LIFE CYCLE ASSESSMENT: Level 3 Building Elements of the Douglas Kenny Building

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CIVL 498C

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PROVISIO

This study has been completed by undergraduate students as part of their coursework at the University of British Columbia (UBC) and is also a contribution to a larger effort – the UBC LCA Project – which aims to support the development of the field of life cycle assessment (LCA).

The information and findings contained in this report have not been through a full critical review and should be considered preliminary.

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Executive Summary

Life Cycle Assessment is the only tool in which decisions regarding environmental impacts can be made. LCA uses sufficient scientific data to provide impact results to air, land, and water while analysing products and product systems. This project breaks down a previous LCA on The University of British Columbia's Douglas Kenny Building. The previous LCA looked at the cradle to gate which is similar to this study. The previous model was reviewed and all assumptions were evaluated. The previous model was then broken up into CIQS level 3 building elements. These building elements make up the complete building. The level 3 building elements is the format that professional surveyors who give cost estimates to clients use. By categorizing building materials into level 3 elements LCA can be brought in to the design stage of buildings. By having LCA in the design stage a client can make decisions based on LCA results and costs. The previous LCA study used a LCA tool called the Athena Impact Estimator which is a computer program designed for building LCA. The previous model was reorganized in AIE into level 3 elements and then basic materials and impact results were calculated. The use of a functional unit allowed for the normalization so that comparison between elements and eventually buildings can be compared. The impact results for the Douglas Kenny Building are fairly high since the majority of the building is made of cement. It was found that the main impacts from the cement manufacturing were due to the product manufacturing stage. When compared to a benchmark from 16 other LCA studies that were completed during the same time, the Douglas Kenny building exhibited higher performance. The benchmark for every impact category was higher than the impacts obtained from the Douglas Kenny Building. The method, data, model, goal and scope are subjected to various degrees of uncertainties.

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1.0 General Information on the Assessment

Purpose of the assessment

The purpose of doing a building life cycle assessment (LCA) is to quantify the environmental performance of the building. By quantifying the product inputs, the construction process inputs and outputs, energy, material use, and disposal of the product, the total environmental impacts for the building can be assessed. By analysing the environmental impacts, the product systems that have the least environmental impacts can be seen.

Green building systems and standards are becoming more dominant in building regulation. As UBC strives to be more sustainable, LCA will become increasingly more important since they are an exceptional tool to measure sustainability from a scientific approach. The format of this assessment is particular in that it will make it easier to use LCA instep with building design.

Previous LCA studies were done on UBC buildings in the years previous to 2013. The previous LCA's modeled the entire building from cradle grave. In doing so, environmental impacts for the entire building were analysed.
The purpose of this LCA is to categorize the different elements that make up the building and complete individual LCA's on each element. By collaborating with other individuals who completed elemental LCA's on other UBC buildings a benchmark was created. This benchmark was created by averaging each element from all the buildings studied.

This LCA can be used by UBC's sustainability office, UBC building development team, developers, architects, engineers, governments and so on, to compare which elemental building designs have the least environmental impact and thus more sustainable. This is done by completing comparative assertions on a building's element to a benchmark and to other building's elements.

High attention to detail is required to obtain accurate environmental impact results. The level of detail that goes into completing a LCA is very significant. All data collected must be accurate and justifiable so that calculations for quantifying building material and the impacts associated with the product can be reliable.

Identification of building

This LCA studied the environmental impacts associated with the building elements from the Douglas Kenny building's. The Douglas Kenny building is also known as UBC's "Psychology Building" and is located at 2136 West Mall on the West Side of the UBC campus.

The building was designed by Reno Negrin and Associates and was constructed in the years between 1982 and 1984. The total construction cost of the Douglas Kenny Building was $1.25 million in 1982[1] which is roughly $2.56 million in today's dollars. The design of the building is relatively simple in the sense that UBC in the early 1980's had a limited budget[2]. At that time in 1982, UBC had a budget shortfall of $7.4 million and as a result UBC increased tuition an average 32.8%[3].

The Douglas Kenny Building is almost entirely constructed of concrete with steel stud interior walls. The gross floor area of the building is 8972m^2. This is measured from the outside of the exterior walls. It has four main floors with a penthouse used as a mechanical room. The main floors are comprised mainly of offices, research laboratories, and classrooms. The building contains 110 offices, 183 labs, 21 classrooms, 20 washrooms, and a large atrium that extends all four floors to a 300m^2 skylight.

Other Assessment Information

As previously mentioned, this study was based off the results obtained from a whole building LCA that was done in March 2010 by a UBC student. Both studies used US EPA TRACI methodology and Athena Impact Estimator. Further assessment information is given in Table 1 below.

Table 1 Assessment Information

Client for Assessment	Completed as coursework in Civil Engineering technical elective course at the University of British Columbia.
Name and qualification of the assessor	First Author: Kendrick Carnes, Environmental Engineering Second Author: Not Available
Impact Assessment method	US EPA TRACI methodology, Athena Impact Estimator 4.2.0208
Point of Assessment	29 years
Period of Validity	5 years.
Date of Assessment	Completed in December 2013.
Verifier	Student work, study not verified.

[1] (Author, Unknown, 2010)
[2] (Library, UBC, 2013)
[3] (Library, UBC, 2013)

2.0 General Information on the Object of Assessment

2.1 Functional Equivalent

In order to compare the impacts from one building to another, a common unit was chosen. The common unit or functional unit that was chosen for this LCA was "per meters squared". This unit allows for comparison between elemental impacts with different uses and between buildings with different uses. These different uses require different building systems. For example, a building used mainly for offices would have far more partitions than a building that would be used for large lectures. This functional unit allows us to normalize the environmental impact, which enables us to quantify the element's building performance against elements and other buildings which is this LCA's intended application.

Table 2 Functional Equivalent Definition

Aspect of Object of Assessment	Description
Building Type	Institution
Technical and functional requirements	Office Space, Research Laboratories, classrooms
Pattern of use	House UBC Psychology Department, promote interaction between faculty members and students
Required service life	100 year

2.2 Reference Study Period

Most LCA's have a reference study period for the entire building life and/or the required service life. In the case of this LCA, the reference study period was from cradle to gate so a service life of one year was chosen rather than a service life of say 100 years. The reason for this is that the main goal of this LCA is to assess building elements from a design prospective rather than a functional perspective. By eliminating the product use and end of life phases the impacts associated with the various design elements of the building were isolated.

2.3 Object of Assessment Scope

The object of assessment scope is the building structure that sits on the Douglas Kenny Building footprint. The assessment only looked at the building structure and did not take into account finishes such as flooring, electrical systems, HVAC systems, and other 'details and finishings'.

The Douglas Kenny Building is built on ten types of rectangular footings and five type of strip footings. The slab on grade was constructed on the ground surface with minimal excavation required covering an area of 2655m^2. Since the building was constructed at grade it does not have any walls below grade and therefore all exterior walls were assumed to be above grade. All concrete used in the building was categorized as 25mpa concrete. As mentioned the majority of the building was constructed using concrete. The columns, beams and floors are all constructed using concrete as well.

The columns in the building are round and extend four floors from the slab on grade. Between the columns are large square concrete girders spanning all directions with smaller intermediate beams built into the concrete pad floor system running in a single direction.[4]

The two type of roofing systems are made of concrete for the main roof and steel for the penthouse roof. The concrete roof is similar to the floor system with an additional membrane and ballast aggregate. The penthouse roof system consists of an open web steel joist structure with metal roof deck. The roof deck is overlaid by a roof membrane as well as 75mm rigid insulation and a 50mm aggregate ballast.

The other area that makes up the roof is the 300m^2 skylight. The support for the skylight is made of hollow structural steel. The skylight is connected to a curtain wall that extends down into the atrium. Connected to the atrium is a series of interior walls with many glass windows facing into the atrium. Attached to the atrium are 200mm thick concrete walls. The remaining interior walls are steel stud with drywall on either side.

The previous model broke down the building categories into five specific categories. The five categories from the previous model were the following: Foundations, Walls, Columns and Beams, Roofs, Floors, and Extra Basic material. For this LCA the previous five categories were broken down into Canadian Institute of Quantity Surveyor's (CIQS) Level 3 Elements. The definition of an element is defined by the CIQS as, "a major component common to most buildings, fulfilling the same function irrespective of its design, specification or construction"[5]. The elements and descriptions are shown in Table 2. The main reason for splitting the model into Level 3 elements is so that the results from this LCA can be brought into the designing stage when designing future buildings at UBC and elsewhere. By having the environmental impacts broken down into level 3 elements, a designer can compare different level 3 elemental designs and choose which one is most cost effective and sustainable.

[4] (Author, Unknown, 2010)
[5] (CIQS, 2011)

Table 3 Building Definition Template

CIVL 498C Level 3 Elements		Description	Quantity (Amount)	Units
A11	Foundations	Rectangular and Strip Footings	2655	m^2
A21	Lowest Floor Construction	Slab On Grade, Ground Floor Beam	2655	m^2
A22	Upper Floor Construction	Stairs, Stairwell floor, 2nd/3rd/4th/Penthouse Column and Beams Supporting Floor, 2nd/3rd/4th Floor Construction	6317	m^2
A23	Roof Construction	Roof, Columns and beams Supporting Roof, Skylight, Roof Parapet	2356	m^2
A31	Walls Below Grade	None	0	m^2
A32	Walls Above Grade	Exterior Walls (Cast in Place, Steel Stud),	17913	m^2
B11	Partitions	Interior Walls(All floors Steel Stud), Concrete Block Wall, Brick, Standard Glazing	10564	m^2

3.0 Statement of Boundaries and Scenarios Used in the Assessment

3.1 System Boundary

This LCA study has a fairly narrow scope, in that only two stages are considered. The life cycles included in this study only include the product stage and the construction process stage. The product stage includes the raw material supply, transport and manufacturing. The construction stage includes transport and construction and installation processes. Each stage takes into account the inputs and outputs for the particular stage process. Inputs include energy, materials, and resources while the outputs are the finished product, co-products, emissions, and waste.

Each stage looked at has its own upstream and downstream processes. Upstream processes are processes that occur before a particular stage. Similarly, downstream processes are processes that occur after a particular stage.

The scope is dependent on the LCA tool that was used for this study. The tool used for this LCA study is a computer program called the Athena Impact Estimator (AIE). The AIE has different inputs depending on the system boundary of the object to be assessed. These inputs are discussed in detail in 3.2 and 3.3. The estimator automatically takes into account the environmental impacts of the following processes given accurate inputs are entered:

1. Material Manufacturing
2. Related Transportation
3. On-Site Construction
4. Regional Variation in Energy
5. Building Type and Lifespan
6. Maintenance and Replacement Effects
7. Demolition and Disposal

The Athena Institute, the company responsible for the AIE, has completed hundreds of LCA studies and obtains all their data “in house”[6]. The data is backed by the most current and reliable data available. The software draws from LCI and LCA data files that are built in to the program. These LCA files are completed following ISO 14040 and ISO 14044 standards. Each file that the program draws from is a complete LCA on the building product material. Some of these studies that the manufacturer approved can be found on the Athena website. These studies include the construction, demolition and disposal phases of the product.

3.2 Product Stage

The product stage is an upstream process for the construction stage. This stage produced reference flows for the construction stage of the building. The product stage is known as a “cradle to gate” process. The product stage includes three main sub stages which are raw material supply, transport, and manufacturing of all the building material products. The product stage includes the delivery of the finish product to the “gate” in this case, the construction site.

As mentioned in 3.1 the AIE draws on relevant LCA files for particular building materials. These LCA’s were completed for each building material that is found in the AIE. The AIE has inputs for the city that the building is constructed in. That being said, the software uses local suppliers data for each product in the program. The software has regional statistics for building materials. These stats are very thorough in

[6] (Institute, Athena Sustainable Materials, 2013)

that they have accounted for almost every possible scenario. For example, the concrete for the Douglas Kenny Building probably came from a local manufacturer. This local manufacturer is probably located near a port in which raw materials are barged to. The delivery of raw supplies by the barge would most likely have a lower environmental impact than from trucking the raw materials in.

The software takes into account these details and many other details to provide a probability based assessment on where and how the building materials are manufactured and transported. The software includes the regional variation in energy as well. Here in British Columbia our impacts from energy use are minor compared to the impacts from Alberta where they burn coal instead of relying on hydro power. The software considers all these details when the providing outputs for each building material. The environmental impacts for each building element as well as for the entire building can be found in Annex D.

Construction Stage

The construction stage covers the processes from the factory gate of the different construction products to the practical completion of the construction work. The Construction processes impacts are evaluated during the Construction Stage. Similarly to the Product Stage, the Athena Impact Estimator takes into account many details for the construction process. The Software takes into account how the building material is assembled into the building structure. This may include temporary heating of the material or storage processes. One main environmental impacts for the construction stage is energy use. This energy is the energy that is required to construct the building through to structural completion. For example, lumber and other building materials require the use of a fork lift to transport them around the construction site, and thus the burning of fossil fuels are evaluated. The software also includes the impacts from transporting the finished product to the construction site. The software relies on data collected for average distances from a manufacture to a construction site within Vancouver. Furthermore the software takes into account construction waste for the various materials. For example, it is known for a given product that a certain percent of that product will be thrown out as waste instead of being consumed in the building. The disposal of this waste is also included within each products initial LCA of which the AIE draws from. Other impacts looked at within the construction stage are the emissions to air, water and land during the on-site activity.

4.0 Environmental Data

4.1 Data Sources

The environmental data that this study is based on is from the Athena LCI Database for the material process data and the US LCI Database for energy combustion and pre-combustion for electricity generation and transportation. The Athena LCI Database is very large, with LCI and LCAs for the most widely used building products. Athena Institute claims that the AIE can model 95%of the building stock in North America.[7] The Athena LCI and LCA studies are all done in house by their own experts in LCA who follow ISO standards, CSA standards, and US EPA standards. The AIE supports the US Environmental Protection Agency's TRACI v 2.1 (2012) in the sense that it uses the six midpoint impact estimation models. The midpoint impacts are discussed further in section 5.0.

Athena's experts have been doing LCA and LCI studies for quite some time now. They have over 150 ISO compliant LCA and LCI studies completed. The first version of the AIE was released in 2002 when LCA for buildings was initially starting out. The AIE is built from the ground up as it does not rely on trade or government data. All data is actual data obtained by Athena's experts for actual mill or engineered processes. The UC LCI data base is managed by the National Renewable Energy Laboratory (NREL).

Data Adjustments and Substitutions

Overall, the previous model was based on good, appropriate assumptions with accurate calculations. The data and inputs for the previous model was checked and the assumptions were evaluated. Research was done on the Athena Website and other LCA databases to see if old data could be replaced with new, more relevant data. The previous study was done in March of 2010 and thus it was difficult finding new LCA studies.

Like any model, some inaccuracies were present. The largest material inaccuracy was from the assumption that all concrete in the building was 30Mpa instead of the actual concrete strength of 25Mpa. This assumption was made because the AIE only has inputs for 15MPA or 30Mpa. No 25Mpa LCA studies were found during the research so the assumption and adjustments remained unaltered. Another inaccuracy was from the footing columns. The AIE has a maximum thickness of 500mm while some of the footings in the building are actually much greater. Simple calculations were done in the previous model to extend the length input in the AIE to make up for the extra volume lost in a reduced thickness. The thickness was checked in the AIE, which is the most recent version however the max thickness is still 500mm. The volume calculations were checked and verified so that the assumption was validated. A minor material type inaccuracy was found for the brick used on the interior atrium wall. It was found that the brick may actually contain veneer however after the construction drawings were checked it was still unclear whether or not the brick contains veneer so the original assumption was kept.

The program On-Screen Takeoff was used in the original survey of the building for the material quantification. The original survey file was looked over and evaluated and found that there wasn't any major errors. The previous student did an exceptional job in quantifying the different building materials so no further adjustments were necessary.

[7] (Institute, Athena Sustainable Materials, 2013)

Data Quality

Data quality describes the characteristics of the data used in terms of its ability to satisfy stated requirements. It is challenging for an LCA to be accurate in every single way. Many assumptions are made where there is insufficient data or data is unavailable or inaccurate; because of this there are many uncertainties throughout a model and LCA. The types of uncertainty in the LCA method are associated with data, model, temporal, spatial and variability between sources.

Data is highly dependent on the methods associated with the data collection. The Athena Database uses average results from industry and so not all data may be completely accurate. Supplies may have come from other sources where data isn't available. There is some uncertainty in the inventory analysis where the collection and allocation methods are inaccurate or values are missing. The age of data is also important to the overall quality of data. The Douglas Kenny Building was built 29 years ago and since then many things have changes so actual impacts may be significantly different. Technology is also constantly improving so that waste is minimized and efficiencies are enhanced. There are uncertainties having to do with the impact assessment, where the lifetime and the travel potential of substances may vary. For example, in the case of Eutrophication, nutrients may not reach waterways and thus not have an eutrophication impact.

The actual model of the product system also has uncertainty associated with it by having different functions of the outputs. Models can be linear or non-linear depending on the product system. For example, the impacts for producing 100kg of a material may be significantly different for producing 10 batches of 10kg of the same material. Most processes increase in efficiency as an optimum output is reached. Depending on these relationships the model may or may not be accurate.

Temporal variability is important especially in Northern areas where fluctuations in weather can be significant. There may be varying emissions depending on the time of year caused by say heating in the winter, maintaining a certain temperature for system processes, etc. The different treatment methods and end of pipe ideologies are also included in temporal variability. These methods and ideologies are constantly changing. Twenty years ago dilution was an accepted waste treatment method and now it may be frowned upon by certain individuals, groups, governments, etc.

Spatial Variability uncertainties were minimalized by the detailed LCA and LCI's that the Athena Institute have carried out. Factory inputs, outputs and emissions may differ from region to region. Some regions may have typically higher impacts. Different regions may also be impacted differently than other regions. In other words, some regions may be more sensitive to say eutrophication than acidification.

There is also some variability between objects and sources. For example, there may be differences between two similar factories but with different technology. Two factories may produce the same product but their impacts may be completely different depending on the technology used in the process. The difference between sources is mainly due to the difference in exposure patterns where some objects may react different to the exposure.

5.0 List of Indicators Used for Assessment and Expression of Results

The impact assessment method that is used in the Athena Impact Estimator is US EPA's TRACI. TRACI uses a six point midpoint estimators to assess major environmental impacts. In addition to the six midpoint estimators, fossil fuel consumption is also considered in the AIE. The six midpoint estimators are the following:

- Global Warming Potential (kg CO2 eq)
- Acidification Potential (kg SO2 eq)
- Human Health Particulate (kg PM2.5 eq)
- Eutrophication Potential (kg N eq)
- Ozone Depletion Potential (kg CFC-11 eq)
- Smog Potential (kg O3 eq)

Global Warming Potential is measured in units of kilograms of carbon dioxide equivalent. One kilogram of CO_2 equivalent has the same global warming impact of 1 kg of CO_2. Methane contributes to global warming much more than $CO_{2,}$ so methane would have a higher value of CO_2 equivalent. Global warming has countless possible endpoint impacts, which to name a few include rising ocean temperatures, draughts, more intense rainfall and hurricanes.

Acidification Potential is measured in units of kilograms of sulfur dioxide equivalent. One kilogram of SO_2 equivalent has the same acidification impact as one kilogram of SO_2. Acidification Potential describes the potential effect of acidification of soils and water by transformation of pollutants into acid. Potential endpoint impacts include acidification of lakes, oceans, soil, poor crop yields, destruction of plant life, disruptions in ecosystems and so on.

Human health (HH) particulate is a measure of very small pieces of matter that are of great concern due to their ability to be inhaled by humans. HH Particulate is measured in units of particulate matter that is 2.5 microns in diameter equivalent. Once inhaled the fine particulate matter is able to travel deep into an individual's lungs. Adverse health effects are associated with fine particulate matter.

Eutrophication Potential is a measure of increased biological activity in the air, water and soil as a result of an increase in available nutrients. Eutrophication potential is measured in kg of nitrogen equivalent. Usually nutrients limit the amount of biological activity in a medium. Once nutrients are added the biologically activity increase dramatically consuming an energy source and the nutrients. Once the energy source or nutrient source is depleted the biological microbes or bacteria die and fall to the bottom if in a water body. Once on the bottom they decay consuming the oxygen in the medium and thus causing an oxygen depleted medium. This entire process is known as Eutrophication. Possible effects of eutrophication include death of fish and other marine species, toxicity to mussels, clams and other filter feeders.

Ozone depletion is caused by compounds that react with the ozone layer made up of O_3 to form O_2 and another co-product depending on the compound. Ozone depletion is measured in kilograms of chloral floral carbons (CFC-11) equivalent. The ozone protects the earth from harmful ultraviolent radiation. By depleting the ozone layer possible effects include increase cases of skin cancer, cell damage, and plant damage.

Smog Potential is measured in kilograms of ozone equivalent. Smog deteriorates air quality immensely leading to health effects such as asthma, carbon monoxide poisoning, eye and nose irritation, bronchitis and other respiratory effects. Some compounds that contribute to smog are Sulfur compounds (SO_X) and Nitrogen compounds ($NO_{x).}$

6.0 Model Development

The original inputs were obtained using construction drawings to quantify building materials. The software, OnScreen TakeOff was used to make quantifying the building materials more manageable and more accurate. OnScreen TakeOff is used by surveying companies who give cost estimates based on the quantity and price of the building materials. In our case we used the software to quantify the building materials in order to calculate the environmental impacts associated with the different materials.

As introduced in section 2.3 the previous model was broken down into Level 3 elements. The first step in breaking down the previous model was to look at the inputs and assumptions documents from the previous model. From the input document the level 3 elements were easily broken down into CIQS Level 3 elements. This was done by looking at each input and making a decision of which element each input fell under. Since the inputs were already broken into the “five categories” it made things simple to distinguish since the categories were similar. The building inputs were broken down into the following six elements listed below. Further information on assumptions and model inputs can be found in Annex-D.

A11-Foundation

The previous model’s first category was foundations and so all the inputs in AIE were copied to a new model called ‘A11 – Foundation’. The inputs under this model were the 10 types of rectangular footings and the 5 types of strip footings. The concrete used throughout the entire building was specified at 25Mpa. The software does not have an input for 25 Mpa concrete so the next closest strength, 30 Mpa was used. No new LCI data was found for 25 Mpa concrete and so the old assumption was accepted.

A21 – Lowest Floor Construction

The lowest floor construction model included the slab on grade concrete and the vapour barrier layer, and ground floor beam. The previous model had a single entry for the slab on grade and the vapour layer in such that an envelope was entered in. The software has inputs of 100 and 200mm available for the thickness of concrete. The thickness of concrete in the building was 130mm and so a volume calculation was done in order to make up for the difference in selection 100mm thickness. After review the envelope was accepted as an accurate representation.

A 22- Upper Floor Construction

Upper Floor Construction consisted of all floors except from the ground floor, stairs, and all columns and beams not supporting the roof. All the floors except the ground floor were modeled in the previous model as a single entry. This entry was copied over to the new model since it included exactly what is required for the 'Upper Floor Construction element'. The material for the stairs was originally modeled as part of the foundations due to the freedom to specify the amount of rebar. Since there still isn't a stair function in the AIE, the stairs input were copied over to the new model. The columns and beams for each floor was entered as a single input. These were also copied to 'Upper Floor Construction' except of course the ground floors columns and beams.

A 23- Roof Construction

The two Roof systems from the old model were copied into the new model without any changes. The concrete roof system is similar to the floor system where the beams are built into the roof system. The AIE has the exact input for the penthouse roof system so this input was used in the model. The skylight was originally modeled as a curtain wall since the software doesn't have an input for skylights. The curtain wall supports the skylight so it was also modeled under 'Roof Construction'. The last input that was modeled as 'Roof Construction' was the 1.2m tall 200mm thick parapet that surrounds the main roof. The parapet was viewed as part of the roof system and therefore was also modeled as Roof Construction. The parapet could have been modeled under 'Walls Above Grade' since it could be argued as an extension of an exterior wall.

A-32 Walls Above Grade

As mentioned previous there are no walls below grade so all exterior walls are modeled as walls above grade. The majority of exterior walls consist of 200mm thick cast in place concrete wall followed by 89mm steel stud interior and filled with 'Batt' insulation and covered with 15.9mm sheet of poly drywall on the interior. The other exterior walls are the walls that make up the penthouse. They are modeled as steel stud walls with metal cladding. The windows that make up the exterior wall were also modeled as 'Walls Above Grade'. The AIE has an input function for the wall envelope which includes the type and quantity of windows.

B-11 Partitions

Pretty much all inputs from the previous model that was not already classified into elements was modeled as Partitions. Categories that fell into the Partition's element include all interior walls, interior windows and doors, washroom walls, concrete block wall, and the brick that surrounds the atrium. Steel

Stud walls made up the majority of the interior walls. The ground floor alone had over one kilometer of walls. This is mainly due to the extreme number of small offices and laboratories.

From each of these models a reference flow was obtained which is the "measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit"[8]. Each element has a certain function that it performs. These different elements can then be compared to other element based on the functional unit. For all the elements the functional unit is meters squared. The areas however are different for each element. Table 4 defines what the functional unit represents.

Table 4 Descriptions of Measurements for Level 3 Elements

CIVL 498C Level 3 Elements		Units	Description of What Was Measured
A11	Foundations	m^2	Total Area of Slab On Grade
A21	Lowest Floor Construction	m^2	Total Area of Slab on Grade
A22	Upper Floor Construction	m^2	Sum of the total area of all upper floor(s) measured from the outside face of the exterior walls
A23	Roof Construction	m^2	Sum of total area of the roof(s) measured from the outside face of the exterior walls.
A31	Walls Below Grade	m^2	Sum of total surface area of the exterior walls below grade.
A32	Walls Above Grade	m^2	Sum of total surface area of the exterior walls above grade.
B11	Partitions	m^2	Sum of total surface area of the interior walls

As you can see the functional unit is the same for all element but what the unit represents is different. After each model was complete in the AIE, a bill of materials was obtained. The bill of materials for each element is given in Table 5.

[8] (National Standard Of Canada, 2006)

Table 5 Bill of Materials for Each Element

Element	Material	Quantity	Unit
A11	Concrete 30 MPa (flyash av)	474.6	m3
	Rebar, Rod, Light Sections	3.04	Tonnes
A 21	Concrete 30 MPa (flyash av)	374.8	m3
	Rebar, Rod, Light Sections	6.06	Tonnes
	Welded Wire Mesh / Ladder Wire	3.12	Tonnes
A 22	Concrete 30 MPa (flyash av)	2331.4	m3
	Precast Concrete	578.2	m3
	Rebar, Rod, Light Sections	577.8	Tonnes
	Welded Wire Mesh / Ladder Wire	7.33	Tonnes
A 23	5/8" Moisture Resistant Gypsum Board	437.6	m2
	Aluminum	6.08	Tonnes
	Ballast (aggregate stone)	107100	kg
	Concrete 30 MPa (flyash av)	182.30	m3
	EPDM membrane (black, 60 mil)	78.37	kg
	Extruded Polystyrene	6446.9	m2 (25mm)
	Galvanized Decking	3.94	Tonnes
	Galvanized Sheet	0.42	Tonnes
	Glazing Panel	15.14	Tonnes
	Hollow Structural Steel	10.86	Tonnes
	Joint Compound	0.44	Tonnes
	Modified Bitumen membrane	18539.1	kg
	Nails	0.13	Tonnes
	Open Web Joists	4.63	Tonnes
	Paper Tape	0.01	Tonnes
	Precast Concrete	172.5	m3
	Rebar, Rod, Light Sections	4.55	Tonnes
	Screws Nuts & Bolts	0.21	Tonnes
	Welded Wire Mesh / Ladder Wire	2.18	Tonnes
A 31	-	0.0	-
A 32	1/2" Moisture Resistant Gypsum Board	641.4	m2
	1/2" Regular Gypsum Board	3585.7	m2
	6 mil Polyethylene	4076.5	m2
	Aluminum	15.09	Tonnes
	Commercial(26 ga.) Steel Cladding	641.4	m2
	Concrete 20 MPa (flyash av)	579.7	m3
	Concrete 30 MPa (flyash av)	684.5	m3
	Double Glazed No Coating Air	555.5	m2
	EPDM membrane (black, 60 mil)	1031.8	kg
	FG Batt R11-15	10699.2	m2 (25mm)
	Galvanized Sheet	7.50	Tonnes
	Galvanized Studs	12.32	Tonnes
	Joint Compound	4.22	Tonnes

	Nails	1.28	Tonnes
	Paper Tape	0.05	Tonnes
	Rebar, Rod, Light Sections	65.35	Tonnes
	Screws Nuts & Bolts	0.53	Tonnes
	Small Dimension Softwood Lumber, kiln-dried	5.68	m3
	Water Based Latex Paint	120.14	L
B11	1/2" Moisture Resistant Gypsum Board	1142.36	m2
	1/2" Regular Gypsum Board	29218.10	m2
	Aluminum	1.81	Tonnes
	Concrete Blocks	6459.76	Blocks
	Double Glazed No Coating Air	125.60	m2
	EPDM membrane (black, 60 mil)	123.56	kg
	FG Batt R11-15	1392.63	m2 (25mm)
	Galvanized Sheet	26.28	Tonnes
	Galvanized Studs	41.77	Tonnes
	Joint Compound	30.30	Tonnes
	Mortar	123.43	m3
	Nails	1.38	Tonnes
	Ontario (Standard) Brick	556.78	m2
	Paper Tape	0.35	Tonnes
	Rebar, Rod, Light Sections	21.02	Tonnes
	Screws Nuts & Bolts	1.80	Tonnes
	Small Dimension Softwood Lumber, kiln-dried	37.01	m3
	Solvent Based Alkyd Paint	4.72	L
	Water Based Latex Paint	333.46	L

7.0 Communication of Assessment Results

Life Cycle Results

The impact results for the entire building and individual elements are outputted in table format. The results are summarized in the figures 1 through 7. Once again there isn't any walls below grade, so all impacts for the element "Walls Below Grade" are zero. Since concrete is the main material in the Douglas Kenny Building, the majority of the impacts are from the manufacturing and transport of the concrete. Global warming potential was chosen to be to be the main focus of the environmental impacts for the UBC 2013 benchmarking. Further analyses of global warming potential for building and building elements are discussed further in Annex A.

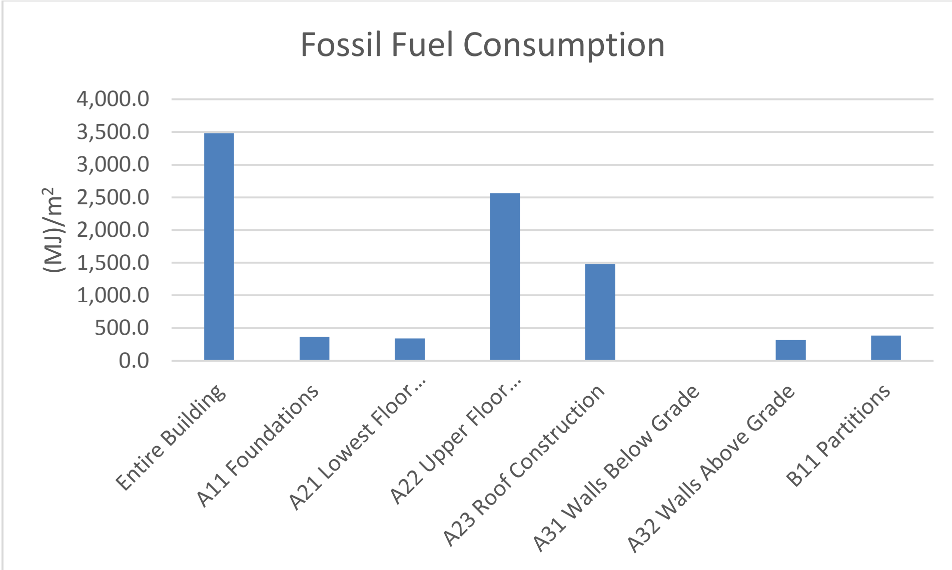

Figure 1 Fossil Fuel Consumption

It should be noted that if you sum up all the elemental impacts, the result will be greater than the actual impacts from the entire building. This is because additional impacts are factored in due to the construction of a building element. For example, the transportation impacts of transporting concrete may be lower if a large quantity of concrete was transported rather than many small quantities. The main impacts for fossil fuel consumption comes from the manufacturing process. Fossil fuel is also used for transportation to the site and for the transportation of materials around the site. The Douglas Kenny building is also 17.6m tall so raising materials up to the roof has also been factored in.

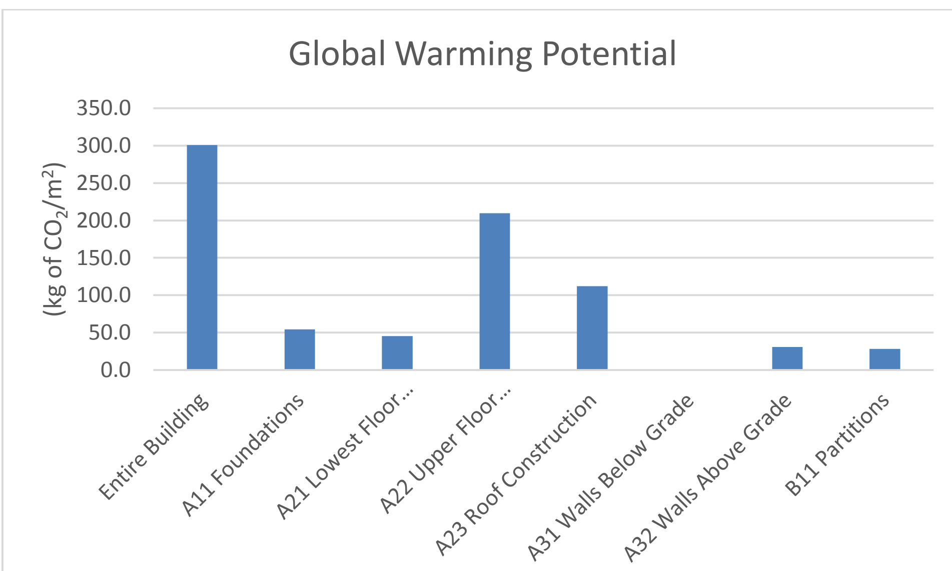

Figure 2 Global Warming Potential

The global warming potential is also highly connected to the manufacturing of concrete. All foundations, floors, and the majority of the roof are constructed using concrete. This is the main reason why the upper floor construction and roof construction have particularly high global warming potential.

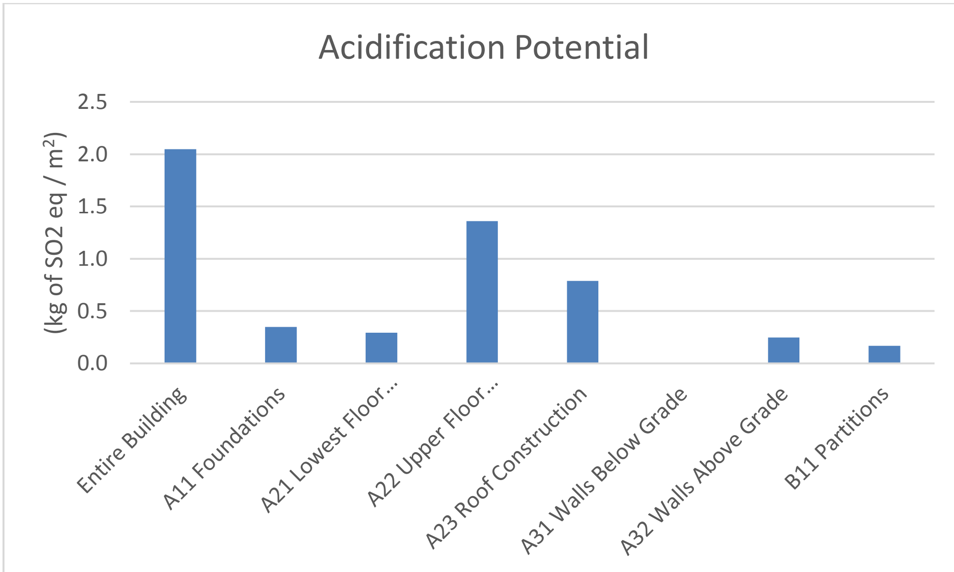

Figure 3 Acidification Potential

The acidification potential as seen in figure 3 above, is relatively low. This is partly due to the fact that here in British Columbia, our electricity comes from hydro power. It would be expected that if the building was constructed in a location that solely depends on coal fired power, the acidification impacts would be much greater. The same reasoning can be applied to the human health criteria where the poor air quality is associated with burning coal and other fossil fuels. The main impacts for human health are from the manufacturing stage. Very little of the impacts are associated from the transport and construction.

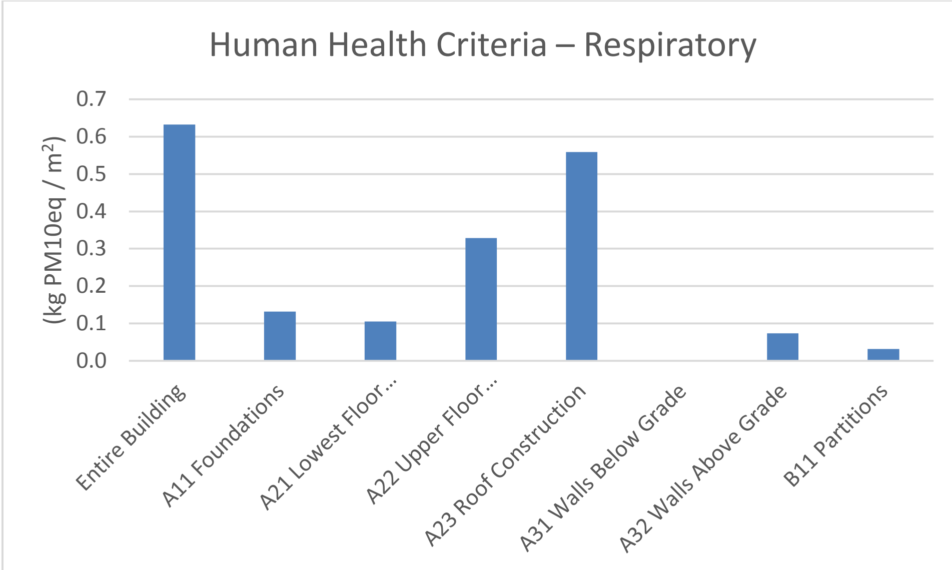

Figure 4 Human Health Midpoint Impact

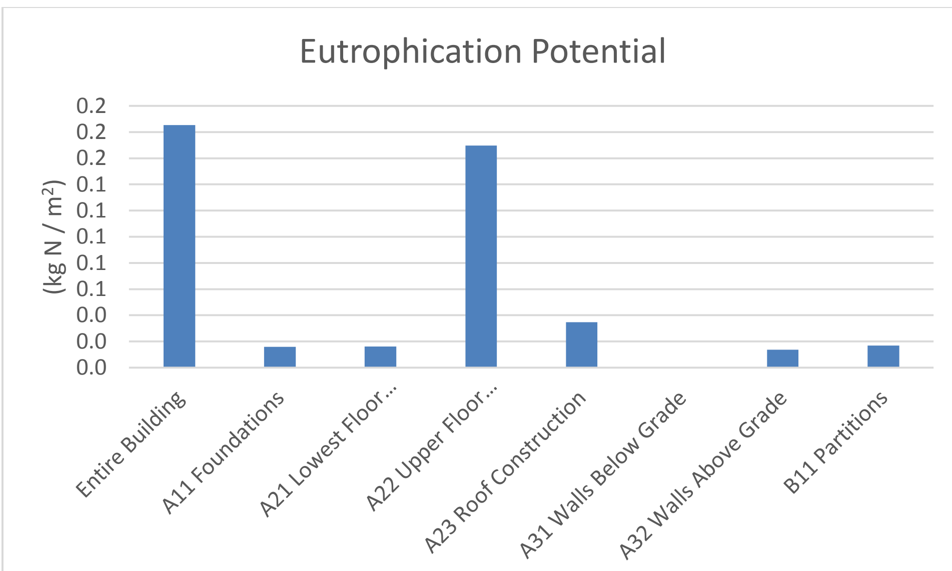

Figure 5 Eutrophication Potential

It is expected that the eutrophication potential for buildings would be fairly low. Eutrophication is a big concern in farming and chemical manufacturing industry. Most building supplies require minimal chemical fertilizers and other products that contribute to eutrophication.

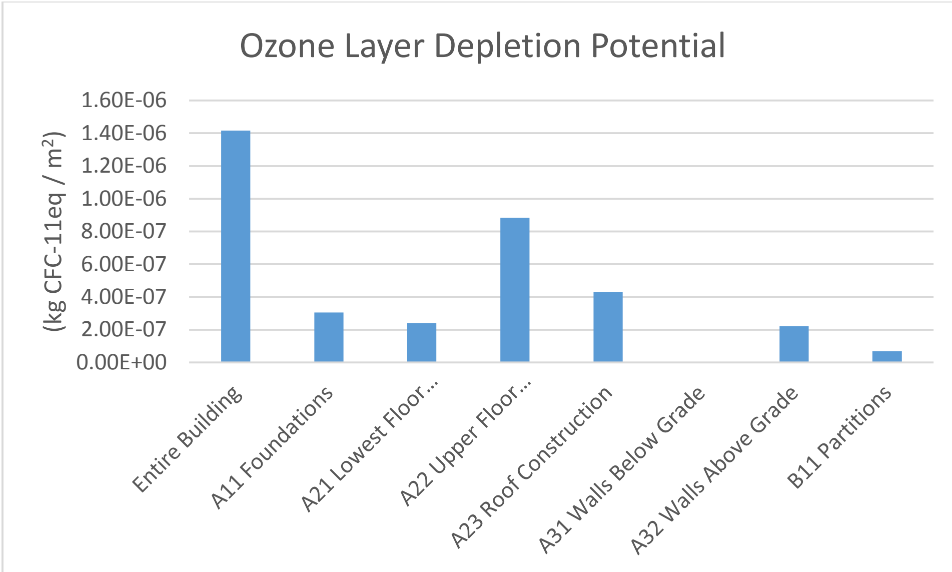

Figure 6 Ozone Layer Depletion Potential

The Douglas Kenny has minimal impacts to the depletion of the ozone layer. As seen in figure 5 the total ozone layer depletion potential is in the order of $1*10^{-6}$ kg of CFC-11/m^2. CFC's are mostly associated with aerosols and refrigeration units.

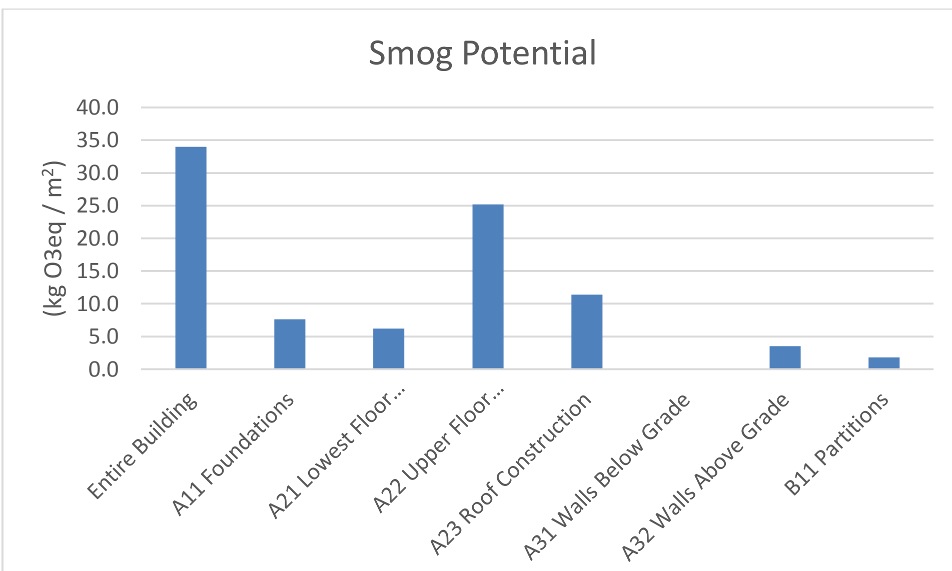

Figure 7 Smog Potential

The smog potential is also associated with the vast quantity of concrete. As mentioned previously, the concrete that makes up the upper floor construction and roof construction contribute to the high environmental impacts.

The partitions used in the Douglas Kenny building have minimal overall impacts. This is very interesting because the building as over a kilometer of interior walls on the first floor alone. The steel stud interior walls have a low environmental impact. In order to see what design of building elements have the least environmental impacts similar studies were done in order to create a data base in that an average benchmark was calculated. The UBC 2013 benchmark is discussed in Annex A. The recommendations from the benchmark and from this LCA study can be found in Annex B.

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Annex A - Interpretation of Assessment Results

Benchmark Development

The concept of benchmarking in LCA is to get a better idea of the impacts of the object in assessment by comparing them to the average impacts of similar product or product systems. In doing so, the person doing the assessment can verify which processes are least environmentally friendly and which processes should be adopted so that current processes can be made better.

In our case the product was a particular building in which an LCA was completed. The Douglas Kenny LCA study was completed in the same time frame as 16 other LCA studies that were done on other institutional buildings at UBC. These studies were completed by UBC students from varying backgrounds during the CIVL 498C class in the fall semester of 2013.

Each study had the exact same common goal, scope, and model development as this LCA study. By having the exact same goal and scope, similar models were created such that the results could be compared during comparative assertion. In order for a comparative assertion, a functional unit was chosen so that institutional buildings that have different uses could be compared. This was done by taking the impact results from the AIE and dividing it by the total area of the building or total area of the element.

The Benchmark shows on average how UBC's buildings have impacted the environment. As UBC continues to become more sustainable, decision makers can look at future designs for buildings and compare it to the benchmark. By using the benchmark and LCA data base for various building designs UBC can request specific designs and make decisions that are backed by both scientific data and cost estimating.

UBC Academic Building Benchmark

The environmental impact results from 16 other building LCA's were averaged for each element as well as the entire building. These average were then labelled as the "UBC 2013 Benchmark". In order to compare the Douglas Kenny Building to the benchmark the percent difference was calculated between the Douglas Kenny building and the benchmark. The results for the percent difference are shown below in figure 8.

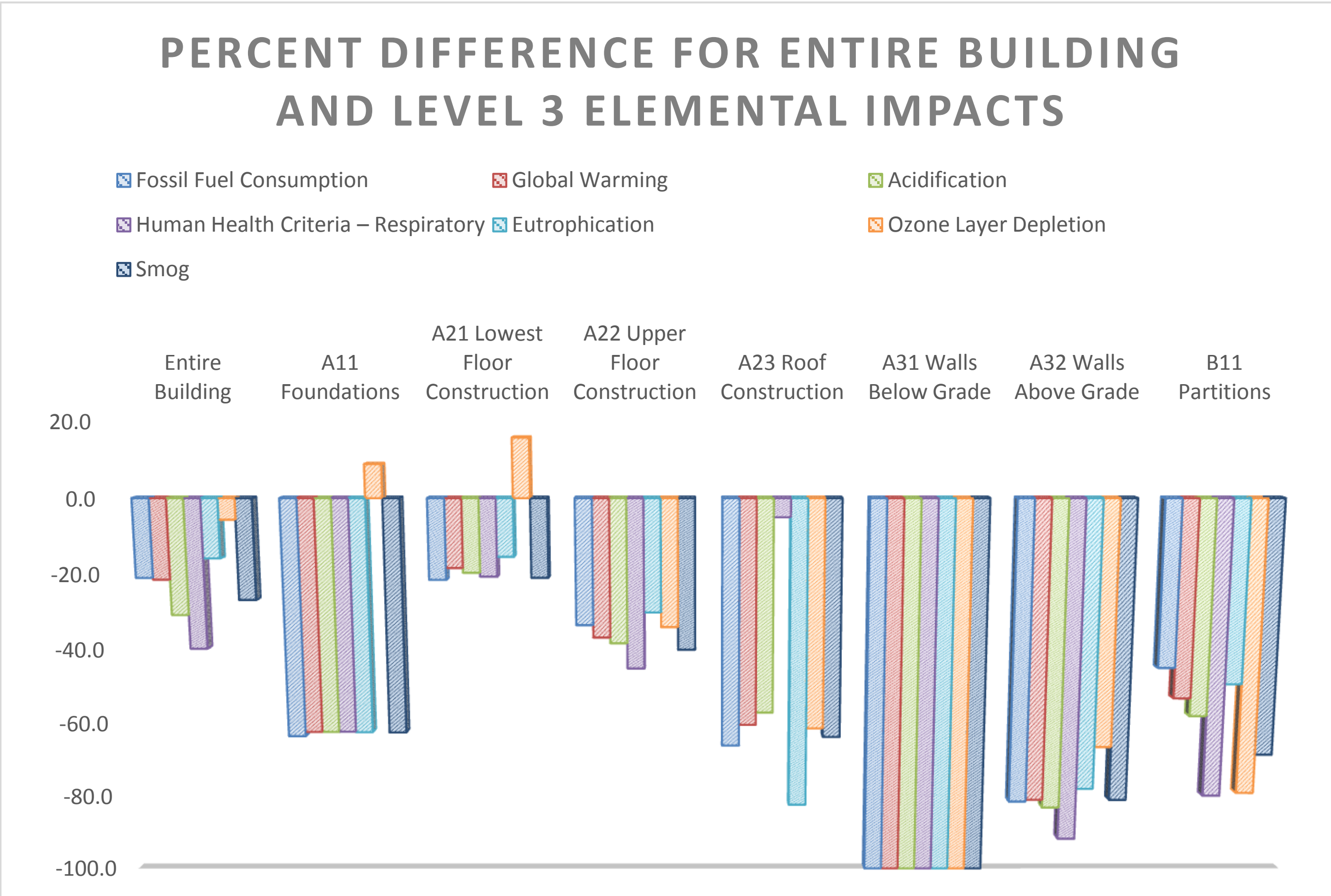
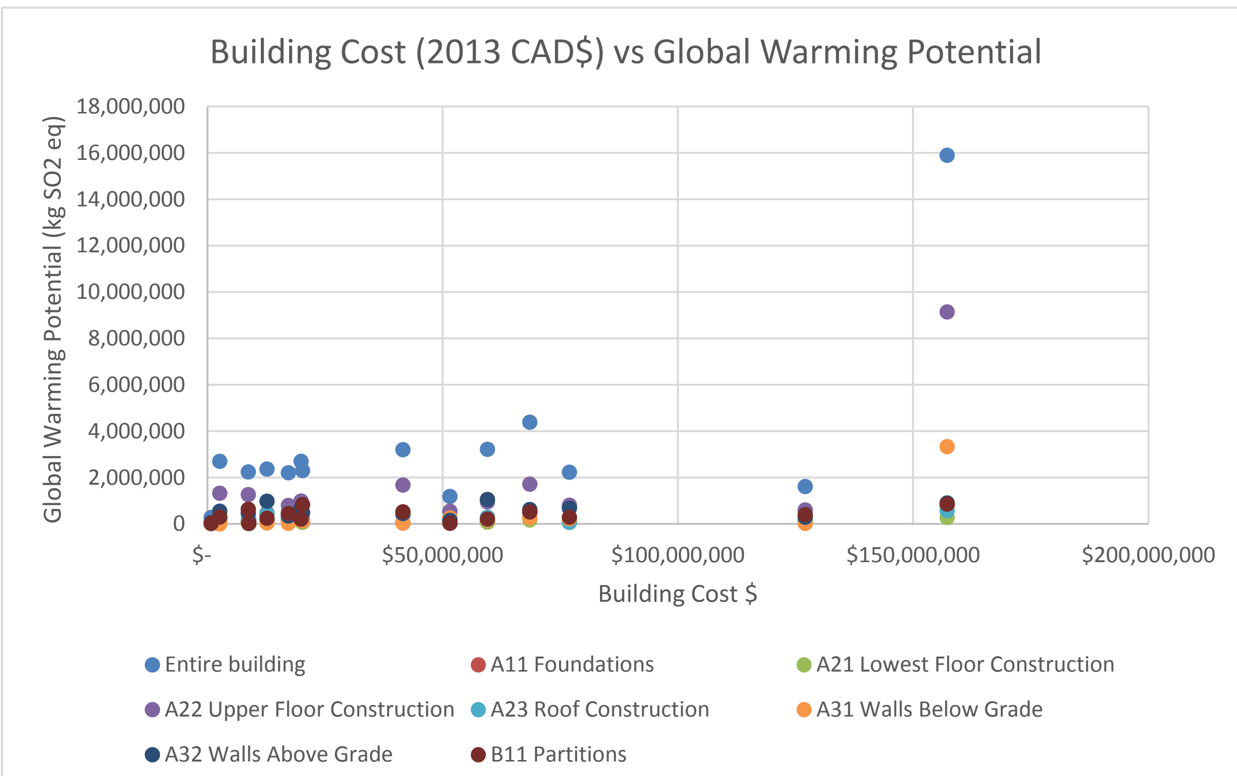


Figure 8 The difference in percent between the building and element from the UBC 2013 benchmark

It can be seen that the Douglas Kenny building is well below the benchmark for all environmental impact categories except for ozone depletion in the Foundation Element and the Lowest Floor Construction Element. There is a one hundred percent difference for the walls below grade. This is because the building doesn't have any walls below grade. This contributes immensely for the overall building effects since large excavations were not necessary, thus decreasing the construction process impacts. The majority of the roof system is constructed from concrete so that is partially the reason for the increased impact levels for human health. As mentioned in section 7.0 the ozone layer depletion results are minimal for buildings. The actual ozone depletion impact for the entire building is only 0.01kg of CFF-11 equivalent, so because of this percent difference could be potentially ignored.

To get a better sense of how the Douglas Kenny building compares to other UBC buildings the cost of the building was graphed against the global warming potential as seen in figure 9. Global warming potential was designated by the class to be studied in more detail because the class was most concerned about climate change. The global warming potential equivalent in the figure is in total kilograms of carbon dioxide equivalent. It can be seen that buildings with a higher construction cost typically have a much higher global warming potential impact. This may be due to the size of the building and thus the amount of materials in the building rather than the actual design of the building components.

The Douglas Kenny Building had a construction cost of $2.56M (2013 $CAD) so it is in the lower left hand corner of the figure. Compared to other UBC buildings, the building has low global warming potential. The Douglas Kenny building construction cost would have been directly related to the price of concrete. There is a possibility that concrete at the time of construction was fairly inexpensive, and thus might be



the reason why the design was chosen; which is likely due to UBC's tight budget at that time.

Looking at individual elements we can see that the Douglas Kenny building is in line with other building that were constructed with the same budget. Figure 10 shows the lower left hand corner of figure 9 in greater detail.

Figure 9 Building cost for each building looked at in the 2013 UBC study verses the Global Warming Potential for each building and building element.

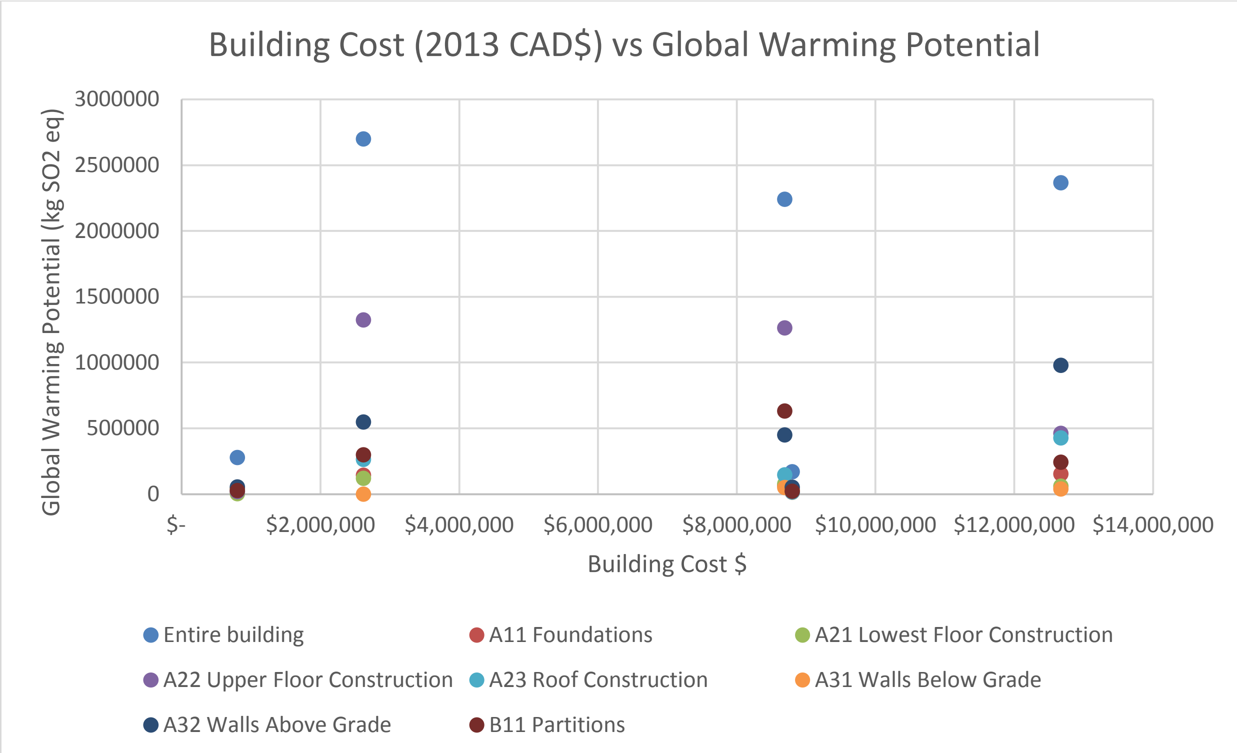


Figure 10 Inexpensive Buildings vs. Global Warming Potential

The Douglas Kenny Building has a slightly higher GWP for the entire building. This may be due to the fact that the building has many interior walls. The main functions of the Douglas Kenny Building is for faculty offices and research laboratories, both of which require small rooms. This is shown further when looking at the Partition elemental impact.

Overall the Douglas Kenny building is significantly better than the benchmark that was calculated. The majority of the buildings looked at within this benchmarking study are buildings that were constructed over the past 100 years. The Douglas Kenny building in retrospect is a fairly new building and may be a reason for lower impacts. On a “per meter” squared basis, the building out performs the benchmark in every single way. The fact that the ozone layer depletion is higher than the benchmark may be due to uncertainties.

Annex B - Recommendations for LCA Use

Life cycle assessments have a wide range of uses. They have been used to increase product system efficiencies on a wide variety of products. They have been able to pin point parts of processes that have large environmental impacts. By knowing the major cause of these impacts, companies, owners, governments and so on can make their processes more environmentally friendly.

Until recently LCA's have mostly been associated with products orientated towards consumers. It wasn't until this past decade that LCA's began to be incorporated into building design. UBC is at the forefront of this new paradigm. UBC has shown great interest in setting an example towards students and other universities of what a sustainable university really is. This is evident with the construction of the new biomass plant and new internal heating as well as the award winning CIRS building. UBC is however, very distant from actually setting up design policies for new buildings to be constructed.

LCA's have yet to be analysed in the design stage of new building considerations at UBC. In order for LCA to be operationalized a few things need to occur. It is recommended that an alternative tool be developed that is more geared towards building elements. The tool used during this study is geared towards whole building LCA.

The AIE was acceptable in this study since all of the other buildings studies were using the same tool and methods as well. The AIE was not ideal since each model had an input for building height and building area. For each model the floor area was set to $1m^2$ and the building height to 17.6m. Some tests were done that showed that the difference between $1m^2$ and $100m^2$ had little change. Nonetheless it still adds some uncertainty to the model.

Going forward for using LCA's at UBC, the 'Building Use' and 'End of Life', should be taken into account for the complete life cycle of the building. 'Building Use' would include the yearly energy consumption, water consumption as well as maintenance. Some of the older buildings at UBC may also undergo heavy renovations to modernize the buildings. A detailed goal and scope would have to be developed in order to take into account many of these details. The end of life of the buildings may be difficult since the building life may not yet be decided. Once a good understanding of LCA by decision makers has been reached, it can then be brought into the planning of new buildings, specifically at the design stage of the building.

It would be best to compare both environmental impacts and costing for particular designs during the design phase. A new version of Onscreen Takeoff that includes a modified AIE would be most ideal. Surveying companies that specialize in cost estimating could also include LCA to bring LCA into the design stage. These companies are experts at estimating quantities and categorizing buildings into building elements and thus they would be good at LCA too if given proper training in LCA. If they were able to provide LCA results as well as cost estimates to a client, UBC in this case, it would easy to operationalize.

UBC could facilitate this by creating policies that request LCA results be submitted along with costing for given designs. A designer could either get the surveying company to provide the LCA results or another third party. UBC now also has a LCA database from previous designs. This database could be used for setting examples for where they want to go with new designs. For example, UBC can say that they want a building that has less environmental impacts than the building with the least amount of impacts or some percentage better than the benchmark.

Like in any LCA study, data quality and model quality are exceptionally important. The LCA in this study as well as all the other LCA's done in order to reach the UBC 2013 benchmark, should be externally reviewed. Like any university course, some students may not put in as much of an effort so some models will be very good and some will be poor. Poor models that rely on weak assumptions should be discarded and eventually redone. Data quality will improve with improving technologies and will become more available. This LCA only considered the impact categories that the AIE provided. Other impact categories such as ocean acidification, depletion of resources and so on should be evaluated for society's concerns and feasibility. It is unlikely to take into account every single impact category due to time and cost constraints and thus only the most concerning impacts should be looked at.

Annex C - Author Reflection

I am 4th year environmental engineering student who had little building construction knowledge prior to CIVL 498C. I have completed a couple courses that touched on LCA and sustainability. The courses I took at UBC were Sustainable Development and Green Engineering. Both of these courses briefly looked at LCA. I was introduced to LCA but still lacked the thorough knowledge it takes to complete a well-rounded LCA. Through this course I learned in depth on how to set a detailed goal and scope, the different uncertainties with data, model, and so on. I was interested in learning the various software used in this course and in doing a term project on an actual UBC building.

I understand that my name will be added to a list as well as all those who contributed to the benchmark and UBC's LCA data base. I have not had anyone review my work before submitting it, so it may contain human errors such as calculation errors and inappropriate methods, etc. I expect that these errors be within acceptable limits. I spent a considerable amount of time on this report, on my model, and on learning the LCA concepts. Unfortunately this was also one of my busiest semesters so I was unable to allocate the amount of time I would like to have allocated. I feel that gained a lot of good experience, and have become more motivated to bring sustainability to everything I do.

	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.

1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A = applied	Volume calculations, extending length of footings, walls, etc. Critical review of calculations and assumptions.
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	A = applied	Find solutions to errors from previous model, solve problems that Rob gave us,
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.	A = applied	Interpretation of LCA data, where are the most sensitive areas and how do they effect the overall effect

4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	I = introduced	Introduced to the design of LCA data base project at UBC. Incorporation of LCA into UBC's sustainability policies.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	IDA = introduced, developed & applied	Use of Athena Impact Estimator, Onscreen Takeoff, Excel, Word. Learned how to operate two engineering related programs in depth.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	DA = developed & applied	Many in class group activities where we were asked to solve complex problems.

7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	A = applied	Class discussions, group discussions, report writing, etc.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	A = applied	Learned more in depth about environmental impacts of buildings and how to use scientific data to assess them.
9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural	DA = developed & applied	Learned how various engineering designs have different impacts to air, land and water.

		aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.		
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A = applied	Term Report that will be actually be used, had to use appropriate methods.
11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	A = applied	Brought past construction values into current dollars using escalation rates.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	D = developed	Learned from a passionate instructor who taught new, still in development concepts that will be very important for today's society and future engineering projects.

Annex D – Impact Estimator Inputs and Assumptions

The following table contains all the inputs that were entered into the Athena Impact Estimator. The Athena Input in some cases, had to be modified from the OST Outputs. The calculations can be found in the excel document.

	Quantity	Units	Assembly Type	Assembly Name	Input Fields	OST Outputs	Athena Input
A11 Foundation	486	**m²**					
			1.1 Concrete Footing				
				1.1.1 Footing_Column_Type1			
	3.0625				Length (m)	1.75	21.09
					Width (m)	1.75	1.92
					Thickness (mm)	600.00	500.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.1.2 Footing_Column_Type2			
	5.29				Length (m)	2.30	26.18
					Width (m)	2.30	2.91
					Thickness (mm)	800.00	500.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	20M	20M
				1.1.3 Footing_Column_Type3			
	4				Length (m)	2.00	7.10
					Width (m)	2.00	2.37
					Thickness (mm)	700.00	500.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	20.00	20.00
				1.1.4 Footing_Column_Type4			
	7.84				Length (m)	2.80	17.71
					Width (m)	2.80	3.54
					Thickness (mm)	800.00	500.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	25.00	20.00

			1.1.5 Footing_Column_Type5			
9				Length (m)	3.00	7.10
				Width (m)	3.00	3.55
				Thickness (mm)	700.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	25.00	20.00
			1.1.6 Footing_Column_Type9			
27				Length (m)	6.00	13.89
				Width (m)	4.50	5.44
				Thickness (mm)	700.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	20M	20M
			1.1.7 Footing_Column_Type10			
82.5				Length (m)	11.00	16.50
				Width (m)	7.50	13.00
				Thickness (mm)	1300.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	20M	20M
			1.1.8 Footing_Column_Type11			
72.25				Length (m)	8.50	13.17
				Width (m)	8.50	13.17
				Thickness (mm)	1200.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	20M	20M
			1.1.9 Footing_Column_Type13			
4.8				Length (m)	1.20	1.63
				Width (m)	4.00	4.43
				Thickness (mm)	750.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	20M	20M
			1.1.10 Footing_Column_Type14			
65				Length (m)	10.00	12.10
				Width (m)	6.50	8.60
				Thickness (mm)	800.00	500.00
				Concrete (MPa)	25.00	30.00
				Concrete flyash %	-	average
				Rebar	20M	20M
			1.1.11 Footing_Strip_Type6			
				Length (m)	30.00	30.00

					Width (m)	0.85	0.85
	25.5				Thickness (mm)	350.00	350.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.1.12 Footing_Strip_Type7			
					Length (m)	189.00	189.00
	122.85				Width (m)	0.65	0.65
					Thickness (mm)	250.00	250.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	15.00	15.00
				1.1.13 Footing_Strip_Type8			
					Length (m)	56.00	56.00
	36.4				Width (m)	0.65	0.65
					Thickness (mm)	250.00	250.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.1.14 Footing_Strip_Type12			
					Length (m)	7.00	7.00
	5.25				Width (m)	0.75	0.75
					Thickness (mm)	250.00	250.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	15M	15M
				1.1.15 Footing_Strip_Type15			
					Length (m)	11.00	11.00
					Width (m)	1.40	1.40
	15.4				Thickness (mm)	250.00	250.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	15M	15M
A21-Lowest Flow Construction	2653	m^2					
			1.2 Concrete Slab-on-Grade				
				1.2.1 SOG_100mm			
					Length (m)	51.51	58.73
					Width (m)	51.51	58.73
					Thickness (mm)	130.00	100.00
					Concrete (MPa)	25.00	30.00

					Concrete flyash %	-	average
				Envelope	Category	Vapour Barrier	Vapour Barrier
					Material	Polyethylene 6 mil	Polyethylene 6 mil
					Thickness	6mm	6mm
				3.1.1 - Column_Concrete_Beam_GroundFloor			
					Number of Columns	35.00	35.00
					Number of Beams	-	
					Floor to Floor Height (m)	0.40	0.40
					Bay Sizes (m)	10000.00	10000.00
					Supported Span	10000.00	10000.00
					Live Load (kPa)	3.60	3.60
A 22 Upper Floor Construction		63 17					
				1.1.16 Footing_Stairs			
					Length (m)	-	15.85
					Width (m)	-	15.85
					Thickness (mm)	-	200.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	10M	10M
				1.1.17 Footing_StaiwellFloors			
					Length (m)	15.23	15.23
					Width (m)	15.23	15.23
					Thickness (mm)	200.00	200.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	-	average
					Rebar	10M	10M
	3 Colums						
			3.1 Concrete Column				
				3.1.2 - Column_Concrete_Beam_Floor2			
					Number of Columns	35.00	35.00
					Number of Beams	56.00	56.00
					Floor to Floor Height (m)	4.30	4.30
					Bay Sizes (m)	10.00	10.00

				Supported Span	10.00	10.00
				Live Load (kPa)	3.60	3.60
			3.1.3 - Column_Concrete_Beam_Floor3			
				Number of Columns	34.00	34.00
				Number of Beams	52.00	52.00
				Floor to Floor Height (m)	4.30	4.30
				Bay Sizes (m)	10000.00	10000.00
				Supported Span	10000.00	10000.00
				Live Load (kPa)	3.60	3.60
			3.1.4 - Column_Concrete_Beam_Floor4			
				Number of Columns	31.00	31.00
				Number of Beams	42.00	42.00
				Floor to Floor Height (m)	4.30	4.30
				Bay Sizes (m)	10000.00	10000.00
				Supported Span	10000.00	10000.00
				Live Load (kPa)	3.60	3.60
			3.1.5 - Column_Concrete_Beam_Penthouse			
				Number of Columns	20.00	20.00
				Number of Beams	33.00	33.00
				Floor to Floor Height (m)	4.30	4.30
				Bay Sizes (m)	10000.00	10000.00
				Supported Span	10000.00	10000.00
				Live Load (kPa)	3.60	3.60
	4 Floors					
		4.1 Concrete Pre Cast Double T				
			4.1.1 - Floor_PrecastDoubleT			
				Number of Bays	57.09	57.00
				Bay Sizes (m)	10.00	10.00
				Span (m)	10.00	10.00
				Live Load (kPa)	3.60	3.60
A 23 Roof Construction	**2183** m2					
	5 Roof					
		5.1 Concrete Precast Double T				
			5.1.1 -			

Roof_ConcretePrecastDoubleT_Main					
	Envelope	Number of Bays	16.58	17.00	
		Bay Sizes (m)	10.00	10.00	
		Span (m)	10.00	10.00	
		With or without concrete topping	Topping Included	Topping Included	
		Live Load (kPa)	3.60	3.60	
		Category	Roof Envelopes	Roof Envelopes	
		Material	Roof Membrane	Standard Modified Bitumen Membrane 2 Ply	
		Thickness (mm)	-	-	
		Category	Insulation	Insulation	
		Material	Rigid Insulation	Polystyrene Extruded	
		Thickness (mm)	75.00	75.00	
		Category	Roof Envelopes	Roof Envelopes	
		Material	Gravel Ballast	Ballast (aggeragate Stones)	
		Thickness (mm)	50.00	-	
5.2 Open Web Steel Joist					
5.2.1 - Roof_OpenWebSteelJoists_Penthouse					
	Envelope	Roof Width (m)	39.78	39.78	
		Span (m)	10.00	10.00	
		Live load (kPa)	3.60	3.60	
		Steel Joists	Open Web	Open Web	
		Decking Type	Steel	Steel	
		Category	Gypsum Board	Gypsum Board	
		Material	Exterior Drywall	Gypsum Moisture Resistant	
		Thickness (mm)	15.90	5/8"	
		Category	Roof Envelopes	Roof Envelopes	
		Material	Roof Membrane	Standard Modified Bitumen Membrane 2 Ply	
		Thickness (mm)	-	-	
		Category	Insulation	Insulation	
		Material	Rigid Insulation	Polystyrene Extruded	
		Thickness (mm)	75.00	75.00	
		Category	Roof Envelopes	Roof Envelopes	

					Material	Gravel Ballast	Ballast (aggeragate Stones)
					Thickness (mm)	50.00	-
	6 Extra Basic Materi al						
			6.1 Concrete				
				6.1.1 ExtraBasicMaterial_Concrete			
					30 MPa Average Flyash (m^3)	88.62	88.62
			6.2.1 Steel				
				6.2.1 ExtraBasicMaterial_Steel			
					Tonnes	110.75	110.75
			2.4 Curtian Wall				
				2.4.1 Wall_Curtain_AllFloors			
	475.56				Length (m)	3.22	3.22
					Height (m)	147.69	147.69
					Percent Viewable Glazing	86.88	86.88
					Percent Spandrel Panel	13.12	13.12
					Thickness of Insulation	none	0.00
					Type	Metal Spandrel Panel	Metal Spandrel Panel
					With or without concrete topping	Topping Included	Topping Included
A 32 Walls above Grade	17913	m^2					
	2 Walls						
			2.1 Cast In Placen Concrete				
				2.1.1 Wall_Cast-in-Place_AllFloors			
					Length (m)	675.28	675.28
					Height (m)	4.30	4.30
	2903.704				Thickness (mm)	200.00	200.00
					Concrete (MPa)	25.00	30.00
					Concrete flyash %	average	average
					Rebar	20M	20M
				Window Opening	Number of Windows	58.00	58.00
					Total Window Area (m2)	61.55	61.55
					Fixed/Operable	Fixed	Fixed
					Frame Type	Aluminum	Aluminum
					Glazing Type	Standard Glazing	Standard Glazing

		Door Opening	Number of Doors	47.00	47.00
		2.1.2 Wall_Cast-in-Place_SteelStud_AllFloors			
		Concrete	Length (m)	907.62	907.62
			Height (m)	4.24	4.24
			Wall Type	Exterior	Exterior
			Thickness	200.00	200.00
3848.3088			Reinforcement	20M	20M
			Concrete (MPa)	25.00	30.00
			Concrete flyash %	-	average
		Steel Stud	Sheathing Type	none	none
			Stud Spacing	400.00	400.00
			Stud Weight	Light Weight	Light Weight
			Stud thickness	39 x 92	39 x 92
		Window Opening	Number of Windows	497.00	497.00
			Total Window Area (m2)	557.39	557.39
			Fixed/Operable	Fixed	Fixed
			Frame Type	Aluminum	Aluminum
			Glazing Type	Standard Glazing	Standard Glazing
		Door Opening	Number of Doors	18.00	18.00
			Door Type	Solid Wood Door	Solid Wood Door
		Envelope	Category	Insulation	Insulation
			Material	Fiberglass Batt	Fiberglass Batt
			Thickness (mm)	68.50	68,5
			Category	Vapour Barrier	Vapour Barrier
			Material	Polyethylene 6 mil	Polyethylene 6 mil
			Category	Gypsum board	Gypsum board
			Material	Gysum Regular 1/2"	Gysum Regular 1/2"
		2.2.7 Wall_SteelStud_Penthouse_Exterior			
		Steel Stud	Length (m)	88.84	88.84
			Height (m)	6.72	6.72
			Wall Type	Exterior	Exterior
597.00			Sheathing Type	none	none
			Stud Spacing	400.00	400.00
			Stud Weight	Light Weight	Light Weight
			Stud thickness	39 x 152	39 x 152
		Window Opening	Number of Windows	none	none
		Door Opening	Number of Doors	8.00	8.00
			Door Type	Solid Wood	Solid Wood

							Door
				Envelope	Category	Cladding	Cladding
					Material	Metal Cladding	Steel Cladding- Comercial (26 ga.)
					Thickness	-	-
					Category	Insulation	Insulation
					Material	Fiberglass Batt	Fiberglass Batt
					Thickness	150.00	150.00
					Category	Vapour Barrier	Vapour Barrier
					Material	Polyethylene 6 mil	Polyethylene 6 mil
					Category	Gypsum board	Gypsum board
					Material	15.9 Exterior Drywall	Gypsum Moisture Resistant 5/8"
					Thickness		-
					Category	Gypsum board	Gypsum board
					Material	15.9 Exterior Drywall	Gypsum Moisture Resistant 5/8"
					Thickness		-
B11 Partition	10564						
					Thickness	-	-
			2.2 Steel Stud				
				2.2.1 Wall_SteelStud_ Ground Floor			
					Length (m)	1029.81	1029.81
					Height (m)	4.30	4.30
					Sheathing Type	none	none
					Stud Spacing	400.00	400.00
					Stud Weight	Light Weight	Light Weight
					Stud thickness	39 x 92	39 x 92
				Window Opening	Number of Windows	35.00	35.00
					Total Window Area (m2)	55.71	55.71
					Fixed/Operable	Fixed	Fixed
					Frame Type	Aluminum	Aluminum
					Glazing Type	Standard Glazing	Standard Glazing
				Door Opening	Number of Doors	133.00	133.00
					Door Type	Solid Wood	Solid Wood Door
				Envelope	Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness	-	-

			Envelope	Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
			2.2.2 Wall_SteelStud_ Floor2			
				Length (m)	565.89	565.89
				Height (m)	4.30	4.30
	2433. 327			Wall Type	interior	interior
				Sheathing Type	none	none
				Stud Spacing	400.00	400.00
				Stud Weight	Light Weight	Light Weight
				Stud thickness	39 x 92	39 x 92
			Window Opening	Number of Windows	6.00	6.00
				Total Window Area (m2)	8.85	8.85
				Fixed/Operable	Fixed	Fixed
				Frame Type	Aluminum	Aluminum
				Glazing Type	Standard Glazing	Standard Glazing
			Door Opening	Number of Doors	85.00	85.00
				Door Type	Solid Wood	Solid Wood Door
			Envelope	Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
				Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
			2.2.3 Wall_SteelStud_ Floor3			
				Length (m)	814.01	814.01
				Height (m)	4.30	4.30
	3500. 243			Wall Type	interior	interior
				Sheathing Type	none	none
				Stud Spacing	400.00	400.00
				Stud Weight	Light Weight	Light Weight
				Stud thickness	39 x 92	39 x 92
			Window Opening	Number of Windows	14.00	14.00
				Total Window Area (m2)	17.80	17.80
				Fixed/Operable	Fixed	Fixed
				Frame Type	Aluminum	Aluminum
				Glazing Type	Standard Glazing	Standard

							Glazing
				Door Opening	Number of Doors	115.00	115.00
					Door Type	Solid Wood	Solid Wood Door
				Envelope	Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness	-	-
					Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness	-	-
				2.2.4 Wall_SteelStud_ Floor4			
					Length (m)	691.41	691.41
					Height (m)	4.30	4.30
	2973. 063				Wall Type	interior	interior
					Sheathing Type	none	none
					Stud Spacing	400.00	400.00
					Stud Weight	Light Weight	Light Weight
					Stud thickness	39 x 92	39 x 92
				Window Opening	Number of Windows	3.00	3.00
					Total Window Area (m2)	2.90	2.90
					Fixed/Operable	Fixed	Fixed
					Frame Type	Aluminum	Aluminum
					Glazing Type	Standard Glazing	Standard Glazing
				Door Opening	Number of Doors	117.00	117.00
					Door Type	Solid Wood	Solid Wood Door
				Envelope	Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness	-	-
					Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness	-	-
				2.2.5 Wall_SteelStud_ Penthouse			
					Length (m)	10.77	10.77
					Height (m)	3.60	3.60
	38.77 2				Wall Type	interior	interior
					Sheathing Type	none	none
					Stud Spacing	400.00	400.00

				Stud Weight	Light Weight	Light Weight
				Stud thickness	39 x 92	39 x 92
			Window Opening	Number of Windows	none	none
			Envelope	Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
				Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
			2.2.6 Wall_SteelStud_ Washrooms			
				Length (m)	252.00	252.00
				Height (m)	4.30	4.30
1083.6				Wall Type	interior	interior
				Sheathing Type	none	none
				Stud Spacing	400.00	400.00
				Stud Weight	Light Weight	Light Weight
				Stud thickness	39 x 92	39 x 92
			Door Opening	Number of Doors	26.00	26.00
				Door Type	Solid Wood	Solid Wood Door
			Envelope	Category	Gypsum board	Gypsum board
				Material	15.9 Exterior Drywall	Gypsum Moisture Resistant 5/8"
				Thickness		-
				Category	Gypsum board	Gypsum board
				Material	Gysum Regular 1/2"	Gysum Regular 1/2"
				Thickness	-	-
		2.3 Concrete Block Wall				
			2.3.1 Wall_ConcreteBlock_SteelStud_AllFloors			
				Length (m)	124.50	124.50
				Height (m)	4.30	4.30
535.35				Rebar	-	10M
			Steel Stud	Wall Type	interior	interior
				Sheathing Type	none	none
				Stud Spacing	400.00	400.00
				Stud Weight	Light Weight	Light Weight
				Stud thickness	39 x 92	39 x 92
			Door Opening	Number of Doors	16.00	16.00

					Door Type	Steel Interior Door	Steel Interior Door
				Envelope	Category	Gypsum board	Gypsum board
					Material	Gysum Regular 1/2"	Gysum Regular 1/2"
					Thickness		-
	6 Extra Basic Material						
			6.2 Extra Cladding Material				
				6.3.1 ExtraBasicMaterial_ExtraCladdingMaterial			
					Ontario (Standard) Brick (m^2)	530.27	530.27
			6.3 Extra Envelope Material				
				6.4.1 ExtraBasicMaterial_ExtraEnvelopeMaterial			
					Standard Glazing (m^2)	95.86	47.93

The following table is all the assumptions made for each calculation and input.

Element	Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
A11- Foundation				
	1 Foundation			
		Concrete Strength of 25 Mpa was used, In Athena 30 Mpa was the closest input. No Fly ash concentration was specified, so average was used. Athena limits thickness to 500mm, to account for this limitation extra length and width is added to keep the footing volume the same, by the equation: (Extra length/ width) = [-(lenght+width)+sqrt((length+width)^2 + 4*(length*width*(thickness-500)/500))]/2 In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. Extra Length = (old length + Extra Length/Width)* Number of Footings The footings from 1.1.12 and below are strip footings		
		1.1 Concrete Footing		
			1.1.1 Footing_Column_Type1	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed.

					(Extra length/ Width) = = (-(1.75+1.75) + SQRT((1.75+1.75)^2 + (4*1.75*1.75*(600-500)/500)))/2 = 0.167 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (1.75 + 0.167) * (11 columns) = 21.09 m
				1.1.2 Footing_Column_Type2	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed. (Extra length/ Width) = = (-(2.30+2.30) + SQRT((2.30+2.30)^2 + (4*2.30*2.30*(800-500)/500)))/2 = 0.609 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (2.30 + 0.609) * (9 columns) = 26.18 m
				1.1.3 Footing_Column_Type3	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed.

					(Extra length/ Width) = = (-(2.00+2.00) + SQRT((2.00+2.00)^2 + (4*2.00*2.00*(700-500)/500)))/2 = 0.366 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (2.30 + 0.366) * (3 columns) = 7.1 m
				1.1.4 Footing_Column_Type4	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed. (Extra length/ Width) = = (-(2.80+2.80) + SQRT((2.80+2.80)^2 + (4*2.80*2.80*(800-500)/500)))/2 = 0.742 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (2.30 + 0.742) * (5 columns) = 17.71 m
				1.1.5 Footing_Column_Type5	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed.

					(Extra length/ Width) = = (-(3.0+3.0) + SQRT((3.00+3.00)^2 + (4*3.00*3.00*(700-500)/500)))/2 = 0.550 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (3.00 + 0.550) * (2 columns) = 17.71 m
				1.1.6 Footing_Column_Type9	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed. (Extra length/ Width) = = (-(6.0+4.5) + SQRT((6.00+4.50)^2 + (4*6.00*4.50*(700-500)/500)))/2 = 0.944 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (6.00 + 0.944) * (2 columns) = 13.89 m
				1.1.7 Footing_Column_Type10	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed.

				(Extra length/ Width) = = (-(11.0+16.5) + SQRT((11.00+16.50)^2 + (4*11.00*16.50*(1300-500)/500)))/2 = 5.50 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (11.00 + 5.50) * (1 columns) = 16.50 m
			1.1.8 Footing_Column_Type11	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed. (Extra length/ Width) = = (-(8.50+8.50) + SQRT((8.50+ 8.50)^2 + (4*8.5*8.5*(1200-500)/500)))/2 = 4.67 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (8.5 + 4.67) * (1 columns) = 13.17 m
			1.1.9 Footing_Column_Type13	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed.

				(Extra length/ Width) = = (-(1.20+4.00) + SQRT((1.20+ 4.00)^2 + (4*1.20*4.00*(1200-500)/500)))/2 = 0.427 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (1.20 + 0.427) * (1 columns) = 1.63 m
			1.1.10 Footing_Column_Type14	The slab thickness is limited to 500mm in the impact estimator. The following calculation was done in order to determine the extra length and width needed. (Extra length/ Width) = = (-(10.0+6.50) + SQRT((10.0+ 6.50)^2 + (4*10.0*6.50*(800-500)/500)))/2 = 2.097 m In addition there is a number of each footing, as a result the number of footings was multiplied by the length to yield the correct volume. New Length = (12.10 + 2.10) * (1 columns) = 12.10 m
			1.1.11 Footing_Strip_Type6	
			1.1.12 Footing_Strip_Type7	
			1.1.13 Footing_Strip_Type8	
			1.1.14 Footing_Strip_Type12	
			1.1.15 Footing_Strip_Type15	
A21- Lowest Floor Construction				
		1.2 Concrete Slab-on-Grade		
			1.2.1 SOG_100mm	The slab on grade

				thickness is only available in 100mm and 200mm slabs in the impact estimators. The following calculation was done in order to determine the extra length and width needed to account for proper slab thickness. Because the actual slab is 130mm the 100 mm slab was used with the extra length and width added on to keep the volumes the same. (Extra length/ Width) = = (-(51.51+51.51) + SQRT((51.51+51.51)^2 + (4*51.51*51.51*(130-100)/100)))/2 = 7,22 m
			3.1.1 - Column_Concrete_Beam _GroundFloor	There are no beams on the first floor a 130mm SOG was used. The first floor of concrete columns and beams come directly up from the footings as a result they are shorter than the other floors. To find the height from the footing to the first floor a weighted average was used. There are no beams on the first floor a 130mm SOG was used. The calculations is shown below: First Floor Height = ∑[(First Floor Height* # of columns for this height)/(# of columns)] First Floor Height = 450*11/31 + 450*9/31 + 300*3/31 + 300*5/31 + 300*2/31 + 300*1/31 First Floor Height = 396.77 mm = 0.397 m
A22-Upper Floor Construction				
			1.1.16 Footing_Stairs	The stairs were modeled as footing because of the ability to specify the rebar used. All the stairwells are measured to find the volume and this

				volume is converted to an equivalent area for a 200mm thickness. The first volume calculation that was performed was to account for the lower stairwell in the atrium it was done by taking the top area and multiplying it by the height: Lower Atrium Stairs Volume = (Above projected Area)*Height = 10.85*0.487 = 5.28 m^3 The next portion of the atrium stairway volume is calculated by taking the side area and multiplying it by the width: Middle Atrium Stair Volume = (Side projected area)*Width = 6.04*2.17 = 13.12 m^3 Upper Atrium Stair Volume = (Side projected area)*Width = 2.07*2.85 = 5.90 m^3 The remainder of the stairwells in the building are located at the corners of the building. The individual stairwell volumes are calculated by using the equation below: Volume = (x*y/2 - x'*y'/2 - b*h*n/2)*Width = (2.825*2.296/2 - 1.7*1.354/2 - 2.35*1.42*12/2) *1.07 Volume = 0.693 m^3 Each of the individual stairwells are the same volume so a single volume was calculated then the number of stairwells counted and multiplied by the single stairwell volume. This volume is then added to the volume from the

				stairs in the atrium and the total volume is calculated. Total Stairwell Volume = 28 stairwells*0.693 + 5.28 + 13.12 + 5.90 = 50.26 m^3 The slab on grade dimensions are calculated by the equation below: SOG dimensions = sqrt (50.26 / (200mm/1000)) = 15.85 m
			1.1.17 Footing_StaiwellFloors	This floor is primarily located on surrounding the stairwells and the cast in place walls at the corners of the building. Also these floors extend in a few walkways over top of the atrium. They were modeled as a footing because they are not supported by the column and beam system, and they have no consistent span. Modeling as a footing allows the volume of concrete and rebar will likely be more accurate than by using a existing flooring system.
	3 Columns and Beams			
		Concrete Strength of 25 Mpa was used, In Athena 30 Mpa was the closest input. No Fly ash concentration was specified, so average was used. The larger concrete beams are running in both directions between the columns, there are smaller concrete beams built into the floor slab spanning the larger beams. The beams were counted on each floor spanning the columns, the columns are spaced at 10m on center in both directions so each of the span and bay are measured at 10m. Note That all the columns are used for one floor below for accuracy, for this reason the first floor height is the height from the footing to the SOG and there are no columns needed for the penthouse walls. The live load was taken to be the standard for this type of building as 3.6 KPa, it was not specified in the building drawings.		
		3.1 Concrete Column and Beam		
			3.1.2 - Column_Concrete_Beam_Floor 2	The larger concrete beams are running in both directions between the columns, there are smaller concrete beams built into the floor slab spanning the larger beams. The beams were counted on each floor spanning the columns, the columns are spaced at 10m on center in both directions so each of the span and bay are measured at 10m.

			3.1.3 - Column_Concrete_Beam_Floor 3	The larger concrete beams are running in both directions between the columns, there are smaller concrete beams built into the floor slab spanning the larger beams. The beams were counted on each floor spanning the columns, the columns are spaced at 10m on center in both directions so each of the span and bay are measured at 10m.
			3.1.4 - Column_Concrete_Beam_Floor 4	The larger concrete beams are running in both directions between the columns, there are smaller concrete beams built into the floor slab spanning the larger beams. The beams were counted on each floor spanning the columns, the columns are spaced at 10m on center in both directions so each of the span and bay are measured at 10m.
			3.1.5 - Column_Concrete_Beam_Penthouse	The larger concrete beams are running in both directions between the columns, there are smaller concrete beams built into the floor slab spanning the larger beams. The beams were counted on each floor spanning the columns, the columns are spaced at 10m on center in both directions so each of the span and bay are measured at 10m.
	4 Floors			
		4.1 Concrete Precast Double T		
			4.1.1 - Floor_PrecastDoubleT	The actual floor is constructed using larger beams running in both directions along the columns and smaller intermediate girders running between the beams. All of these beams are built into the floor slab. For this reason the Precast Double T floor slab was chosen to model the smaller beams between the larger beams running

				in both directions.
A 23- Roof Construction				
	5 Roof			
		5.1 Concrete Precast Double T		
			5.1.1 - Roof_ConcretePrecastDoubleT_Main	The roof is built using the same construction as the floors, however, it has different overlay materials and rigid insulation. The actual roof is constructed using larger beams running in both directions along the columns and smaller intermediate girders running between the beams. All of these beams are built into the floor slab. For this reason the Precast Double T floor slab was chosen to model the smaller beams between the larger beams running in both directions.
		5.2 Open Web Steel Joist		
			5.2.1 - Roof_OpenWebSteelJoists_Penthouse	The roof was constructed using an open web steel joist which is the exact type of roofing structure that is used in the impact estimator.
	6 Extra Basic Material			
		6.1 Concrete		
			6.1.1 ExtraBasicMaterial_Concrete	This concrete is a result of the roof parapet that surrounds all of the roofs of the buildings other than the penthouse. The volume calculation is shown below: Volume (m^3) = Length*Height*Thickness = 369.24 * 1.2 * 0.2 = 88.6176 m^3
		6.2 Steel		
			6.2.1 ExtraBasicMaterial_Steel	The Steel is a result of

				HSS Steel Sections which are seen in the atrium of the building holding up the skylight and also around the curtain wall for decoration. The diameter of the steel sections were measured by hand on a site visit, and found to be 250mm (10inch), while the wall thickness was assumed to be 12mm (1/2 inch) after researching standard thicknesses for a non structural HSS of the appropriate diameter. The weight calculation is below: Weight = Length*(X-section Area)*Density = 277.31 m * 0.00494 m^2 * 7.85 Tonnes/m^3 Weight = 110.75 tonnes
		2.4 Curtain Wall		
			2.4.1 Wall_Curtain_AllFloors	There is a curtain wall that is present in the atrium and extends up to the ceiling and connects into the skylight. The Skylight above the atrium was also modeled as a curtain wall, it is on an angle. The area of the curtain wall was measured from above, therefore the angle needed to be taken into account and the proper skylight area calculated as shown below. Skylight Area = sqrt((Projected Area)^2 + (Height)^2) = sqrt (299.64^2+4.117^2) = 299.67 m^2 The height and length are calculated by using the actual width of the curtain wall as the width, and the height is calculated accordingly as shown below. Width = 3.22 m Height = (Total

				Area)/(width) = (299.67 + 175.89)/(3.22) = 147.69
A 32 - Walls Above Grade				
	2 Walls			
		Concrete Strength of 25 Mpa was used, In Athena 30 Mpa was the closest input. No Fly ash concentration was specified, so average was used. The Stud Spacing is 400 mm on center, the stud thickness is 67.5 mm however the minimum specified thickness available in the impact estimator is 92 mm. The stud weight is also not specified, however, the light weight stud was used in order to maintain as much accuracy as possible to try and a reduce the error of the larger stud weight that is used. The type of window in the building was not specified in the drawings, so standard glazing was used. The takeoffs of the exterior windows were done from the outside elevations of the building, with a count and area measurement. While the limited number of interior windows were measured using plan view in linear meters and the height of the windows measured during a site visit to determine the proper window area, a count was also completed in the plan view.		
		2.1 Cast In Place Concrete		
			2.1.1 Wall_Cast-in-Place_AllFloors	The majority of these walls are present inside the stairwell towers and in the atrium, they are 200mm concrete walls with no insulation or steel studs on either side of the walls.
			2.1.2 Wall_Cast-in-Place_SteelStud_AllFloors	These walls are exclusively exterior walls. There is a 200mm thick cast in place concrete wall on the exterior followed by 89mm steel studs filled with batt insulation a sheet of poly and 15.9mm drywall. This wall type from all floors have been combined into this one category. The top floor is 3.4m and the other floors are 4.3m, to account for this with using a single input into the Impact Estimator, a weighted average to determine the floor height that should be used for the input. The Calculation is shown below: Total Height = [(linear meters of 3.4m

				wall)*3.4m + (linear meters of 4.3m wall)*4.3]/ (total linear meters) Total Height = (61.42*3.4 + 846.2*4.3) / (907.62) = 4.24 m
			2.2.6 Wall_SteelStud_Penthouse_Exterior	This steel stud wall has vertical metal cladding on horizontal grits. In addition there is two layers of exterior drywall with batt insulation in between. The height of this was taken as the floor to floor height plus the parapet in order to account for the additional wall above the roof.
B11 - Partitions				
		2.2 Steel Stud		
			2.2.1 Wall_SteelStud_Ground Floor	The Steel Stud wall is an interior wall with 89mm studs and drywall on each side. No insulation was used. The window area was calculated by measuring the length from the plan view and multiplying by a hand measured window height during a site visit, the calculation is below: Window Area = Total Length * Measured Height = 52.22m * 1.07m = 55.71 m2
			2.2.2 Wall_SteelStud_Floor2	The Steel Stud wall is an interior wall with 89mm studs and drywall on each side. No insulation was used. The window area was calculated by measuring the length from the plan view and multiplying by a hand measured window height during a site visit, the calculation is below: Window Area = Total Length * Measured Height = 8.30m * 1.07m = 8.85 m2
			2.2.3 Wall_SteelStud_Floor3	The Steel Stud wall is

				an interior wall with 89mm studs and drywall on each side. No insulation was used. The window area was calculated by measuring the length from the plan view and multiplying by a hand measured window height during a site visit, the calculation is below: Window Area = Total Length * Measured Height = 16.69m * 1.07m = 17.80 m2
			2.2.4 Wall_SteelStud_Floor4	The Steel Stud wall is an interior wall with 89mm studs and drywall on each side. No insulation was used. The window area was calculated by measuring the length from the plan view and multiplying by a hand measured window height during a site visit, the calculation is below: Window Area = Total Length * Measured Height = 2.72m * 1.07m = 2.90 m2
			2.2.5 Wall_SteelStud_Penthouse	The Steel Stud wall is an interior wall with 89mm studs and drywall on each side. No insulation was used.
		2.3 Concrete Block Wall		
			2.3.1 Wall_ConcBlock_SteelStud_AllFloors	The Lock Block wall is located on the second floor at the east end of the building. No rebar was specified so 10M will be used for input into the impact estimator.
		6.3 Extra Cladding Material		
			6.3.1 ExtraBasicMaterial_ExtraCladdingMaterial	The brick in the building is located primarily on the outside of the building however there is some located inside the building in the atrium. It is unclear if the brick is veneer, however there is no input for veneer brick in the impact estimator so normal "standard" brick is used.
		6.4 Extra Envelope Material		

			6.4.1 ExtraBasicMaterial_ExtraEnvelopeMaterial	The extra glass used is due to large single pane windows in the atrium. Because not all the sections were available to do takeoffs some additional amount of window area needed to be added. In addition only double pane windows are available, as a result the amount of window area for this calculation is divided by two to get a more accurate window area. The calculation is shown below: Total EBM window = Takeoff Area + Measured Area = 88.5m^2 + 7.36m^2 = 95.86 m^2 Total Standard Glazing used = 95.86 / 2 = 47.93 m^2

Annex E – Net Present Value Cost

Year	Escalation Rate
1989	1.07
1990	0.96
1991	1
1992	1.02
1993	1.03
1994	1.04
1995	1.01
1996	1.03
1997	1.02
1998	1.01
1999	1.01
2000	1
2001	1.01

Year	Cost	
1989	$ 1,250,000	
2013	$ 2,255,362.64	=$1250000*1.80429

Product of Escalation Rate (1989-2012)
1.80429

2002	1.01
2003	1.05
2004	1.08
2005	1.08
2006	1.13
2007	1.09
2008	0.93
2009	0.95
2010	1.04
2011	1.04
2012	1.01