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AN EVALUATION MODEL FOR DEMOLITION WASTE IN THE RESIDENTIAL CONTEXT

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Abstract:

The waste generated during the demolition of residential homes consumes large volumes of limited space in municipal landfills. Unreserved disposal of demolition materials into landfills can be minimized through more methodical deconstruction methods. Sorted materials can then be reused or recycled whereas unsorted material can only be sent to a landfill. To create an incentive for individuals and companies to spend the additional time and money to sort waste, policies must be created by regional municipality. In Calgary for example, the incentive to approach demolition with an emphasis on future use of material is seen in the form of varying disposal rates; higher rate reserved for unsorted material and lower rates for materials that can be recycled. To understand how these different disposal rates affect the total demolition project cost for a typical Calgary home, the model and approach presented herein investigates the relationship between cost savings at disposal and labour investment during demolition. The ultimate goal of this study is to define a model to evaluate the substantial merit for tipping fees and waste management policies in terms of encouraging deconstruction in residential homes.

1 INTRODUCTION

To reduce the amount of waste created during the demolition process, the City of Calgary has introduced several initiatives to create incentives for individuals and companies to divert construction and demolition waste from traditional solid waste streams. The predominant method for reducing the amount of waste entering landfills is to recycle or reuse the waste generated during the demolition of buildings. In order to reuse or recycle materials, buildings need to be demolished in a fashion that facilitates source segregation of materials, allowing for future use. The method of demolition (selective vs conventional) is the predominant factor dictating how much material can be diverted from landfill. Neglecting salvage values and tipping fees, conventional demolition is typically the preferred method due to the high labour requirements inherent to selective demolition. However, the high tipping fees associated with mixed waste and the salvage value that recovered materials command have a profound effect on total demolition project costs.

1.1 The Conventional demolition

Conventional demolition is a preferred method for projects that have constrained timeframes, as the overall process of removing a home using primarily mechanical means takes very little time compared to deconstruction. Pun, Liu and Langston (2005) identify conventional demolition as mechanical demolition relying on equipment such as excavators and bulldozers to pull down a building. This method creates a heterogeneous stockpile of waste destined for a landfill, with very little material being reused or recycled. The reduced labour requirement greatly reduces the initial cost of demolition, but produces mixed waste that command a high tipping fee in comparison to segregated waste.

1.2 The Selective Demolition (Deconstruction)

Deconstruction is described as selective dismantling, or “a first in, last out process where components in a building assembly are removed in the opposite order they were installed” (Dantata, Touran, & Wang, 2004). Materials must be reused or recycled in order to remove them from the solid waste stream at the end of a buildings service life. Reused items retain some resale value but require a high degree of care when removing from the assembly. Examples of items that can be reused include fixtures (electrical or plumbing), aesthetic wood products (such as moldings or banisters), flooring and electrical equipment. The resale value of these items are highly variable as their value will be dependent on the condition and relative demand of the material. The International Panel on Climate Change (IPCC) broadly defines recycling as the recovery of materials (typically paper, plastics, glass, metals and plastics, sometimes wood and food waste) from the waste stream (IPCC, 2006). Reddy (2011) identifies the benefits of recycling as reducing the reliance on virgin materials, reducing pollution, reducing energy consumption, mitigating climate change and reducing the pressures on biodiversity. Recycling is essentially the reduction of a product into its base material which can be reprocessed into a usable item. Examples of items which can be recycled from a residential home include asphalt shingles, metal and plastic items, wood products, electrical cable and concrete. Deconstruction requires greater labour effort at the onset of the project to ensure that materials recovered retain high value, allowing for future use (Pun, Liu, & Langston, 2005). The attention to detail and the added steps associated with deconstruction contribute to a high up front cost; however, several other factors must be considered when employing selective demolition, as outline below:

- **Increased Planning** to safely and effectively deconstruct a building. The planning will be required to identify the safest way to sequence removal of building components. The planning will also be needed to identify which components will retain salvage value when reused and which items are limited to recycle or waste applications.
- **Larger Laydown** to allow for onsite sorting. For urban conditions the size of the available laydown may present a considerable challenge.
- **Greater Labour Skill** compared to conventional demolition. Labour involved in deconstruction will need to have relevant training to ensure that the goals of the project are maintained. Materials need to be disassembled in a correct order.
- **Increased Direct Supervision** to ensure that loads leaving site meet regulatory requirements for sorted material disposal rates.
- **Increased Transportation Costs** due to multiple material types transported separately or semi separately (Multiple bins on a single load).

Deconstruction can be broken up into four major stages: stripping interior components (doors, appliances and plumbing accessories), disassemble walls (remove sheathing, insulation, piping and wires), deconstruct roof and finally the removal of walls and floors (California EPA, 2001).

1.3 Current Municipal Policy

The City of Calgary has created specific policies to promote the more methodical and labour intensive practice of deconstruction. At municipal landfills in Calgary, there exists a tiered system for disposal rates; higher rates for mixed material destined for landfills and lower rates for sorted material that can be diverted from the solid waste stream (City of Calgary, 2016a). This system of categorized rates should make deconstruction a financially viable demolition method by leveling the difference in labour and disposal costs.

In 2015 the city of Calgary revised its 80/20 policy to the diversion of 70% of waste destined for landfill by 2025 (originally calling for 80% diversion by 2020). This reduction comes from the four sectors of waste producers: single family homes, multifamily homes, commercial, and construction/demolition (The City of Calgary, 2016b). To achieve this the City is relying primarily on the reuse/recycling of waste, rather than the reduction of waste production. Calgary, like other municipalities, experiences a large portion of waste entering the landfill system coming from construction and demolition activities. The City estimates that 20% of waste entering landfills comes from construction, demolition and renovation projects; and of this 20%, 31% is recyclable wood, 14% is drywall, 5% is asphalt shingles, 8% is other roofing materials, and 42% is other materials. (The City of Calgary, 2011).

In order to meet the waste reduction targets identified, the City of Calgary introduced a three-pronged approach consisting of economic incentives & disincentives, regulatory requirements and voluntary measures (The City of Calgary, 2011). The economic disincentive for dumping mixed loads is seen in the higher rates for designated material disposal at landfills - $170/tonne of mixed waste compared to $80/tonne of segregated construction waste and $113 for basic sanitary waste (The City of Calgary, 2016a). These materials are highly recyclable and common in conventional construction. The City of Calgary has the following materials classified as designated materials: Concrete (Whole or Crushed); Brick and Masonry Block (Whole or Crushed); Asphalt; Recyclable Wood; Drywall; Paper and Cardboard.

The purpose of this study is to quantify the relationship of total demolition project costs to gross floor area (GFA) of a residential home for both demolition methods, with the specific goal of determining if the current disposal rates stipulated by the City of Calgary promote selective demolition.

2 THE SCOPE

To measure the effectiveness of The City of Calgary's current waste diversion policy of tiered disposal rates, this study focuses on conventionally built single family residential buildings. Conventionally built refers to asbestos-free platform framed construction with 24" stud and joist spacing using modern building materials and codes; typical to that of homes built within the past few decades. The materials identified throughout this study were based on the materials typically used in residential home construction in the past 30 years. Multifamily residences such as town homes and condominiums were not included due to the changes in productivity and equipment requirements when demolishing attached buildings or greater than 2 story heights. Landscaping and earthworks were not considered as the change in lot size and end use will have a considerable impact on labour and disposal costs. Still, this should have minimal impact on the validity of this study as the increase in cost associated with earthworks will be similar in selective and conventional methods. Furthermore, the cost to transport the waste was neglected as each demolition method produced the same amount of waste and used the same waste operator. The selective method could result in slightly higher transport costs due to the separate loads required for each material; however, this increase in cost should be negligible compared to the total project costs. The developed functions and models can be used to determine the relationship of total project costs to GFA for buildings of different types of construction. The functions produced in this study to describe material quantities, material waste disposal fees, labour costs and total project demolition costs are applicable to conventionally built 2-story single family detached homes with GFAs between 150 m^2 and 250 m^2. Methods of demolition were limited to conventional demolition and selective demolition (deconstruction). There were no provisions made for hybrid techniques; referring to a demolition method including varying levels of conventional and selective demolition. Hybrid deconstruction can combine the benefits of the selective (reduced disposal fees) and conventional (low labour requirements) demolition in different assemblies of a home to minimize the total demolition project cost; thus optimizing benefit. Finally, labour rates were adjusted to the Calgary market; and current disposal rates stipulated by the City of Calgary and local waste handlers were used. Therefore, the results of the analysis presented in this report are valid only in the Calgary and must be adjusted to accurately reflect the current market and policies in other regions.

3 THE METHODOLOGY

A quantity takeoff was carried out on a complete set of construction drawings for a 186 m^2 Calgary home. The takeoff considered structural elements (exterior/bearing walls and floor systems); functional architectural systems (interior partitions); and building envelope materials (insulation and weather barriers). Utilities including electrical, HVAC, and plumbing were neglected due to the high metal content of these components. Due to the high salvage value as well as ease of extraction of the utility components, it was assumed that these materials would be removed for salvage prior to demolition in both selective and conventional methods. Architectural finishes such as trim and floor finishes were also neglected due to the high variability in unit weights among finishes.

The performed takeoff produced a building inventory that was used as a baseline for a typical 186 m^2 home. This building inventory was then extrapolated in order to describe the quantity of material in terms of GFA in homes with a GFA between 150 m^2 and 250 m^2, based on the rate that each material quantity increases with respect to GFA.

Cost functions to describe labour costs and disposal fees in selective and conventional demolition methods were then developed by applying labour rates and productivities to material quantity functions; and by applying material unit weights and disposal fees to material quantity functions. All labour rates and productivities were obtained from RS Means Building Construction Cost Data (2016), and material unit weights were obtained from various sources specified in the analysis section. Waste disposal fees were obtained from the City of Calgary (2016a) and Fish Creek Excavating (2016).

The total cost for each method was then determined by summing the labour costs and disposal fees for each method. This ultimately allowed for a comparison to be made on total demolition project costs based on GFA between 150 m^2 and 250 m^2 for selective and conventional demolition methods.

4 THE RESULTS

Quantity takeoff was performed on the structural, architectural and envelope components of the sample 186 m^2 home, neglecting all utilities as well as interior finishes. Considering the foundation, exterior and interior wall assemblies as well as flooring and roofing systems, the house yielded a total disposal weight of about 130 tonnes. The quantities taken off from the housing plans can be found in Table 1.0, and a complete breakdown of assemblies and material quantities can be found in Table 1.1.

Table 1.0: Takeoff Quantities by Level

Basement	Main Floor	Second Floor
Found. Wall (Basement) = 40.8 m Found. Wall (Garage) = 20.7 m	Ext. Wall = 40.2 m Garage Ext. Wall = 20.7 m	Ext. Wall = 47 m
# Conc. Pads (Basement) = 3 # Cont. Pads (Garage) = 5	Int. Bearing Walls = 6.7 m Arch. Walls = 21.5 m	Int. Plumbing Walls = 3.0 m Arch. Walls = 46.2 m
Slab (Basement) = 87.7 m2 Slab (Garage) = 43.1 m2	Floor Area = 87.7 m2	Floor Area = 110.7 m2

The sample home yielded a building inventory consisting of:

- Cast-in-Place Concrete – 100.09 tonnes
  - Rebar – 4.0 tonnes
  - Concrete – 96.08 tonnes
- Dimensional Lumber – 5.33 tonnes
  - 2x4 lumber – 2.36 tonnes
  - 2x6 lumber – 2.96 tonnes
- Plastics – 0.66 tonnes
  - Vinyl Siding – 0.47 tonnes
  - Vapour Barrier – 0.18 tonnes

- Wood Products – 6.16 tonnes
- Asphalt Shingles – 1.53 tonnes
- Gypsum Board – 7.49 tonnes
- Fiberglass Insulation – 3.99 tonnes

Table 1.1: Breakdown of material weights by assembly

Type of Assembly	Material	Material Class	Takeoff Quantity	Volume (m^3)	Weight (tonnes)
Foundation	Concrete	Concrete	41.57 m^3	41.57	100.09
	Rebar	Steel	*Included in Concrete		4.00
Exterior Walls	2x6 lumber	Wood	992.43 m	5.28	2.96
	OSB Sheathing	Eng. Wood	288.56 m^2	2.75	1.76
	Insulation	Fiberglass	234.49 m^2	32.75	3.68
	Vapour Barrier	Plastic	288.56 m^2	-	0.14
	Vinyl Siding	Plastic	288.56 m^2	-	0.47
Interior Walls	2x4 lumber	Wood	217.76 m^2	2.42	1.35
	Drywall	Gypsum	567.92 m^2	7.21	5.55
Floors	TJI Joists	Eng. Wood	477.32 m	1.89	1.21
	OSB Sheathing	Eng. Wood	116.13 m^2	1.11	0.71
Roof	Shingles	Asphalt	116.13 m^2	-	1.53
	Trusses	Wood	160.72 m^2	1.79	1.00
	Insulation	Fiberglass	28.32 m^3	35.40	0.31
				TOTAL	129.27

The foundation considered a concrete density of 2400 kg/m^3, or 150 lb/ft^3 (McGraw-Hill, 2012) and a steel content (rebar) of 4% by weight. Walls considered 24” stud spacing plus 2 studs per corner with a density of 560 kg/m^3 for dimensional lumber (Engineers Edge, 2016). OBS sheathing quantities were based on the area of exterior wall with a density of 640 kg/m^3 for engineered wood (European Panel Federation, n.d.), while drywall was based on the area of both faces of interior wall with a density of 770 kg/m^3 (American Gypsum, 2010). Exterior walls also considered vapour barrier, building paper, and siding based on the area of exterior wall, with densities of 0.4555 kg/m^2 (3M, 2014), 0.183 kg/m^2 (University of Waterloo, 2001), and 1.95 kg/m^2 (NIST, 2007) respectively; as well as R20 fiberglass BATT insulation between wall studs with a density of 112 kg/m^3 (NIST 2007). Floors considered I-Joists spaced at 24” with a density of 580 kg/m^3 based on the densities of dimensional lumber and wood, as well as the area of web and flange within a 30cm deep cross section (BOCA International, 2002). OSB sheathing and drywall quantities were based on total area of floor. Roof covering material (OSB and shingles) were based on half the total floor area (considering a 2-story home) multiplied by a factor of 1.25 to consider roof slope, with a shingle density of 13.2 kg/m^2 (The Engineering Toolbox, n.d.). Trusses considered 27.4 m of 2x4 dimensional lumber for each 8-m span Pratt truss spaced at 60cm, and attic insulation considered 38cm of blown in fiberglass with a density of 8.81 kg/m^3 (NIST, 2007). A complete breakdown of the building inventory can be found in Table 1.1

5 THE ANALYSIS

Based on the quantities of material in each wall assembly, as well as the rate at which each assembly quantity increases with respect to floor area, functions were developed to describe the quantity of material in a home with a similar floor plan based on GFA in the domain of $\{x \in R \mid 150 \leq x \leq 250\}$. This domain was selected based on the 186 m^2 floor area and considering that layout and floor plan will change significantly as floor area increases or decreases. Relations of material to floor area can be found in below. Note that a relation to perimeter represents a proportionality to $\sqrt{A}$.

Basement Slab; Floors Systems; Roof System $\propto$ ***Area***
Foundation Walls; Exterior &Interior Wall Assemblies $\propto$ ***Perimeter***

5.1 Quantity of Material Based on Gross Floor Area

Using the quantities of materials in Table 2.1 and the relationships of material increase per assembly described above, the functions to describe the quantity of material per unit floor area in m^2: were developed. Total length in m, area measured in m^2, and volume in m^3. were then applied to every type of material identified in Table 2.1 and labour rates to obtain the total demolition costs of selective and conventional demolitions.

5.2 Material Weights Based on Gross Floor Area

The total weight of each material was found by applying material cross sections and thicknesses to quantities measured per unit area and length respectively, then applying material densities; and by applying material densities to quantities measured per unit volume. The weight of each material was then generated in the building inventory in tonnes.

5.3 Material Disposal Costs

The City of Calgary (2016a) and Fish Creek Excavating (2016) stipulate disposal costs for mixed and segregated waste as outlined in Table 2.0 The segregated waste produced in the selective demolition method will be disposed of at the rate of each respective material, while the waste produced in the conventional demolition method will be disposed of at the rate of $170/tonne for designated materials.

Table 2.0 – Waste Disposal Rates

Cost/tonne	Type of Waste
$0[1]	Hardened Concrete (concrete, rebar)
$80[2]	Sorted C&D Waste (Asphalt Roofing, Drywall, Wood)
$113[2]	Sanitary Waste (Insulation, Building Paper, Vapour Barrier, Siding)
$170[2]	Designated Materials

[1]Disposal Rate of Fish Creek Excavating

[2]Disposal Rate of the City of Calgary

Note that the City of Calgary accepts concrete waste, however, it must be in small pieces free of rebar and commands a disposal rate of $0 – $5/tonne. Fish Creek was selected as the concrete waste handler as they accept reinforced or unreinforced hardened concrete free of charge.

5.3.1 Segregated Waste Disposal Cost

Concrete and rebar will be disposed of at the rate of $0/tonne for clean fill; asphalt roofing material, drywall, and wood will be disposed of at the rate of $80/tonne for sorted construction and demolition waste; and insulation, building paper, vapour barrier and vinyl siding will be disposed of at the rate of $113/tonne for sanitary waste.

$$\begin{aligned}\text{Disposal}_{\text{Segregated}} &= (W_C + W_R)*(0) + (W_{AR} + W_{DW} + W_{DL} + W_{OSB} + W_{IJ})*(80) + (W_I + W_{EM} + W_s)*(113) \\ &= 4.008548387A + 105.03233\sqrt{A}\end{aligned}$$

Note that the various W_i represent the material weights based on gross floor area as discussed in 5.2

5.3.2 Mixed Waste Disposal Cost

The mixed produced in the conventional demolition method will be disposed of at a rate of $170/tonne for designated materials. It should be noted that in the demolition sequence typically calls for the demolition of the superstructure followed by the substructure; allowing for the segregation of superstructure materials from substructure materials. For the sake of simplicity, segregation of material by demolition phase was neglected in the conventional demolition method. The waste disposal as a function of the gross floor area is shown below.

$$\text{Disposal}_{Mixed} = (W_C + W_R + W_{DW} + W_{DL} + W_{OSB} + W_{IJ} + W_{EM} + W_I + W_S)*(170)$$
$$=32.74129032A + 1113.597864\sqrt{A}$$

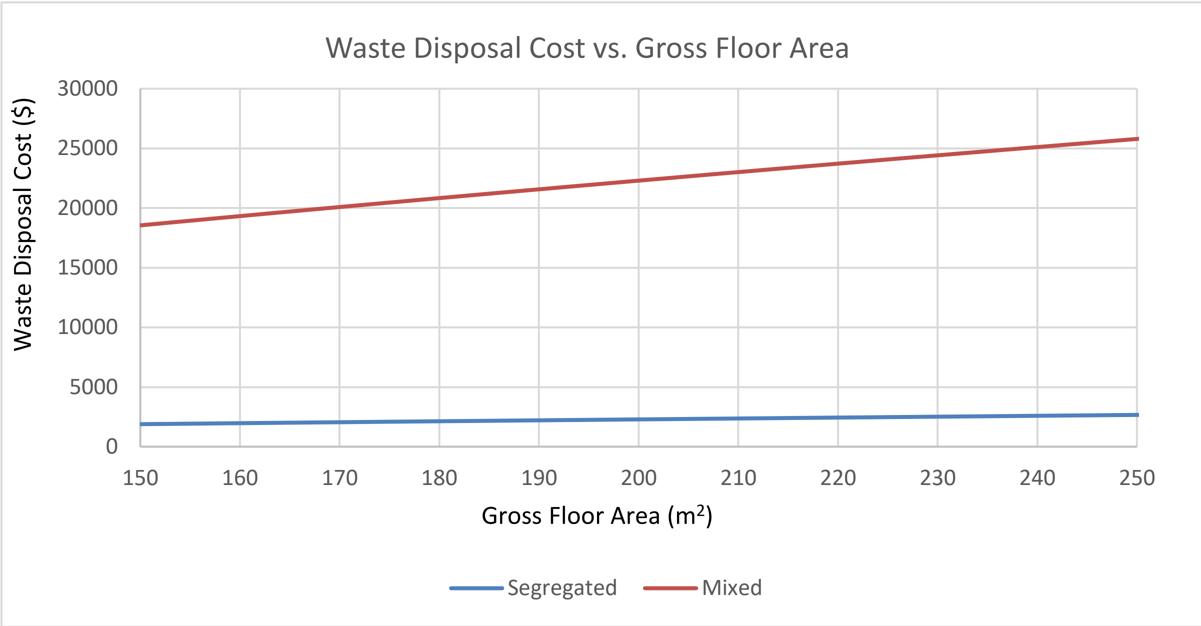

Figure 3.0 – Gross Floor Area vs. Waste Disposal Costs

5.4 Labour Time based on Gross Floor Area

The total time to remove the total building stock in both selective and conventional methods was found by applying labour productivities to material quantities. The labour productivities were provided by RSMeans Building Construction Cost Data (2016); the functions relating the time required to remove each material in the selective method in days were tabulated. The analysis considered a labour productivity of 0.67 home/day for a 232 m^2 per home. This was normalized to a gross area-based productivity of 156 m^2/day. The time in days required to demolish this entire sample home was then defined as a function of the gross area.

5.5 Labour Costs

The segregated waste produced in the selective method used labour rates of $303.20, $606.40, $1532.00, and $1759.60 for each respective assembly, while the mixed waste produced in the conventional method used the rate of $3345.20 for the entire building demolition. A multiplier of 1.048 was applied to labour to consider the Calgary Cost Index for demolition. RS Means (2016) stipulated crew sizes and daily costs for each assembly demolition as outlined below:

Table 3.1: Labour Rates by Assembly

Cost/day	Crew	Assembly Applied to
$303.20	1 Labourer	Dimensional Lumber; Drywall; Insulation; Envelope Material; OBS-Roof; Siding
$606.40	2 Labourers	OSB-Floors/Walls; I-Joists; Trusses
$1532.00	1 Labour Foreman, 4 Labourers	Asphalt Roofing
$1759.60	1 Labourer, 1-250 cfm Air Compressor, 2-1.5” 50’ Air Hoses, 2-60 lb Pavement Breakers	Concrete
$3345.20	1 Labour Foreman, 2 Laboureres, 1 Equipment Operator, 2 Truck Drivers	Whole Building

5.5.1 Selective Demolition Cost (Producing Segregated Waste)

$Labour_S = [(t_{DL} + t_{DW} + t_I + t_{EM} + t_{OSB\text{-}R} + t_S)(303.20)] + [(t_{OSB} + t_{IJ} + t_{Tr})(606.40)] + [(t_R)(\$1532.00)] + [(t_C)(\$1759.60)] * 1.048$

$= 58.414472272382A + 1005.9513149606\sqrt{A}$

5.5.2 Conventional Demolition (Producing Mixed Waste)

$Labour_C = (t_{whole})(3345.20) * 1.048$

$=22.528794881201A$

Figure 3.1 – Labour Cost vs Gross Floor Area

5.6 Total Project Cost

Total project cost for selective and conventional demolitions were determined by adding the material disposal costs and labour costs for each method. Total costs are illustrated in Figure 3.2.

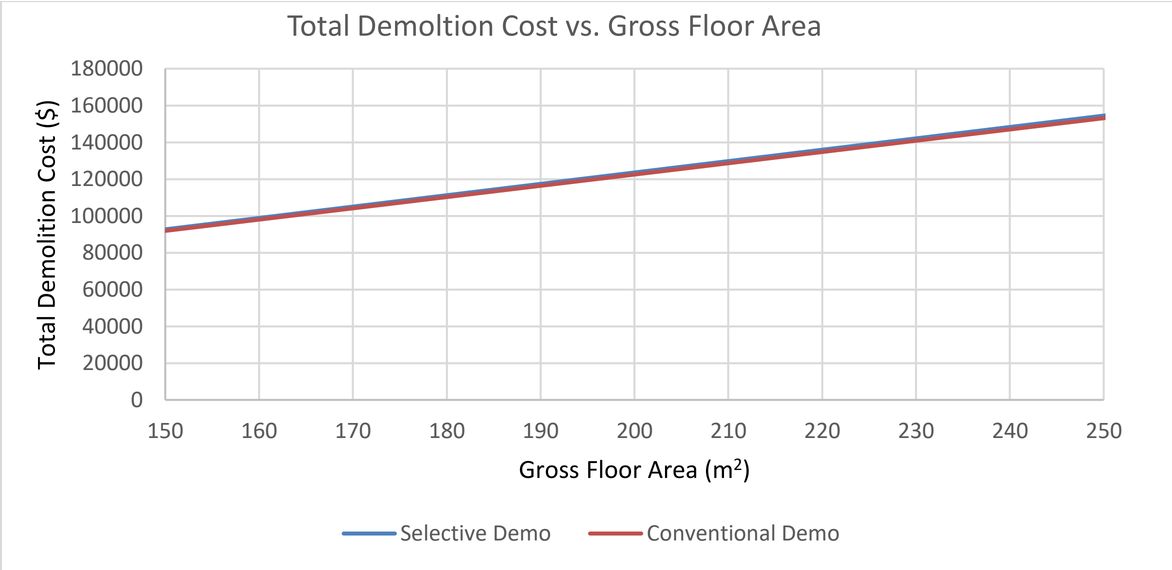

Figure 3.2 – Total Demolition Cost vs. Gross Floor Area

It is thereby noted that with current disposal rate policies, the total demolition costs for selective and conventional methods are shockingly similar for the 186 m^2 sample home. The analysis revealed a cost increase of about 5% for selective over conventional, however, this cost is more than made up for through the social and environmental benefits associated with deconstruction and material reuse

6 LIMITATIONS OF THE STUDY

The analysis successfully identified total project costs for selective and conventional demolitions based on gross floor area in the domain of $\{x \in R \mid 150 \leq x \leq 250\}$. The selection of this domain presents its own shortcomings as floor plan and layout change significantly as area changes. The conventional demolition considered demolition of the entire building producing mixed waste for the entire building. As mentioned earlier, the demolition sequence typically calls for demolition of the superstructure followed by demolition of the substructure, allowing for fragmented mixed waste production. In the case of fragmentation, the foundation material could be disposed of at the cost of $0 at Fish Creek Excavating, significantly lower the material disposal cost of waste produced in the conventional demolition. This idea was neglected, reducing the validity of the study. Labour rates were obtained from a single source to ensure consistency, however, due to availability of data, material unit weights were obtained from multiple sources. This inherently increases the error of the study as there is a reduced uniformity in the data source.

7 CONCLUSION

There is no doubt that selective demolition requires a greater effort than that of conventional. Considering the increased planning and labour skill required, it is not wonder that there is a reluctance to adopt the deconstruction methodology. However, due to the existing waste disposal policies stipulated by the City of Calgary, the financial burden of adopting a selective demolition approach are countered by the immense mixed waste disposal fees associated with conventional demolition.

With confidence, it can be concluded through this study that current City of Calgary policies are promoting selective demolition within the residential sector. This conclusion can be made based on overlaying Figures 3.0 **–** Gross Floor Area vs. Waste Disposal Costs and 3.1 **–** Gross Area vs. Labour Costs. These figures demonstrate that although there is a much higher labour cost to performing selective demolition then conventional, there is a corresponding significantly higher cost to dispose of mixed conventional waste as opposed to sorted selective demolition waste when applying current City of Calgary tipping fees. Based on the analysis it was found that selective demolition costs about 5% more than conventional demolition.

This slight cost increase can be considered negligible, and is more than made up for in the environmental and social benefits stemming from deconstruction. The practice of disassembly allows for reduced demand on raw materials, increased service lives of landfills, and preservation of embodied energy. Furthermore, deconstruction creates a salvage material market for extracted materials, and employs a more people of higher skill than conventional demolition. The adoption of a selective demolition also results in reduced dust and noise production compared to conventional practices. From this, it can be seen that although selective demolition costs slightly more than conventional, the benefits produced far outweigh the costs.

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