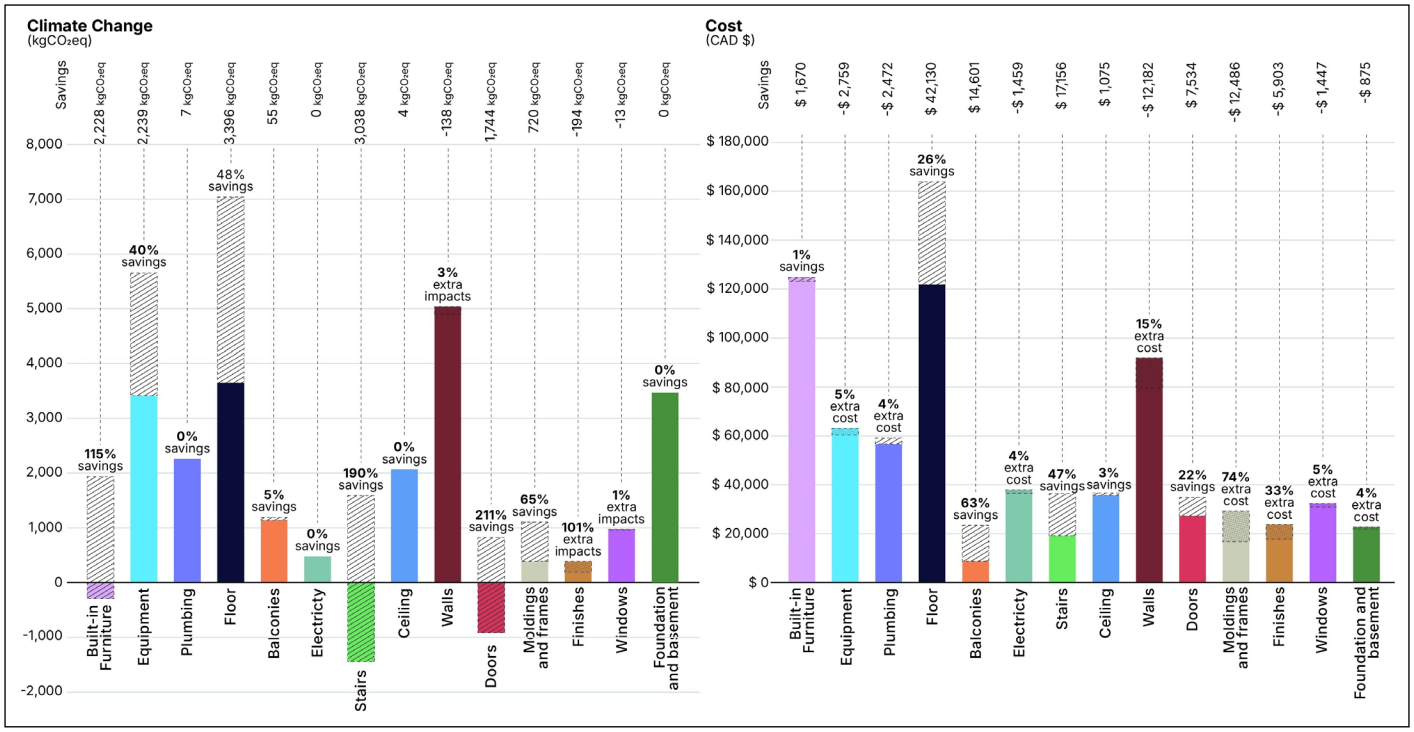


Figure 8: Potential reduction, or increase, in greenhouse gas (GHG) emissions and monetary costs by implementing reuse (S3) as opposed to a business-as-usual (BAU) approach (S1) across all assembly types in the triplex.

Note: GHG emission reductions are achieved based on environmental credits; cost savings are achieved based on lower costs for reused materials.

3.3 CONTRACTOR-ORIENTED DECONSTRUCTION GUIDE

The outcome of the collaboration is a contractor-oriented deconstruction guide (SURCY *et al.* 2025) that translates environmental and economic assessments into practical recommendations for circular renovation. It situates CRD waste in the Montreal context and frames reuse as an alternative to linear construction practices. It presents comparative results on carbon emissions and costs across scenarios for a triplex and a single-detached house, providing an evidence base for decision-making.

The guide outlines a practical framework for implementation, including resource audits, identification of secondary material markets, and material-specific recommendations for deconstruction and reuse. These include pathways such as on-site reuse, resale through online platforms, or donation to local actors. Figure 9 illustrates how assessments are translated into actionable tools, including material recovery scenarios and decision-support elements. The guide also considers key cost and labour variables and concludes with a roadmap for scaling circular renovation practices.

4. DISCUSSION

4.1 LEARNING OUTCOMES FROM ACADEMIA–INDUSTRY COLLABORATION

The collaboration generated methodological and operational insights on how academia–industry partnerships support the implementation of circular strategies in renovation contexts, improving clarity, and reducing delays associated with misinterpretation of technical and operational requirements. These insights are transferable to similar collaborative contexts.

- *Alignment is essential to connect academic and industry objectives*

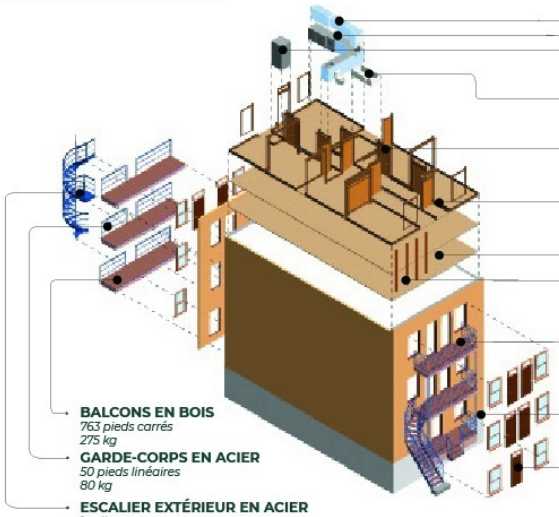
  The research team established a shared definition of system boundaries, objectives, and expected outputs, which ensured alignment between academic and industry priorities. This reduces mismatches between analytical depth and practical applicability. Clear communication of this alignment across stakeholders is equally important, using illustrative examples where necessary to support shared understanding.

Le plex montréalais

dans le cadre du scénario projeté de réemploi

Le scénario du 'strip' inclut la rénovation intérieure complète et un changement de façade arrière pour estimer les impacts d'un chantier transformant jusqu'à 50% de la structure existante, ce qui constitue généralement la limite maximale permise avant que les travaux ne soient considérés comme une démolition pour la plupart des arrondissements à Montréal.

Le scénario projeté dépasse les pratiques actuelles en maximisant la récupération et le réemploi des éléments. La prochaine page présente les économies de carbone et de coûts associées à ce scénario ambitieux de réemploi.



BALCONS EN BOIS
763 pieds carrés
275 kg

GARDE-CORPS EN ACIER
50 pieds linéaires
80 kg

ESCALIER EXTÉRIEUR EN ACIER
1 colimaçon
452 kg

Éléments réutilisables

MOBILIER DE CUISINE
112 pieds linéaires
1458 kg

COMPTOIRS DE CUISINE
72 pieds carrés
181 kg

ÉQUIPEMENT ÉLECTRIQUE ET MÉCANIQUE
13 éléctros + 30 éq. éléc. + 3 chauffe-eaux
1156 kg

APPAREILS DE PLOMBERIE
24 unités
605 kg

PORTES INTÉRIEURES
26 unités
618 kg

MOULURES
11 592 pieds linéaires
980 kg

PLANCHER EN BOIS
2156 pieds carrés
3509 kg

STRUCTURE EN BOIS
3 296 pieds linéaires
469 kg

BALCONS EN BOIS
145 pieds carrés
119 kg

BRIQUE
1038 pieds carrés
7223 kg

PORTES ET FENÊTRES EXTÉRIEURES
29 unités
895 kg

Des **52 t** de matériaux sortants, jusqu'à **21 t** peuvent être récupérées*

41% des matériaux sortants sont récupérables*

Des **37 t** de matériaux entrants, jusqu'à **7 t** peuvent provenir de sources existantes*

20% des matériaux entrants sont réutilisés*

* dans le cadre du scénario de réemploi projeté et analysé

Recommandations par matériau

Structure

STRUCTURE EN BOIS

- Privilégier la réparation ponctuelle plutôt que le remplacement complet.
- Distinguer les éléments plus sollicités (poteaux-poutres, bois d'ingénierie) et veiller à la régularité des pièces pour constituer des lots homogènes, longueur minimale de 4'.
- La vente en lots à des artisans (mobilier, design) est possible, à condition de vérifier le taux de séchage du bois. Les acheteurs récupèrent souvent eux-mêmes les pièces.
- Des frais supplémentaires sont à prévoir pour le déclouage ou le meulage. Attention aux clous ou vis qui peuvent endommager les outils de menuiserie.
- Difficulté à évaluer certains éléments s'ils ne sont pas visibles.

Intérieurs

PLANCHER DE BOIS FRANC

- 2 à 4 fois plus cher que d'installer du stratifié neuf, mais rentable pour un matériau d'une qualité similaire.
- Temps de dépose et déclouage élevé, donc viable seulement si le client est motivé.
- Pose plus longue (bois sec, déformé, nettoyage des joints requis).
- Lorsque vissés-collés, les planchers et sous-planchers sont rarement récupérables.

ÉLEMENTS DE CUISINE

- Armoires et caissons : faciles à démonter si rénovés ou plus récents que 1950-1970, à partir de quand ils sont devenues modulaires et standardisés.
- De nouvelles portes d'armoires et charnières peuvent suffire pour revamper une cuisine démodée sans tout remplacer.
- Les comptoirs de qualité (granite, quartz) peuvent être vendus séparément.

FINITION INTÉRIEURE

- Céramiques : La dépose doit être testée. Souvent plus elles sont anciennes, plus elles sont récupérables, car le mortier était réversible.

PORTES INTÉRIEURES

- Si la porte est conservée en intégralité, cela n'est habituellement pas plus long à démonter qu'à démolir, mais nécessite plus de précautions.
- Futur réemploi facilité si le cadre est conservé avec le panneau.
- Plus long à réinstaller car souvent croche, bien mesurer avant les travaux.
- Investissement justifié pour portes de qualité (vitrées, bois massif, vintage), surtout si le client participe à la restauration.
- La quincaillerie ancienne (charnières, loquets, etc.) est récuperable et de qualité.

MOULURES / PLINTHES

- Regrouper par pièce lors d'une réutilisation dans le même projet.
- Anciennes moulures à profil unique : utiles pour une rénovation partielle.
- Déclouage, meulage et décapage nécessaire et coûteux.
- S'enlèvent facilement avec un « trim puller », mais les couches de peinture multiples réduisent la rentabilité du réemploi — à privilégier seulement avec l'aide du client ou pour les lots importants.

Services

ÉQUIPEMENTS MÉCANIQUES

- Potentiel de revente s'ils sont récents et encore fonctionnels.
- Encore difficiles à valoriser, sauf dans le cas des foyers et thermopompes qui trouvent souvent preneur et/ou s'ils sont repris par le fabricant (REP).
- Certaines composantes peuvent intéresser des réparateurs (ex. moteurs).

APPAREILS DE PLOMBERIE

- Robinetterie difficile à récupérer (étanchéité).
- Les appareils sanitaires en bon état trouvent facilement preneur. Revente possible si dans un état presque neuf.

Figure 9: Excerpt from the contractor-oriented deconstruction guide illustrating material recovery scenarios, cost and labour considerations, and material-specific recommendations for contractors.

- *Bridging different priorities requires coordination*

  Industry actors typically focus on project-based solutions and immediate implementation constraints, while academic research tends to emphasise methodological rigor and broader analytical objectives. Addressing this difference requires a mediating function to support coordination and mutual understanding. This function may be embodied in different tools (agreements, coordination protocols, or dedicated roles).

- *Collaboration requires clearly defined contributions from partners*

  Industry stakeholders provide detailed operational data that reflect real construction practices, while academic researchers adapt their analytical models to these conditions. Contractors contributed with data on construction processes, timelines, and feasibility constraints, informing assessments. For example, differences in labour time between demolition and material recovery were critical to parameterise LCCA calculations. Academic models were adjusted accordingly, including variations in labour time, material recovery feasibility, and process limitations. This iterative adjustment highlights the need to align analytical models with real construction conditions.

- *Continuous feedback processes are critical*

  Early-stage testing and partial validation of model components proved more effective than late-stage reviews. Late-stage feedback increases complexity and reduces efficiency. Regular working sessions focused on specific components support incremental understanding of system boundaries, assumptions, and outputs. This approach improves validation and reduces the risk of late-stage revisions.

- *Developing contractor-oriented outputs requires involving their intended users*

  Implementation depends not only on analytical robustness but also on how outputs are organised and presented. Contractor feedback informed the guide's structure, content, and format, aligning results with practical expectations. The results were synthesised into a practitioner-oriented guide combining quantitative outputs with implementation guidance for real renovation contexts.

4.2 POLICY IMPLICATIONS

As demonstrated in the results, this study is relevant to existing policy frameworks at the provincial and municipal levels in Quebec, including the Circular Economy Roadmap 2024–2028 (Gouvernement du Québec 2025) and the Priority Action Plan for the CRD sector 2024–2026 (RECYC-QUÉBEC 2024). Both of which identify material reuse and responsible procurement as priority actions for the construction industry. The involvement of APCHQ and Société d'habitation du Québec as partners in this research reflects the growing regulatory and market pressure on contractors to reduce embodied carbon and improve material recovery rates.

The study demonstrates that contractors adopting reuse strategies consistent with existing policy directions can achieve measurable environmental and economic benefits within current Montreal market conditions. The contractor-oriented deconstruction guide developed through this collaboration provides an operational tool that translates policy objectives into project-level guidance, bridging the gap between regulatory framework and reuse practices.

4.3 LIMITATIONS AND FUTURE WORK

The temporal boundary is not the same for the LCA and LCCA, which can create some inconsistency in the temporal frame. The LCA adopts a cradle-to-cradle scope, incorporating avoided burden credits that assume future beneficial use of recovered materials across multiple life-cycles. The LCCA, however, is framed by a single renovation timeframe, consistent with contractor decision-making horizons. While this approach ensures consistency with real-world decision-making and enhances the practical relevance of the guide, it limits the ability to capture long-term environmental and economic impacts across the full life-cycle. Therefore, cumulative benefits and

trade-offs across multiple replacement cycles are not fully captured. This limitation is evident in elements with short service lives, such as finishes (*e.g.* paint), which require repeated replacement but are considered only once within the contractor-oriented scope.

The assumptions related to reuse, resale, and material recovery were informed by existing secondary material markets in Montreal. These markets remain relatively small and fragmented, with limited availability and inconsistent supply for certain materials. Occasionally, limited suppliers required the use of available prices as reference points. Accordingly, the absence of standardised pricing and established supply chains introduces variability in the data. The empirical basis of the study is also limited to a small number of cases and collaborators, which may not capture the full diversity of practices. Accordingly, the results should be interpreted as context-specific approximations of current market conditions.

Addressing these limitations opens several directions for future research and practical development. Future work should explore extended LCCA temporal modelling (*e.g.* 60–100 years) using the same boundary conditions as the LCA, to enable a fully consistent cradle-to-cradle economic assessment. This also raises questions on responsibility and value distribution, suggesting alternative models such as service-based or leasing approaches. Further work should include validation through real renovation projects and expansion to other contexts and typologies. From a practical perspective, future work should advance toward more detailed, material-specific protocols for disassembly and reuse, moving toward a technical manual or catalogue. This requires systematic on-site documentation, including procedures, visual records, and guidance for handling reused components.

5. CONCLUSIONS

The study demonstrates how life-cycle assessment (LCA) and life-cycle cost assessment (LCCA) can be grounded in real renovation contexts and translated into contractor-oriented deconstruction guidelines through academia–industry collaboration. It aligned analytical methods with construction practices using real-world data on labour, material recovery, and feasibility constraints. It also highlighted challenges, including differing priorities between actors and the need for continuous feedback.

Quantitative results indicate that reuse strategies can reduce significant greenhouse gases (GHG) emissions and costs in both case studies. The single-detached house in S3 (reuse scenario) reduced GHG emissions by over 100% (due to credits) and costs by 19% compared with S1. While the triplex achieved 39% and costs by 6% in S3. Although selective deconstruction (SD) increases labour and upfront costs, these are offset by savings in material procurement, shifting cost across phases.

Translating analytical results into contractor-oriented tools is critical for implementation. The guide shows that environmental and economic assessments can support on-site decision-making and help bridge the gap between analytical models and construction practice. Some pioneering contractors already demonstrate the feasibility of reuse practices; however, challenges remain, including higher upfront costs, logistical complexity, and limited training, guidance, and client demand. Contractors can help initiate this transition, but broader systemic conditions must evolve to enable scaling. This includes the development of more structured secondary material markets, policy support (*e.g.* incentives and regulation), and sectoral capacity building. This also involves integrating reuse into upstream practices such as specification, procurement, and design for disassembly.

In S3, economic benefits are realised primarily in material procurement and installation, as selective deconstruction increased the project cost due to additional labour for SD. Hence, currently this is a major resistance factor, as SD is seen as much costlier and riskier than demolition. In circularity, however, it is an essential step in order to leverage economic gain through material reuse. Environmental and economic trade-offs are central to the implementation of circular renovation strategies. While S3 demonstrates clear benefits, these are not fully aligned with conventional decision-making frameworks. Capturing these environmental and economic benefits requires addressing how costs, risks, and benefits are distributed across actors and over time, including

defining frameworks that identify how savings generated by circular strategies are distributed across actors and under what conditions.

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AI DECLARATION

The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in the drafting, analysis, or preparation of this manuscript.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA ACCESSIBILITY

Data are available from the authors upon reasonable request.

ETHICAL APPROVAL

In accordance with Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2) Article 2.1, no ethics approval was required for this research as interviewees were personnel authorised to release information about their organizational processes and procedures. Hence, the authors did not need ethics approval as the questions asked did not ask for the interviewees' opinions on those processes and procedures. Such individuals are not considered participants for the purposes of the TCPS 2 Policy (Canadian Institutes of Health Research *et al.* 2022).

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SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at: https://doi.org/10.5334/bc.841.s1

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