Life Cycle Analysis for the Walter H. Gage Residence

Civl 498c
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Abstract

The life cycle analysis (LCA) being carried out for this project is one of thirteen others that are being carried out at the same time for residential and academic buildings at the University of British Columbia (UBC). The purpose of this study is to determine the impacts associated with these buildings using the Athena Environmental Impact Estimator (EIE). The building assigned for this report is the Walter H. Gage Residence, a multi-unit residential rental building that is made up of three 17 floor towers and a one floor commons block linking the three towers.

Architectural and structural drawings were provided for Gage by the UBC Records Department to perform takeoffs for the EIE inputs. The EIE presented the impact assessment in the summary measures of the Gage building, which was then compared with other values obtained for the thirteen other buildings. The impact summary measures were further analysed through sensitivity analysis to figure out how changing the quantity of a material would affect the impacts. In addition, the energy performance model was completed based on the current and an improved version of the building to determine the energy payback period.

The results obtained from the findings were often difficult to quantify due to the many uncertainties associated with carrying out LCA. Uncertainties and assumptions inherent in this study are outlined within it and also contained in the EIE Assumption Document. One certain result from this project is that the use of LCA on will most definitely be an important tool to be used for the future for all buildings to come.

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1.0 Introduction

The building studied in this life cycle analysis (LCA) study is the Walter H. Gage Residence. Located in the heart of the University of British Columbia near the Student Union Building, the Student Recreation Center, and the bus loop. It serves as residence for undergraduate students all year round. It is also widely used for conference groups during the summer. The building is named after Dr. Walter Henry Gage, to honour his 50th year of service in 1971 at UBC. The original construction began in 1972 at a cost of $8 million, with an addition of an apartment block in 1984 at a cost of $6.5 million. The original construction called for three main 17 floor residential towers, which is the focus of this study. However, there is also a single commons block that connects the three residential towers, and the apartment block that was later built. Altogether, the building houses 1419 beds.

Figure 1.0 Walter H. Gage Residence

Gage is primarily made of cast in place concrete. Each typical floor contains 4 units. Each unit contains 6 private bedrooms, a shared living room, kitchen, and washroom. Table 1.0 lists the general characteristics of Gage residence. Once again, the LCA study of this building will be focused on the three towers; North, South and East.

Table 1.0 General Characteristics of Gage Residence

Building System	Specific Characteristics of Gage building tower
Structure	Concrete walls supporting concrete suspended slabs
Floors	Basement: Concrete slab on grade; First to Seventeenth (Typical) Floors: Suspended slabs with some acoustic battery insulation
Exterior Walls	Basement: Cast in place concrete walls with thin coat plaster on gypsum board on extruded polystyrene; Typical Floor: Concrete cast in place walls with and extruded polystyrene and gypsum board
Interior Walls	Basement: steel stud walls extruded polystyrene and gypsum board; Typical Floor: gypsum on steel stud walls with extruded polystyrene
Windows	All windows are standard glazed with aluminium framing
Roof	Main Roof: PVC Membrane Roofing System with extruded polystyrene
HVAC/heating	Steam from central power plant (CPP), natural gas-fired boiler

2.0 Goal of Study

The life cycle analysis being carried out for this project is part of a series of thirteen other projects being carried out together on residential and academic buildings of UBC that also follow the same goals and scopes of study. These LCA are being done as a study to determine the environmental impacts of these building designs with the Athena Impact Estimator software. For this article, the LCA will be done on the Walter H. Gage Residence.

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the Gage building. An exemplary application of these references are in the assessment of potential future performance upgrades to the structure and envelope of the Gage building. When this study is considered in conjunction with the twelve other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions. Furthermore, as demonstrated through these potential applications, this Gage building LCA can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects.

The intended core audience of this LCA study are those involved in building development related policy making at UBC, such as the Sustainability Office, who are involved in creating policies and frameworks for sustainable development on campus. Other potential audiences include developers, architects, engineers and building owners involved in design planning, as well as external organizations such as governments, private industry and other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations.

3.0 Scope of Study

The product system being studied in this LCA are the structure, envelope and operational energy usage associated with space conditioning of the Gage building on a square foot finished floor area of residential building basis. In order to focus on design related impacts, this LCA encompasses a cradle-to-gate scope that includes the raw material extraction, manufacturing of construction materials, and construction of the structure and envelope of the Gage building, as well as associated transportation effects throughout.

3.1 Tools, Methodology and Data

Two main software tools are to be utilized to complete this LCA study; OnCenter's OnScreen TakeOff and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

The study will first undertake the initial stage of a materials quantity takeoff, which involves performing linear, area and count measurements of the building's structure and envelope. To accomplish this, OnScreen TakeOff version 3.6.2.25 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in Annexes A and B respectively.

Using the formatted takeoff data, version 4.0.51 of the IE software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the Gage building in the Vancouver region as an residential building type. The IE software is designed to aid the building community in making more environmentally conscious material and design choices. The tool achieves this by applying a set of algorithms to the inputted takeoff data in order to complete the takeoff process and generate a bill of materials (BoM). This BoM then utilizes the Athena Life Cycle Inventory (LCI) Database, version 4.6, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results focus on the manufacturing and transportation of materials and their installation in to the initial structure and envelope assemblies. As this study is a cradle-to-gate assessment, the expected service life of the Walter Gage residence is set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building's life cycle being left outside the scope of assessment.

The IE then filters the LCA results through a set of characterization measures based on the mid-point impact assessment methodology developed by the US Environmental Protection Agency (US EPA), the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2. In order to generate a complete environmental impact profile for the Gage building, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

- Global warming potential

- Acidification potential
- Eutrophication potential
- Ozone depletion potential
- Photochemical smog potential
- Human health respiratory effects potential
- Weighted raw resource use
- Primary energy consumption

Using the summary measure results, a sensitivity analysis is then conducted in order to reveal the effect of material changes on the impact profile of the Gage building. Finally, using the UBC Residential Environmental Assessment Program (REAP) as a guide, this study then estimates the embodied energy involved in upgrading the insulation and window R-values to REAP standards and calculates the energy payback period of investing in a better performing envelope.

The primary sources of data for this LCA are the original architectural and structural drawings from when the Gage residence was initially constructed in 1972. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as the associated envelope and openings (ie. doors and windows) within each of these assemblies. The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, as well as to minimize the uncertainty of the model. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software in order to generate the bill of materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they energy in the Building Model section and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Annex B.

4.0 Building Model

As mentioned in the goals and scope, the two main tools to create the building model were Onscreen Takeoff and Athena Environmental Impact Estimator (IE). The process of creating the building model will be presented in further discussion in the next section.

4.1 Takeoffs

The use of Onscreen Takeoff has allowed takeoffs to be completed for this project at a much greater speed, ease and precision. Takeoffs done by hand through measurement of ruler are more prone to errors. One also must be careful with organization of measurements and data. On the other hand, with Onscreen Takeoff, this entire process is digitized. The primary feature being measurements can be achieved in quick and accurate manner. Much of the calculations involved with measurements such as area can also be done using Onscreen. In addition, Onscreen offers excellent way layering of takeoff views and organization of takeoffs.

The difficulties in creating the building model and performing the takeoffs, therefore, did not lie in the actual process itself, but the lack of information. Onscreen Takeoff relies on architectural and structural drawings to be completed. These drawings were obtained from the UBC Records Department. Unfortunately, the records department has no control over the quality of these drawings, or if all the drawings are intact. The contractors in charge of the building simply hand to the Records Department what drawings they have. It is often the case that many drawings are missing. This is especially the case for older buildings, as computers may not have existed at those times, where digital copies could not be pulled up from computer storage in case drawings are lost. Unfortunately, this was the case for this project, where entire details for the one floor commons block linking the three apartment towers were missing. Even for the towers itself, some key details and drawings were also missing. In addition to missing drawings, the quality of drawings are not up to par compared to the CAD drawings today. Drawings in the past were all done by hand, and sometimes blurry and difficult to read. In some cases, the drawings have been damaged. The following

Assumptions and calculation details of each assembly group will now be outlined below. These values are then plugged into Athena EIE for impact assessment. Unfortunately, further assumptions may be required due to limitation of the impact estimator software. For example, there are boundary limits for certain input parameters for assemblies. These will are mentioned in detail below:

4.2 Foundations

The foundation assembly group consists of footings, slab on grades, and stairs. Slab on grade(SOGs) were modelled as area conditions in takeoffs due to length, width, and thickness input requirements in the IE. Concrete footings were all modelled as area conditions. For the case of Gage building, pad footings dominated while there were only a few column footings. Column footings were modelled as area conditions due to minimal numbers. Footing thicknesses were limited to between 7.5” and 19.7” thick. Many footings exceeded these boundaries, so the lengths and widths were increased accordingly while maintaining the same volume of footing. The footings and SOGs can be all found in 869-07-002 structural drawing. Stairs were modelled as footings for this project because the IE currently does not have a staircase assembly profile. Stairs were modelled as an area condition based on dimensions within structural drawings 869-07-003 and 869-07-004.

4.3 Walls

Wall assemblies consist of all the walls found within the building. Gage has many rooms and lacks any large rooms, thus reinforced walls supplement the use of columns. Wall classification can be divided up into three major categories: basement(869-06-006), typical (869-06-008), and roof(869-07-007). A ground floor did exist, but it was nearly identical to the typical floor plan with the exception of a lounge room. Therefore, the ground floor was simply modelled as a typical floor. All walls were modelled as linear conditions in takeoffs, where their lengths were measured. Separate count conditions for windows and doors were done with drawings 869-06-011 and 869-06-008 respectively. Envelope and opening details were found in wall detail drawings. Certain assumptions were made regarding envelope and opening details due to their missing details in the drawings. Wall thicknesses were also another assumption made, as EIE only allowed for 8” and 12” thickness walls. Interior steel stud walls were also assumed to be light gauge (25 Ga) with no sheathing.

4.4 Floors

The floors were measured using area conditions. Much like in column and beams, the IE calculated the thickness of the material based on some basic variables regarding the assembly. These include; floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 75psf, as well as setting the concrete strength 4,000 psi, instead of the specified 3,500psi. This was due to the IE’s limitation to model only 3,000, 4,000 or 9,000psi concrete strengths.

4.5 Beams and Columns

Gage Residence has no large open spaced rooms, and thus no columns were found in the tower designs. The building is made up of multi-bedroom units, with all the supports coming from the many room walls. Beams were found in only the first floor in very minimal numbers, but were not modeled due to a lack of beam detail drawings. Missing reflected ceiling drawings for all floors except ground further made beams difficult. Access to the building was completed at the author’s discretion but was limited due to the privacy of the building. It was found no beams could be seen the floors above in the central elevator space of a typical floor.

4.6 Roof

For the roof envelope, the area condition was used to model it. Two roofs, one main roof on the top floor, and a smaller roof located on the top of the floor that houses the elevator room. Both roofs were assumed to be using a PVC membrane roofing system with extrude polystyrene insulation, as roof details could not be found. This assumption is based on a model developed by Athena for a False Creek project, named BC_Typical_MURB.

4.7 Extra Basic Materials

The only ceiling drawings available were for the ground floor which used some cedar planking. Fortunately, ceiling materials remained static for the typical floors and was similar to the ground floor, with the exception of some cedar planking use. Some cedar planking was used in the ground floor. Basement floor was inaccessible, and thus also assumed to be the same as a typical ceiling.

5.0 Bill of Materials

The bill of materials for the Gage building is presented below. As mentioned before, only the towers of Gage were modelled. Fortunately, based on the structural and architectural drawings, it was found the three towers were identical. The bill of materials in Table 2.0 represents one apartment tower in Gage.

Table 2.0 Bill of Materials for North Gage Tower

Material	Quantity	Unit
1/2" Regular Gypsum Board	10086.3468	m2
5/8" Regular Gypsum Board	11444.3355	m2
6 mil Polyethylene	622.8647	m2
Aluminium	47.3902	Tonnes
Ballast (aggregate stone)	38471.056	Kg
Batt. Fiberglass	21215.0845	m2 (25mm)
Concrete 20 MPa (flyash 25%)	881.506	m3
Concrete 30 MPa (flyash 25%)	2058.0873	m3
Concrete 60 MPa (flyash 25%)	1860.9576	m3
EPDM membrane	1871.8841	Kg
Expanded Polystyrene	6.51	m2 (25mm)
Extruded Polystyrene	12467.5186	m2 (25mm)
Galvanized Sheet	0.3264	Tonnes
Galvanized Studs	22.7389	Tonnes
Joint Compound	21.488	Tonnes
Nails	4.1939	Tonnes
Paper Tape	0.2466	Tonnes
PVC membrane	3081.959	Kg
Rebar, Rod, Light Sections	142.9753	Tonnes
Screws Nuts & Bolts	1.489	Tonnes
Small Dimension Softwood Lumber, kiln-dried	12.5751	m3
Softwood Plywood	8088.7686	m2 (9mm)
Solvent Based Alkyd Paint	0.5896	L
Standard Glazing	2494.1845	m2
Stucco over porous surface	71.7397	m2
Water Based Latex Paint	537.3111	L
Welded Wire Mesh / Ladder Wire	0.5043	Tonnes

Table 3.0 below presents the bill of material for all three Gage Towers combined.

Table 3.0 Bill of Materials for All Gage Towers

Material	Quantity	Unit
1/2" Regular Gypsum Board	30259.0404	m2
5/8" Regular Gypsum Board	34333.0064	m2
6 mil Polyethylene	1868.5941	m2
Aluminium	142.1706	Tonnes
Ballast (aggregate stone)	115413.1679	Kg
Batt. Fiberglass	63645.2535	m2 (25mm)
Concrete 20 MPa (flyash 25%)	2644.5179	m3
Concrete 30 MPa (flyash 25%)	6174.262	m3
Concrete 60 MPa (flyash 25%)	5582.8729	m3
EPDM membrane	5615.6523	Kg
Expanded Polystyrene	19.53	m2 (25mm)
Extruded Polystyrene	37402.5558	m2 (25mm)
Galvanized Sheet	0.9793	Tonnes
Galvanized Studs	68.2167	Tonnes
Joint Compound	64.464	Tonnes
Nails	12.5818	Tonnes
Paper Tape	0.7399	Tonnes
PVC membrane	9245.8771	Kg
Rebar, Rod, Light Sections	428.926	Tonnes
Screws Nuts & Bolts	4.4671	Tonnes
Small Dimension Softwood Lumber, kiln-dried	37.7253	m3
Softwood Plywood	24266.3057	m2 (9mm)
Solvent Based Alkyd Paint	1.7687	L
Standard Glazing	7482.5535	m2
Stucco over porous surface	143.4795	m2
Water Based Latex Paint	1611.9333	L
Welded Wire Mesh / Ladder Wire	1.5128	Tonnes

The largest amount of material used in all three Gage towers was concrete. Concrete forms the basis of the entire framework structures of the towers. Unfortunately, for such a key component, specifications such as strength are unknown had to be assumed. Assumptions made can be seen in Appendix A, where the value to the right of a dash indicates that an assumption was made. These assumption are outlined in Appendix B. The assumption of the concrete specifications are crucial to such a large building. Designing tall skyscrapers inevitably calls for different concrete strengths. Inaccurate assumption will lead to an inaccurate LCA of the actual building. An overestimation would lead to a building that is built on unnecessary high strength concrete, and an underestimation would lead to a building that would be physically impossible. Thus, an accurate estimation would not only lead to an accurate portrayal of the building but also a proper LCA, as strength of concrete has much greater environmental impacts as strength increases. To be safe, the 60 MPa concrete was assumed and accounted for 40% of the towers concrete. This was also to account for the lack of strength options, as the only option below 60MPa was 30MPa.

The extruded polystyrene was the assumed insulation material. There was no wall details page to use in identifying what “insulation” was defined to be in the wall detail drawings (869-06-017 and 869-06-018). Although the dimensions were given, the specific thermal resistance of different insulation are very different. This would severely affect the building model and the building performance analysis being performed in later sections.

6.0 Summary Measures

The summary measures produced by the IE are shown in Table 4.0 by life cycle stages and Table 5.0 by assembly groups.

The impact categories used in this study are identified as follows:

- Primary Energy Consumption
- Weighted Resource Use
- Global Warming Potential
- Acidification Potential
- HH Respiratory Effects Potential
- Eutrophication Potential
- Ozone Depletion Potential
- Smog Potential

Primary energy consumption includes direct and indirect energy used to manufcture or transport raw materials into a building. Indirect energies, such as transportation, delivering of fuel and energy is also considered in the IE.

Weighted resource use is the use of raw resources to make a building or associated products. Different raw resources carry different weights depending on relative effects of different resource extraction activities. Scores are given based on these activities relative to each other through an expert panel ranking.

Global warming potential is measured based on CO_2 weight equivalence. CO_2 has been commonly associated as the standard for greenhouse gas effects, and therefore it is used to set the reference for the comparison of other emissions to air. GHG emissions are based on a CO_2 equivalence, which represents their ability to insulate the radiative effects of the sun.

Acidification potential is measured similarly to global warming potential, based on H^+ equivalence on mass basis for air and water emissions.

Human health respiratory effect potential is based on particulate matter that is harmful to human health, specifically PM_{10} and $PM_{2.5}$. Possible effects include damage to the human respiratory system resulting in asthma, bronchitis, etc.

Eutrophication potential is caused by an abundance of nutrients being suddenly introduced to a body of water that was previously lacking these nutrients. This causes proliferation of aquatic photosynthetic plant life, which may affect the current system in the water. Eutrophication is expressed based on a nitrogen equivalence basis.

Ozone depletion is the result of emissions of substances that cause the reduction of the ozone layer in the Earth’s atmosphere, for example, CFCs, and halons. The reference standard of CFC-11 equivalence is used as the indicator for ozone depletion potential.

Smog potential is expressed by ethylene mass equivalence. Smog occurs when certain air emissions become trapped near the earth’s surface. Under sunlight when mixed with such air emissions, volatile organic compounds and nitrogen oxides may form as products.

These impact categories are used in conjunction with life cycle inventory (LCI) data to determine the summary measures, or Impact Assessment of the Gage building. Such impact categories and factors are taken from the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), which is built into the Impact Estimator.

The summary measure tables are presenting some of the valuable data resulting from this study – impacts of the Gage building. However, it is difficult to interpret these measures without comparisons. As mentioned in the Goal and Scope, this project is being carried out on thirteen other buildings. Six of these projects were completed on residential buildings located in the UBC campus. Comparing buildings of similar function allows for a more accurate comparison. At the same time, due to different square footage of the buildings, the aggregated summary measures are all based on a per square foot basis.

Given the aggregated results in Table 6.0, it is still difficult to interpret the summary measure values. A look at the table shows the two newest building impact the environment more than the older ones. One would think the case is the other way around, with older buildings having a greater impact. There are a number of uncertainties associated with this idea. Firstly, newer buildings will typically have more detailed drawings; therefore, those models would have been able to identify more details than older buildings. The age difference in buildings will also affect the LCI data. The Impact Estimator will contain better inventories of more recent materials.

Table 4.0 Summary Measure Table by Life Cycle Stages for All Gage Towers

	Manufacturing			Construction			Total Effects
	Material	Transportation	Total	Material	Transportation	Total	
Primary Energy Consumption MJ	49757350.59	1535138.87	51292489.46	3033543.99	3687556.81	6721100.80	58013590.26
Weighted Resource Use kg	27557160.03	50214.34	27607374.37	139311.82	83919.90	223231.73	27830606.10
Global Warming Potential (kg CO2 eq / kg)	3917673.72	2410.55	3920084.27	207595.28	6881.93	214477.21	4134561.48
Acidification Potential (moles of H+ eq / kg)	1505354.58	844.67	1506199.25	114308.37	2181.72	116490.09	1622689.34
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	18701.88	1.02	18702.90	127.47	2.62	130.09	18833.00
Eutrophication Potential (kg N eq / kg)	82.62	0.01	82.63	0.00	0.02	0.02	82.64
Ozone Depletion Potential (kg CFC-11 eq / kg)	0.01	0.00	0.01	0.00	0.00	0.00	0.01
Smog Potential (kg NOx eq / kg)	24937.86	19.10	24956.96	2757.84	48.72	2806.56	27763.52

Table 5.0 Summary Measures Table by Assembly Group for All Gage Towers

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Material	Total
Primary Energy Consumption MJ	2950837	46816100	0	2223416	9405668	9817	61405838
Weighted Resource Use kg	4067426	16217791	0	870925	5724472	5451	26886064
Global Warming Potential (kg CO2 eq / kg)	755807	6272244	0	233156	1291301	825	8553333
Acidification Potential (moles of H+ eq / kg)	504572	4487010	0	160826	814586	631	5967626
HH Respiratory Effects Potential (kg PM2.5 eq / kg)	375710	3148330	0	115903	640867	535	4281345
Eutrophication Potential (kg N eq / kg)	12677	228692	0	7055	38192	41	286657
Ozone Depletion Potential (kg CFC-11 eq / kg)	374815	3132141	0	115521	639410	533	4262419
Smog Potential (kg NOx eq / kg)	376814	3156261	0	116451	642129	533	4292187

Table 6.0 Aggregated Summary Measures for Residential Buildings

		Residences						
Impact Category	**Units**	**Vanier**	**Totem**	**Gage**	**Fairview**	**Thunderbird**	**MarineDrive**	**Average**
		1959,1961,1968	1964	1972	1985	1995	2005	
Primary Energy Consumption	MJ	288.43	404.14	328.49	282.91	495.45	963.82	460.54
Weighted Resource Use	kg	116.42	196.50	182.15	99.98	182.69	597.22	229.16
Global Warming Potential	(kg CO2 eq / kg)	20.11	29.56	25.64	16.74	28.40	77.88	33.05
Acidification Potential	(moles of H+ eq / kg)	3.66	10.13	10.65	7.03	6.10	27.03	10.77
HH Respiratory Effects Potential	(kg PM2.5 eq / kg)	0.05	0.08	0.13	0.09	0.07	0.26	0.12
Eutrophication Potential	(kg N eq / kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ozone Depletion Potential	(kg CFC-11 eq / kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smog Potential	(kg NOx eq / kg)	0.06	0.14	0.18	0.09	0.10	0.42	0.16

6.1 Sensitivity Analysis

A brief sensitivity analysis was performed on the different materials in the building. The majority of these analysis was based on concrete, as this makes up the core of the Gage building.

The first sensitivity analysis looked at the effect of flyash on impacts. The 6174m^3 of 30MPa concrete used for all three gage towers was looked at. Flyash content for the concrete was varied based on the given inputs in the Impact Estimator from average, 25%, and 35%. The results only consider the construction and manufacturing stages of impacts; they are shown in the figure below.

Table 7.0 Data Table for Fly Ash Content Sensitivity Analysis

	25%	AVG %	35%
Primary Energy Consumption MJ	9691979	10849164	9064682
Weighted Resource Use kg	16855719	17359690	16765795
Global Warming Potential (kg CO2 eq / kg)	1516750	1747958	1385396

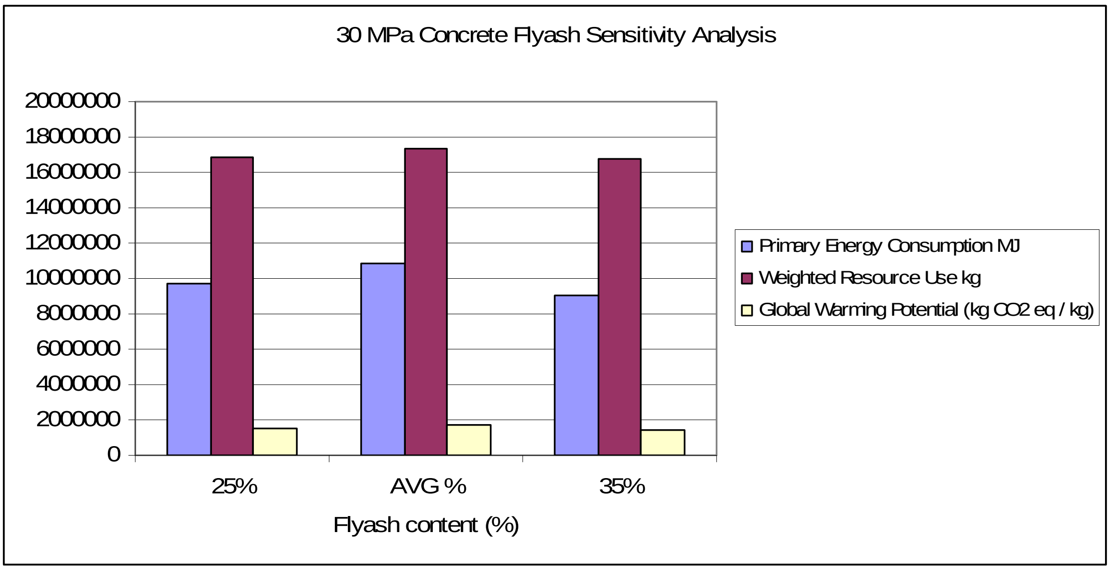

Figure 2.0 Fly Ash Content Sensitivity Analysis

Based on the results, increased flyash does reduce primary energy consumption, weighted resource use, and global warming potential. The numbers seem insignificant compared to many sites that insist flyash is an excellent substitute. Green Resource Center states, "…when high volumes are used in concrete (displacing more than 25% of the cement), it creates a stronger, more durable product and reduces concrete's environmental impact considerably." Fortunately flyash also offers several other characteristic benefits to concrete as quoted from Green Resource Center. These are not quantifiable through the impact estimator, for example, increased durability of concrete. Another interesting note based on the analysis is that the average flyash content in the impact estimator is less than 25%.

Global warming potential of varying concrete strengths was analysed in the next sensitivity analysis. The two different concrete strengths were compared for primary energy consumption, weighted resource use, and global warming potential. Using the volume used for the different concrete strength, as shown in Table 2.0 in the Bill of Materials. Despite the difference, the 30MPa and 60MPa concrete, however, are relatively close in volume. The figure below illustrates the results:

Table 8.0 Data for Global Warming Potential Analysis

	60MPa	30MPa
Primary Energy Consumption MJ	10699163	10849164
Weighted Resource Use kg	16338547	17359690
Global Warming Potential (kg CO2 eq / kg)	1737519	1747958

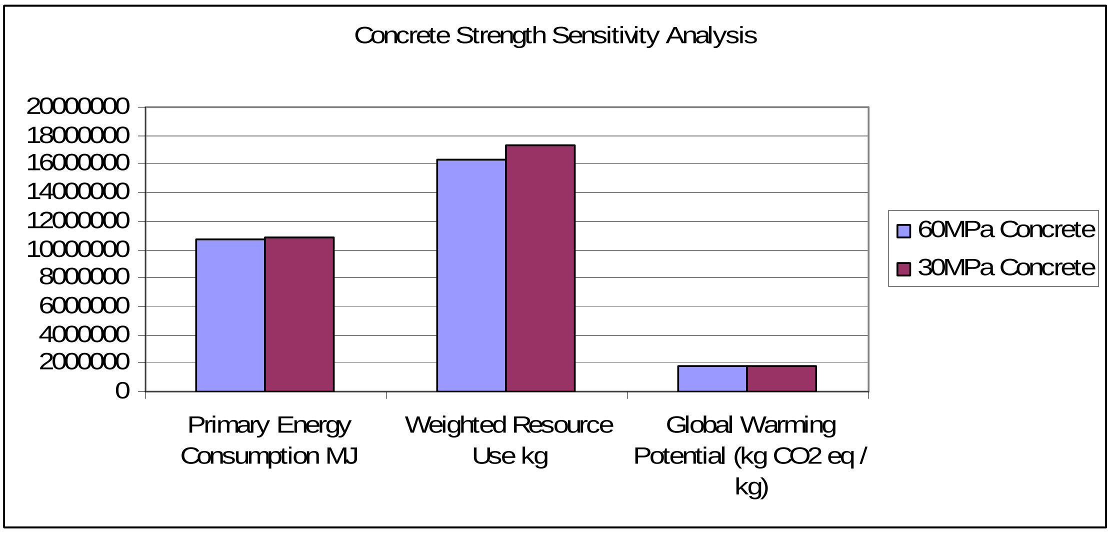

Figure 3.0 Global Warming Potential Sensitivity Analysis

Despite the 60MPa concrete being lower in volume than the 30MPa, it had nearly identical global warming potential seen in Figure 3.0. These impacts only consider the construction and manufacturing stages of concrete. However, it was surprising to find that they were only nearly equal. Typically, creating concrete at double the strength results in nearly double the CO_2 emissions. One would think the 60MPa concrete analysed with nearly identical volume to 30MPa would have a greater global warming potential. However, there are other benefits high strength concrete offers that are not considered in the impact estimator. Eventhough greater impacts are associated with higher strength concrete, high strength concrete can carry more weight with less volume compared to regular strength concrete. This allows for smaller column sizes, which means less intrusion in lower stories, and more living or rental space. Multi level parking decks also benefit from reduced column sizes. In places where land is scarce, this makes all the difference. A study done by Moreno also shows reduced costs associated with high strength concrete. This study reveals that the use of 6,000 psi (41 MPa) compressive strength concrete in the lower columns of a 23-story commercial building requires a 34-in. (865-mm) square column at a cost of $0.92/ft2 ($9.90/m2). The use of 12,000 psi (83 MPa) concrete allows a reduction in column size to 24-in. (610 mm) square at a cost of $0.52/ft2 ($5.60/m2).

Figure 3.0 further illustrates the comparison of the 30MPa and 60MPa concrete in detail. Even though the 60MPa Concrete was 591m^3 lower in volume, it did manage to come close to the 30MPa concrete in terms of global warming potential seen in Figure 3.0.

Table 9.0 Data for Concrete Strength Analysis

	Base Case	10%	-10%
Concrete 30 MPA (6174m^3)	3469997	346774.971	-346774.971
Concrete 60 MPA (5583m^3)	3448620	344676.645	-344676.645

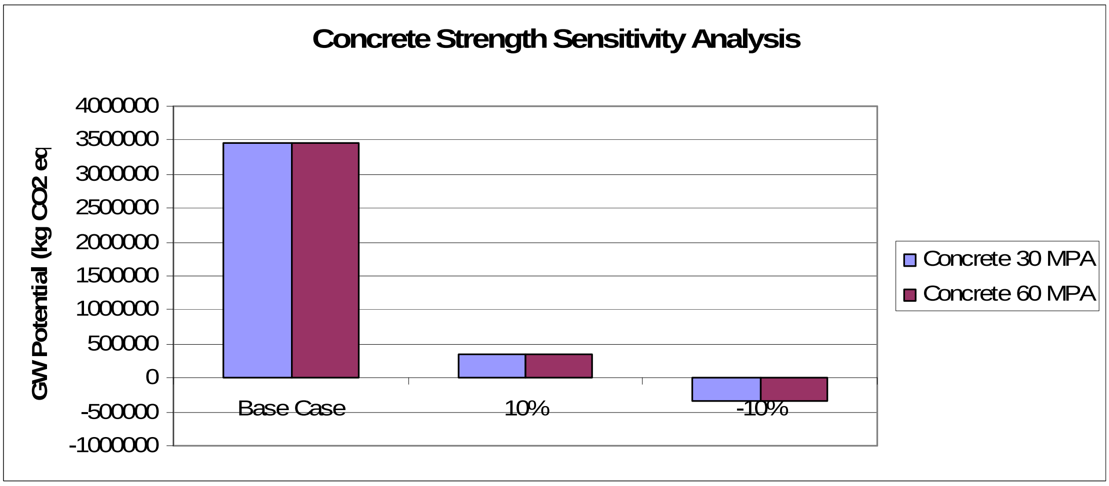

Figure 4.0 Concrete Strength Sensitivity Analysis

The next sensitivity analysis was performed on the main insulation used in the Gage building – extruded polystyrene. The extruded polystyrene was analysed for all impact categories in the Impact Estimator to determine if someone wanted to add or remove insulation, what impact would be the most sensitive. Based on Figure 4.0, one can see that the greatest line with the greatest slope would be most sensitive. In this case, primary energy consumption would have the biggest impact when using extruded polystyrene.

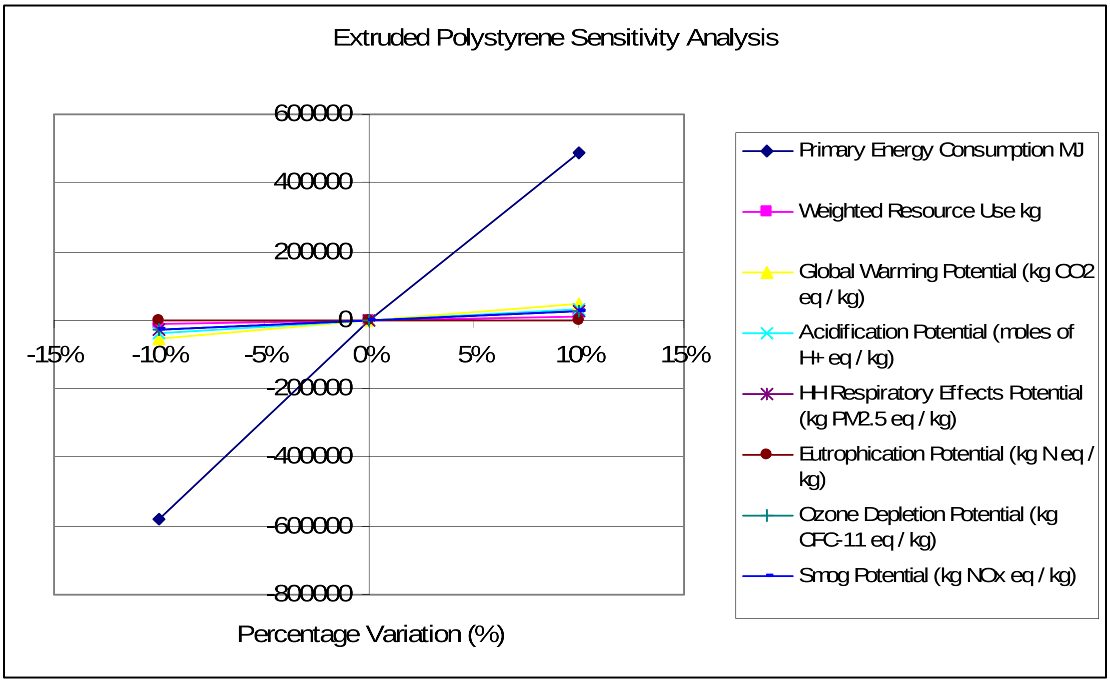

Figure 4.0 Extruded Polystyrene Sensitivity Analysis

The same analysis was performed on the material concrete. One can see in Figure 5.0 that the greatest impact categories for concrete are weighted resource use, primary energy consumption, and global warming potential. These results make perfect sense, as a great deal of energy and resources are required for the production of concrete. CO_2 emissions are also one of the key emissions of manufacturing concrete. Therefore, for one to consider using concrete, these are the impacts for thought.

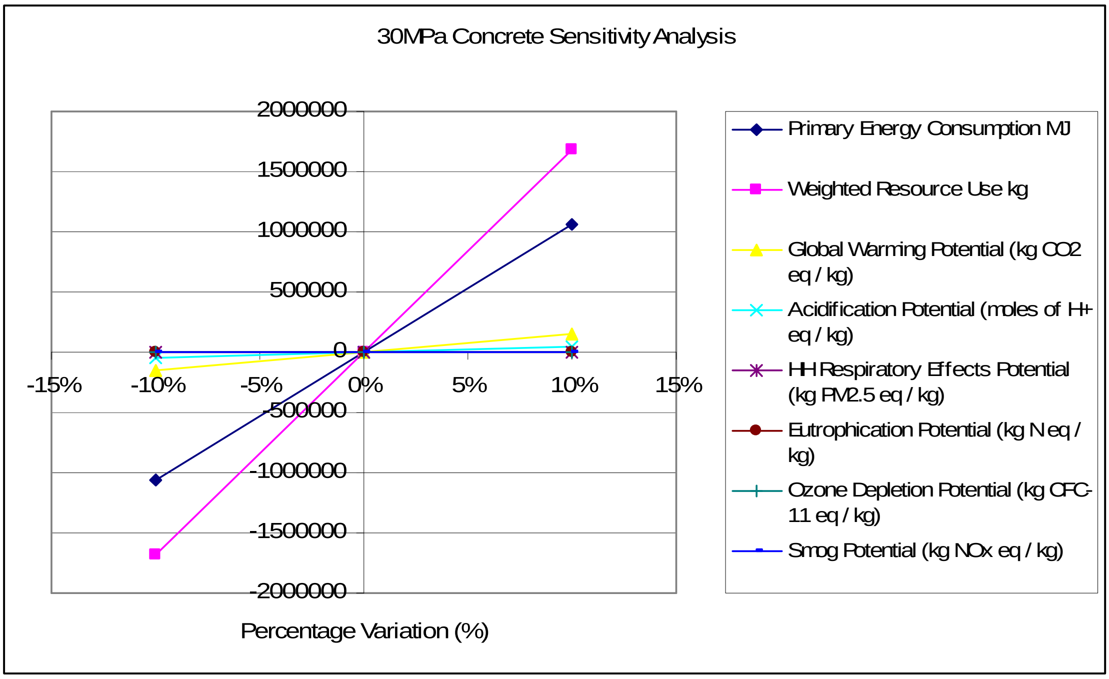

Figure 5.0 Concrete Sensitivity Analysis

The role of the sensitivity analysis can help us identify how the IE analyses specific materials. It can tell us how significant a change in material quantity can affect a building's impacts, or at the same time how insignificant it can be. Often times we are confronted with questions such as, what if we used less concrete and more wood in this building to reduce the global warming potential? The sensitivity analysis can allow us to do such a comparison. Unfortunately, the three Gage residential towers were made entirely out of concrete. This makes it difficult to consider the use of alternate materials, as a whole new structure would need to be planned out for this kind of analysis. Should the building have been made of a more hybrid of materials for its structural components, one would be able to make a quick comparison. In addition, sensitivity analysis can also tell us how the impacts vary over the same type of material. For example, fly ash and strength was varied and compared in the sensitivity analysis above. The effects were found not to be as significant as one would think.

7.0 Building Performance

Building performance analysis was based on a simplified energy modelling method. The associated heat loss sections of the buildings were first considered, that is the exterior walls, windows, and roof, which are exposed to the outside. Varying types of insulation have different degrees of thermal resistance, and this is expressed by their R-value. The R-value is used in the construction industry to measure a materials thermal resistance, with a higher value meaning greater insulation effectiveness. Because the exposed walls, windows, and roofs contain different areas, a weighted average is taken for the R values. These values were then used in a heat loss equation.

$$Q = (1/R) \times A \times \Delta T$$

Where,

R = R-Value in ft^2 °F h/BTU (these are the Imperial units)
A = Area of the Assembly in interest ft^2
ΔT = Inside Temperature – Outside Temperature in °F

The outside temperatures are based on historical averages taken by Environment Canada. Inside temperature is assumed to be maintained at an average temperature of 20 ºC or 68 ºF. The heat loss values are calculated for the entire year and then compared with an improved building model that complies with the minimum Residential Environmental Assessment Program's (REAP's) insulation requirements shown below:

- EA 1.1; Roof – minimum R-40
- EA 1.2; Exterior Wall Insulation – minimum R-18
- EA 1.3; Energy Star Windows – minimum R-3.2

Table 10.0 Current versus Improved R Values

		R-Value (ft2.degF.h/BTU)	
	Area (ft2)	'Current' Building	'Improved' Building
Exterior Wall	61990.5	7.5	18
Window	8102	0.91	3.75
Roof	7765	19.7	40
Weighted Average	77857.5	8.03	18.71

The above table compares the "current" building with its current insulation R values versus REAP's standards. In order to improve the current building to REAP's minimum requirements, the exterior wall's current 1.5 inch of extruded polystyrene insulation was increased by 60 percent (3.75 inches).The standard glazing for the windows were replaced with low E silver argon filled glazing to achieve a 3.75 R value. The roof was replaced with Foam polyisocyanurate as opposed to the current extruded polystyrene. The annual energy usage of the two buildings were compared over a span of 80 years in Figure 6.0.

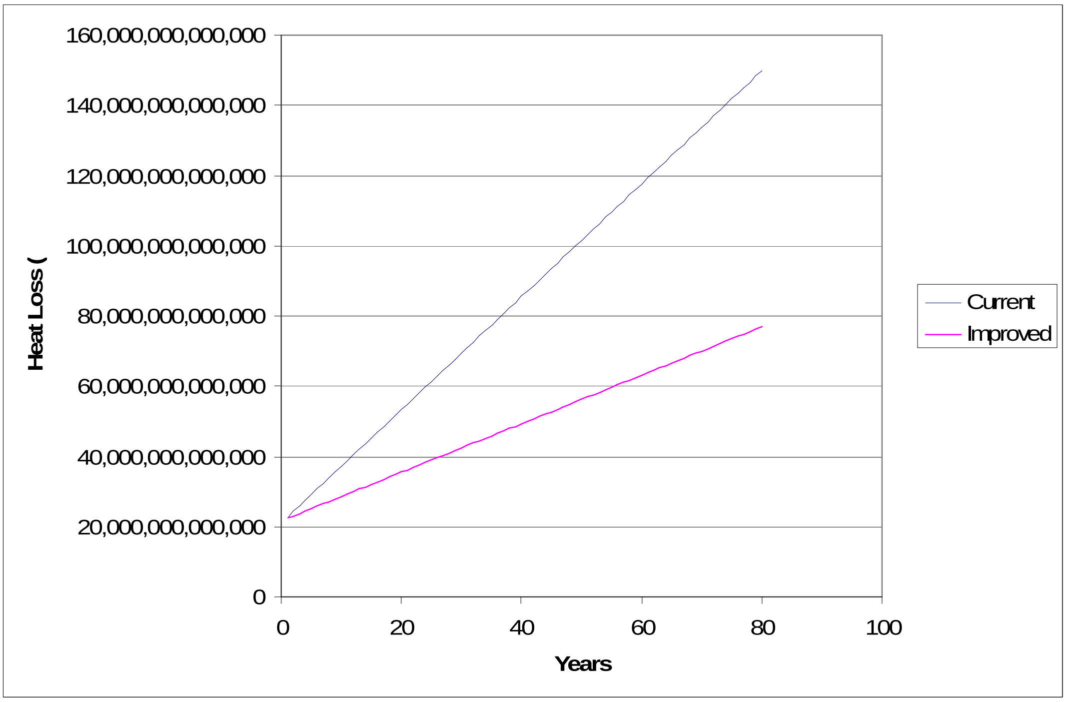

Figure 6.0 Building Performance Comparison

In Figure 6.0, the intersection of the two graphs is the energy payback period. This is how many years it would take to save the increased initial energy that was invested into the material that reduced the building’s heat loss. This was calculated to be less than a year for the Gage building. The explanations given for the building performance outlines the simple approach taken in calculating the energy payback period result. In reality, if one wanted to make a building perform better, it would require a lot more analysis and modeling. For instance, increasing or replacing insulation is not an easy task, and neither is replacing glass panels. Such considerations, along with the cost of the new insulation and installation are not considered in the analysis performed here.

8.0 Conclusion

As a concrete dominated the Gage building building, the primary concern of the building would be the impact categories of primary energy consumption, resource use, and global warming potential. It was placed well below average compared to other residential buildings in UBC. With primary energy consumption of 328 MJ / ft^2, weighted resource use of 182 kg / ft^2, global warming potential of 26 kg CO_2 eq / kg / ft^2 and acidification potential of 11 moles of H+ / kg / ft^2 and negligible amounts in the other four impact categories.

The sensitivity analysis was able to provide details regarding the affects of concrete strength and flyash variation, and impact sensitivities of materials. It was found that increasing strength or varying flyash did not have as great of an impact on the environment as thought would be. Whether this may be true for reality or just a flaw in the Impact Estimator software would require more research to answer. The sensitivity analysis on materials proved useful in determining the greatest impact each material has.

The building performance model in which an improved building was modelled with better insulation factors demonstrated a connection between better performing envelope materials and operating energy. The estimation of an energy payback period of less than one year gives some insight on how much energy can be conserved in this way. However, more detailed energy model would prove more accurate in calculating this payback period.

These analyses showed that performing an LCA on a building is a long and complicated task has inherent uncertainties. For this project, and the twelve others, many were very old buildings with insufficient or missing details. Uncertainties were met and assumptions laid out at every step in order to accomplish the life LCA and allow anyone to easily create the same project. However, as the project progressed, the limitations of the IE software were also identified. Fortunately, the IE software is being improved as we speak with greater options and improved features. Ideally, a LCA should be performed on a building under design phase, so a practitioner would be able to communicate with the architect or engineers on any changes to help make the building more sustainable. It is thus the hope of the students who have taken on this project in this course, that the power of the Impact Estimator be recognized, and used as such.

List of References

Green Resource Center, “High Volume Fly Ash Concrete”, 25 March 2009 <http://www.greenresourcecenter.org/MaterialSheetsWord/FlyAshConcrete.pdf>

Moreno, J., "High-Performance Concrete: Economic Considerations," Concrete International, Vol. 20, No. 3, March 1998, pages 70-77

Appendix A: Impact Estimator Input Tables

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General Description		
	Project Location	Vancouver
	Building Life Expectancy	60 years
	Building Type	Multi Unit Residential - Rental

Assembly Group	Assembly Type	Assembly Name	Input Fields	Ideal Input	Assumed Input
1 Foundation					
	1.1 SOG				
		1.1.1 4" Slab on Grade			
			Length (ft)	77.5	77.5
			Width (ft)	77.5	77.5
			Thickness (in)	4	4
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
	1.2 Footings				
		1.2.1 1' Footing			
			Length (ft)	44.7	44.7
			Width (ft)	44.7	44.7
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
		1.2.2 2' Footing			
			Length (ft)	20	22
			Width (ft)	20	22
			Thickness (in)	24	19.7
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
		1.2.3 4' Footing			
			Length (ft)	52.3	81.6
			Width (ft)	52.3	81.6
			Thickness (in)	48	19.7
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
		1.2.4 5' Footing			
			Length (ft)	25.3	44.2
			Width (ft)	25.3	44.2
			Thickness (in)	60	19.7
			Concrete (psi)	-	9000
			Concrete flyash %	-	25%
			Rebar	-	5
		1.2.5 Stair Type 1			
			Length (ft)	324	324
			Width (ft)	144	144
			Thickness (in)	5	7.5
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
		1.2.6 Stair Type 2			
			Length (ft)	187.2	187.2
			Width (ft)	144	144
			Thickness (in)	5	7.5
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
2 Walls					
	2.1 Cast-in-Place				

2.1.1 10" Typical Exterior Concrete Wall			
	Length (ft)	268	4556
	Height (ft)	8	8
	Thickness (in)	12	12
	Concrete (psi)	-	4000
	Concrete flyash %	-	25%
	Rebar	-	5
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	1.5	1.5
2.1.2 7" Typical Exterior Concrete Wall 1			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	4000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		
Windows Opening			
	Number of Windows	32	32
	Total Window Area (ft2)	463	463
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	-	1.5
2.1.2 7" Typical Exterior Concrete Wall 2			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	4000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		
Windows Opening			
	Number of Windows	32	32
	Total Window Area (ft2)	463	463
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	-	1.5
2.1.2 7" Typical Exterior Concrete Wall 3			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	4000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		

		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 4			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 5			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 6			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32

			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 7			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 8			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 9			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium

			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 10			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 11			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 12			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			

	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	-	1.5
2.1.2 7" Typical Exterior Concrete Wall 13			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	3000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		
Windows Opening			
	Number of Windows	32	32
	Total Window Area (ft2)	463	463
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	-	1.5
2.1.2 7" Typical Exterior Concrete Wall 14			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	3000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		
Windows Opening			
	Number of Windows	32	32
	Total Window Area (ft2)	463	463
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
	Thickness		
	Category	Insulation	Insulation
	Material	-	Polystyrene Extruded
	Thickness (in)	-	1.5
2.1.2 7" Typical Exterior Concrete Wall 15			
	Length (ft)	368	368
	Height (ft)	8	8
	Thickness (in)	7	8
	Concrete (psi)	-	3000
	Concrete flyash %	-	25%
	Rebar	-	5
	Total opening area (ft2)		
Windows Opening			
	Number of Windows	32	32
	Total Window Area (ft2)	463	463
	Frame Type	Aluminium	Aluminium
	Glazing Type	-	Standard Glazing
Envelope			
	Category	Gypsum board	Gypsum board
	Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"

			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 16			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.2 7" Typical Exterior Concrete Wall 17			
			Length (ft)	368	368
			Height (ft)	8	8
			Thickness (in)	7	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	25%
			Rebar	-	5
			Total opening area (ft2)		
		Windows Opening			
			Number of Windows	32	32
			Total Window Area (ft2)	463	463
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.3 10" Typical Interior Concrete Wall			
			Length (ft)	183	3111
			Height (ft)	8	8
			Thickness (in)	8	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	25%
			Rebar	-	5
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Category	Insulation	Insulation
			Material	-	Fiberglass Batt
			Thickness (in)	3.625	3.625
		2.1.4 8" Basement Exterior Concrete Wall			
			Length (ft)	573	573
			Height (ft)	15.1	15.1
			Thickness (in)	8	12

			Concrete (psi)	-	9000
			Concrete flyash %	-	25%
			Rebar	-	5
		Windows Opening			
			Number of Windows	12	12
			Total Window Area (ft2)	231	231
			Frame Type	Aluminium	Aluminium
			Glazing Type	-	Standard Glazing
		Doors Opening			
			Number of Doors	2	2
			Door Type	Steel Exterior Door	Steel Exterior Door
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness (in)	-	1.5
		2.1.5 8" Interior Concrete Basement Wall			
			Length (ft)	96	96
			Height (ft)	15.1	15.1
			Thickness (in)	8	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	Average
			Rebar	-	5
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		2.1.6 10" Basement Interior Concrete Wall			
			Length (ft)	115	115
			Height (ft)	10	10
			Thickness (in)	10	12
			Concrete (psi)	-	9000
			Concrete flyash %	-	Average
			Rebar	-	5
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 5/8"	Gypsum Regular 5/8"
		2.1.5 1' Roof Exterior Concrete Wall			
			Length (ft)	157	157
			Height (ft)	19	19
			Thickness (in)	12	12
			Concrete (psi)	-	3000
			Concrete flyash %	-	average
			Rebar	-	5
		2.1.6 8" Roof Exterior Concrete Wall			
			Length (ft)	685	685
			Height (ft)	5	5
			Thickness (in)	8	8
			Concrete (psi)	-	3000
			Concrete flyash %	-	average
			Rebar	-	5
	2.2 Steel Stud				
		2.2.1 7" Typical Interior Stud Wall			
			Length (ft)	518	8806
			Height (ft)	8	8
			Sheathing Type	none	none
			Stud Spacing	-	16 o.c
			Stud Weight	Light	Light
			Stud Thickness	3 5/8	1 5/8 x 3 5/8
		Doors Opening			
			Number of Doors	44	748
			Door Type	Hollow Core Wood Interior Door	Hollow Core Wood Interior Door
		Envelope			

			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Fiberglass Batt
			Thickness (in)	3.625	3.625
		2.2.2 7" Basement Interior Stud Wall			
			Length (ft)	340	340
			Height (ft)	8	8
			Sheathing Type	none	none
			Stud Spacing	-	16 o.c
			Stud Weight	Light	Light
			Stud Thickness	3 5/8	1 58/8 x 3 5/8
		Envelope			
			Category	Gypsum board	Gypsum board
			Material	Gypsum Regular 1/2"	Gypsum Regular 1/2"
			Thickness		
			Category	Insulation	Insulation
			Material	-	Fiberglass Batt
			Thickness (in)	3.625	3.625
3 Floor					
	3.1 Suspended Slab				
		3.1.1 6" Suspended Slab 1-5			
			Floor Width (ft)	2191	2191
			Span (ft)	11	11
			Concrete (psi)	-	9000
			Concrete flyash %	-	average
			Live Load (psf)	-	75
		Envelope			
			Envelope Category	Gypsum Board	Gypsum Board
			Envelope Material	Regular 5/8"	Regular 5/8"
		3.1.1 6" Suspended Slab 6-12			
			Floor Width (ft)	2630	2630
			Span (ft)	11	11
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Live Load (psf)	-	75
		Envelope			
			Envelope Category	Gypsum Board	Gypsum Board
			Envelope Material	Regular 5/8"	Regular 5/8"
		3.1.1 6" Suspended Slab 13-16			
			Floor Width (ft)	2191	2191
			Span (ft)	11	11
			Concrete (psi)	-	3000
			Concrete flyash %	-	average
			Live Load (psf)	-	75
		Envelope			
			Envelope Category	Gypsum Board	Gypsum Board
			Envelope Material	Regular 5/8"	Regular 5/8"
4 Roof					
	4.1 Suspended Slab				
		4.1.1 6" Suspended Slab			
			Roof Width (ft)	438	438
			Span (ft)	11	11
			Concrete (psi)	-	3000
			Concrete Flyash %	-	25
			Live Load (psf)	-	45
		4.1.2 6" Suspended Elevator Slab Roof			
			Roof Width (ft)	117	117
			Span (ft)	15	15
			Concrete (psi)	-	3000
			Concrete Flyash %	-	25
			Live Load (psf)	-	45
5 Extra Basic Material					
	5.1 Wood				

		5.1.1 Cedar			
			Softwood Lumber (Small dimension, Kiln Dried) (m3)	1.14	1.14
	5.2 Insulation				
		5.2.1 Batt Fiberglass			
			Batt Fiberglass (sf)	476	476
	5.3 Cladding				
		5.3.1 Concrete Plaster			
			Stucco over porous surface (sf)	701	701

Appendix B: Impact Estimator Input Assumption Document

1 Foundation

The foundation assembly group consists of footings, slab on grades, and stairs. Slag on grades (SOGs) were modelled as area conditions in takeoffs due to length, width, and thickness input requirements in the impact estimator. Concrete footings were all modelled as area conditions. For the case of Gage building, pad footings dominated while there were only a few column footings. Column footings were modelled as area conditions due to minimal numbers. Footing thicknesses were limited to 7.5” to19.7” thick. Many footings exceeded these boundaries, so the lengths and widths were increased accordingly while maintaining the same volume of footing. The footings and SOGs can be all found in 869-07-002 structural drawing. Stairs were modelled as footings for this project because the EIE currently does not have a staircase assembly profile. Stairs were modelled as an area condition based on dimensions within structural drawings 869-07-003 and 869-07-004.

1.1 Slab on Grade

1.1.1 4” Slab on Grade

The Slab on Grade represents an area condition, and length and widths are estimated by treating the areas as a square. Basically, all the areas are added up and treated as large square area.

4” Slab on Grade Area: 6011 sf

SQRT (6011) = 77.5 ft

Length: 77.5 ft
Width: 77.5 ft

The concrete specifications were missing and were assumed to be 4000PSI, a median range. The specifications are missing for all concrete poured. Therefore, average 4000PSI value is usually used. For larger sized footings or thicker walls, the highest 9000PSI strength from the EIE is used.

1.2.3 4’ Footing

The maximum thickness in the impact estimator is 19.7 inches. Since the 4 foot footing is 48 inches, it cannot be inputted. The volume of the footing is calculated, and the length and width are adjusted as follows:

4’ Footing Length: 52.3ft
4’ Footing Width: 52.3ft
4’ Footing Thickness: 4ft
4’ Footing Volume: 10941ft^3

$X^2 * (19.7/12) = 10941\ ft^3$
X = 81.6ft

The new footing size with equivalent volume is then 81.6ft by 81.6ft by 19.7 inches.

1.2.5 Stair Type 1

Stair volume was modelled based on side profile views in 869-07-003 and 869-07-004. The thickness and width are given. The length is calculated by the total tread and rise dimensions, which make up two sides of a triangle, with the length forming the hypotenuse.

Stair Type 1 width: 4ft
Stair Type 1 thickness: 5in
Stair Type 1 total rise: 5ft 2in

Stair Type 1 total tread: 7ft 4in

Stair Type 1 length = SQRT[$(5'2")^2 + (7'4")^2$]
= 9 ft

The stairs repeat twice per floor given there are two set of stairs, so the total length and width input must be multiplied by the appropriate factors.

Total length: 9 * 18 * 2 = 324ft
Total width: 4 * 18 * 2 = 144ft

2 Walls

Wall assembly consists of all the walls found within the building. Gage has many rooms and lacks any large rooms, thus walls are used to supplement for columns. Wall classification can be divided up into three major categories: basement (869-06-006), typical (869-06-008), and roof (869-07-007). A ground floor did exist, but it was nearly identical to the typical floor plan with the exception of a lounge room. Therefore, the ground floor was simply modelled as a typical floor. All walls were modelled as linear conditions in takeoffs, where their lengths were measured. Separate count conditions for windows and doors were done with drawings 869-06-011 and 869-06-008 respectively. Envelope and opening details were found in wall detail drawings. Certain assumptions were made regarding envelope and opening details possibly due to lack of a cover page in the drawings. Wall thicknesses were also another assumption made, as EIE only allowed for 8" and 12" thickness walls. Interior steel stud walls were also assumed to be light gauge (25 Ga) with no sheathing.

2.1 Cast-in-Place

2.1.1 10" Typical Exterior Concrete Wall

Typical walls make up the typical floor plan of Gage which makes up floors 1-17. As these walls are repeated every level, they are multiplied by 17 to obtain a total value input for the EIE. The specifications are assumed to be 4000psi, #5 reinforcement, and 25% flyash content. Athena limits input of wall thickness (8"/12"); the 12" was selected to account for a greater factor of safety. In addition, as the wall is one of the thickest used in the building, a higher value was deemed more plausible.

10" Typical Wall Length: 268ft

Total 10" Typical Wall Length: 268ft * 17 = 4556ft

Insulation dimension was given, but type was unknown and assumed to be extruded polystyrene.

2.1.2 7" Typical Wall 1-17

7" Typical walls are similar to 10" but contain windows. In addition, the wall assembly are inputted by floors in the EIE for two reasons. 7" walls are not as structurally important as the 10" walls, so the strength will inevitably decrease with increasing floor levels. The impact estimator limits to a maximum of 100 windows per wall assembly, and the building contains 544 in total (32 per floor).

7" Typical Wall Length 1-17: 368ft / floor
Concrete strength: 9000psi (floors 1-3)
4000psi (floors 4-13)
3000psi (floors13-17)

The following equation was used to make 7" walls into 8" walls (due to wall thickness selection availability in the Impact Estimator). As walls were the same on many floors, ‘typical’ walls were used and multiplied by the respective number of floors they are repeated on. This is also seen in the equation below.

Measured Wall Length * (7/8) * (number of floors typical wall length appears on)
= EIE Input Length

Windows Opening

Window openings are calculated by adding up all the different window areas on one side of a building and multiplying by four (the number of building sides).

Window #1 Area: 5’ * 6’10” = 34.2 sf
Window #2 Area: 5’ * 6’10” = 34.2 sf
Window #3 Area: 9’6” * 5’ = 47.5 sf
Window #4 Area: 9’6” * 5’ = 47.5 sf
Window #5 Area: 8’6” * 2’2” = 18.4 sf
Window #7 Area: 7’2” * 6’6.5” + 8’8” * 5’= 90.2 sf

Total Window Area / Side:
Window #1 + Window #2 + 2 (Window #3 + Window #4) + Window #5 + Window #7 = 367 sf

Total Window Area for Typical Floor:
367sf * 4 = 1468 sf

The window glaze specifications were missing, and assumed to be standard glazing for such an old building.

Door Opening

Door openings were performed on takeoff using count condition. Since the 7” Typical concrete walls are the backing structure for the 7” Typical Steel Stud Walls , they share the same number of door openings. The wholes for these doors created in the walls, but no doors were added, since they are added later in the 7” Typical Stud Wall assemblies. The number of doors on a floor is multiplied by the number of levels associated.

Number of Doors on 7” Typical Stud Wall: 44 doors

Total Number of Doors: 44 * 17 = 748 doors

2.1.4 8" Basement Exterior Concrete Wall

The basement supports a variety of walls. There are two main different types of walls found in the basement. The first type is walls that are extend beneath the slab on grade to connect to the foundations. These are classified as **Basement Walls** for this project. Unfortunately, not all walls are extended beneath ground level. Some of the walls on the basement level simply rest on the slab on grade; these are classified as **Typical Walls**. For **Basement Walls**, they extend beneath the ground level to varying depths in some cases, so a weighted average value will be taken. Refer to 869-07-002 structural drawing for depth values.

Average distances below ground level:
(396/1387)*6’ + (349/1387)5’6”+ (642/1387)6’6” = 6.1ft
8” Basement Wall Height: 9ft

Total 8” Basement Wall Height:
9ft + 6.1ft = 15.1ft

2.2.1 7” Typical Interior Stud Wall

Similar to 2.1.1 Typical Wall, the stud walls are the same from floors 1-17 and therefore modelled as one assembly.

7” Typical Stud Wall Length: 518ft

Total 7” Typical Stud Wall Length: 518ft * 17 = 8806ft

Stud details could not be found and were assumed to be light and 16 o.c. spacing. These details are assumed based on the stud wall being on the interior of the building.

Window Opening

Each floor contained 32 windows and 462 sf opening. These appeared on each of the 17 floors in the building. These were added with no window material were inputted as the windows were added in the concrete wall inputs.

Door Opening

Door openings were performed on takeoff using count condition. The number of doors on a Typical Stud Wall is the same, so it is multiplied by the number of levels associated.

Number of Doors on 7” Typical Stud Wall: 44 doors

Total Number of Doors: 44 * 17 = 748 doors

Stud details could not be found and were assumed to be

Floor

The floors were measured using area conditions. Much like in column and beams, the Impact Estimator calculated the thickness of the material based on some basic variables regarding the assembly. These include; floor width, span, concrete strength, concrete flyash content and live load. The only assumptions that had to be made in this assembly group were setting the live load to 75psf, as well as setting the concrete strength 4,000 psi, instead of the specified 3,500psi. This was due to the IE’s limitation to model only 3,000, 4,000 or 9,000psi concrete strengths.

3.1 Suspended Slab

3.1.1 6” Suspended Slab 1-16

The suspended slabs are separated by levels in order to facilitate a tiered concrete strength system. The lower floors have higher strength than the upper floors. The input strength for the slab assemblies are as follows:

6” Suspended Slab Concrete Strength Floors 1-5: 9000 psi
6” Suspended Slab Concrete Strength Floors 6-12: 4000 psi
6” Suspended Slab Concrete Strength Floors 12-16: 3000 psi

The 17th floor slab is reserved for a unique roof assembly.

The span of was based on an average of spans found within a typical floor and estimated to be 11’

The floor width was obtained by using the cited area in the onscreen takeoff and dividing by the span.

6” Suspended Slab Concrete Strength Floors 1-5 Area: 29325.6 sf

29325.6sf / 12feet = 2443.8 ft

6” Suspended Slab Concrete Strength Floors 1-5 Width = 2443.8 ft

Beams and Columns

Gage Residence has no large open spaced rooms, and thus no columns were found in the tower designs. The building is made up of multi-bedroom units, with all the supports coming from the many room walls. Beams were found in only the first floor in very minimal numbers, and the ineffective way the EIE models beams, along with lack of beam detail drawings led them to be not analysed for this project. Missing reflected ceiling drawings for all floors except ground further made beams difficult. Access to the building was completed at the author’s discretion but was limited due to the privacy of the building. It was found no beams could be seen in the floors above in the central elevator space of a typical floor

Roof

For the roof envelope, the area condition was used to model it. Two roofs, one main roof on the top floor, and a smaller roof located on the top of the floor that houses the elevator room. Both roofs were assumed to be using a PVC membrane roofing system with extrude polystyrene insulation, as roof details could not be found. This assumption is based on a model developed by Athena EIE, named BC_Typical_MURB

4.1 Suspended Slab

4.1.1 6” Suspended Slab

The highest typical floor slab contains unique property different from the other floor slabs. As with most roofs, an envelope roofing system is used. This was assumed to be a PVC membrane roofing system.

Extra Basic Material

The only ceiling drawings available were for the ground floor. Fortunately, ceiling materials remained static for the typical floors and was similar to the ground floor, with the exception of some cedar planking use. Some cedar planking was used in the ground floor. Basement floor was inaccessible, and thus also assumed to be the same as a typical ceiling.

5.1 Wood

5.1.1 Cedar

The ground floor contained some cedar planking used on, shown on the reflected ceiling plan (869-06-021). The volume was obtained through the takeoff Volume quantity.

Cedar Plank Volume: 40cf = 1.14m^3

The exact type of cedar wood is difficult to match with the available selection. Softwood Lumber (small dimension, kiln dried) was found to be the closest available match.

5.2 Insulation

5.2.1 Batt Fibreglass

There is some isolated acoustic isolation found only where there are cedar planks. The same area from the takeoff of cedar plank is used.

Batt. Fiberglass sf: 476sf

5.3 Cladding

5.3.1 Concrete Plaster

The specifics of Concrete Plaster specified in ceiling drawing 869-06-021 were not clearly detailed. A visit to the building noted it was similar to stucco and was modelled as Stucco over porous surface.