UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Institutionalization of Life Cycle Assessment (LCA) on UBC Vancouver Campus

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Executive Summary

Environmental impact of buildings is often ignored in the building industry but recently has become a big issue due to the realization of the worsening environment crisis globally.
Life cycle assessment, a science-based environment impact assessment method, which is used to measure the environmental impacts of a product (building) throughout its life cycle; the application of this knowledge on academic buildings of UBC Vancouver Campus reveals the degree of impact of these buildings on the nine impact categories being studied (global warming, smog, ozone depletion, HH particulate, eutrophication potential, consumption of total primary energy, non-renewable energy and fossil fuel). Analysis has been carried out on the 22 academic buildings so that the identification of building material that has huge impact on the already deteriorating environmental problem is possible.

Apart from the implementation of UBC Renew Program, which aims to renovate aging building to reduce its environmental impacts, efforts on other areas such as transportation, energy supply and management will substantially reduce the environmental impacts of UBC buildings. Alleviation of energy consumption and global warming potential is achieved through the management and reduction of electricity use, while the Academic District Energy System will have reduced greenhouse emission due to the reduced heat distribution losses of the new system

Lastly, it is proposed how UBC should approach the institution of LCA in building design and operations. The discussion concluded that Athena Impact Estimator, is the best available modeling tool, but it is recommended that an additional program be developed to be used side by side with IE to provide a more user friendly interface. Moreover, it is discussed how UBC building database is collected and it is recommended that each new building that is built, be added to the database which will result in improvement of the database over time. Also weighing and integrated financial-environmental analysis is recommended for easier decision making.

Finally, it is emphasized how proper education to students and community members can increase the public demand for LCA and consequently increase sustainability of our communities.

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Introduction

Life Cycle Assessment is a technique to quantify environmental impacts in the entire life cycle of a product or service from-cradle-to-grave (i.e., from raw material extraction to materials processing, manufacture, distribution, use, repair, maintenance, and disposal or recycling). LCA compiles an inventory of relevant energy and material inputs; Evaluates the potential impacts associated with identified inputs and releases and interprets the results to help make a more informed decision. This report intends to study the current environmental impacts that are caused by UBC campus buildings.

This Report explains how LCA can be understood through different programs (such as UBC Climate Action Plan, LEED v4, etc.) and how it is applied specifically with regard to building constructions and various aspects of operations.

Later, the report takes a closer look at each impact category that is specified in Impact Estimator software and uses it to evaluate the current sustainability programs on relevant buildings on campus so that a clearer and qualitative understanding about the programs' purpose and the problems faced during our current use and operations of the buildings can be established.

Lastly, the steps and methodologies we intend to implement in the future on UBC campus with considerations to LCA modeling tools, databases, decision making methods and communication and education resources is studied and suitable recommendations are made.

1.0 Context for Use of LCA at UBC

The first section of the report intends to rationalize the institution of environmental life cycle assessment (LCA) in UBC building design and operations and feasibility of application of LCA to support sustainability in buildings.

When assessing the life cycle of a building, nine impact categories need to be considered as mentioned below.

Global Warming Potential
Acidification Potential
Human Health Particulate
Eutrophication Potential
Ozone Depletion Potential
Smog Potential
Total Primary Energy
Non-Renewable Energy
Fossil Fuel Consumption

Table 1 Nine Impact Categories

To apply LCA study, there are several sustainability programs that are related to buildings and their operations:

- Climate Action Plan
  Climate Action Plan requires that all government agencies and public sector organizations- including UBC- need to work towards "carbon neutral" state by 2010. The ultimate goal is to achieve zero net emission for the UBC campus by 2050 compared to 2007 level[1].
  Therefore we need to study buildings, but also ways of construction and operation during the construction processes.

[1](Climate Action Plan, 2010)

- Vancouver Campus Plan Part 3 Design Guidelines
  These design guidelines are for consultants, staff, project sponsors and members of broader UBC community who initiated, participated and are interested in the design, construction of the UBC campus buildings and infrastructures[2].

- Technical Guidelines
  In 2006, UBC released Inspirations & Aspirations: The Sustainability Strategy. This strategy includes targets for UBC's building stock[3].

- UBC RFI Evaluation Criteria
  As part of the Renew program of existing buildings, UBC intends to upgrade the Old SUB building. The project is expected to be complete by April 2016. The major capital renewals are intended to remove the deferred maintenance elements in the SUB as well as complete tenants improvement fit-outs for multiple UBC tenants, optimizing space and determining the most advantageous life cycle costs while meeting service objectives, current codes and technical standards[4].

- LEED v4.
  LEED, or Leadership in Energy & Environmental Design, is a green building certification program that recognizes best-in-class building strategies and practices. To receive LEED certification, building projects must satisfy prerequisites and earn points to achieve different levels of certification. Prerequisites and credits differ for each rating system, and teams choose the best fit for their project.

These programs have overlaps in the areas of buildings and operations to be discussed. Therefore, this part of the report would be carried out in respect to the different aspect of buildings and operations that LCA can be applied[5].

[2] (UBC Vancouver Campus Plan, 2010)
[3] (UBC Technical Guidelines, 2014)
[4] (UBC RFI, 2013)
[5] (US Green Building Council, 2014)

1.1 Campus development and infrastructure

In Campus Development and infrastructure, Green house Gases are avoided during the construction process through UBC Renew program. This program is to reduce the deferred maintenance in order to reduce various environmental impacts that are included in life cycle assessment, such as carbon dioxide emissions.

The buildings in UBC have already included REAP and LEED in their construction processes, including orientation of the building, which would allow more natural light and solar heating to come through. In the architectural design of the buildings on UBC campus, many environmental concepts are brought in, to apply LCA in the construction phase and the design phase. This brings significant improvements in environmental performance of the buildings. One important application of LCA is the material used. Solar heating is used to heat up the building, but traditional concrete has a high thermal mass that would not transport the heating into the building and as a result, the active heating is reduced.

1.2 Energy supply and management

Electricity comprises a significant proportion of energy use on campus. Computers and equipment are turned off when they are not in use. This reduces not only the electricity directly but also heating effects due to long time running process and more wasted electricity. Life Cycle Assessment study gives us ideas about how to save energy and use them effectively and various impact caused by daily activities and the operation of the building. Turning off the devices run by electricity during night and weekend hours would save great amount of energy. Based on how the electricity is generated, it would affect components such as Non-renewable Energy and Fossil Fuel consumptions. Meanwhile the heating effect contributes to the global warming potential and GHG produced during the power generation processes.[6]

[6] (*Life cycle energy and environmental performance of a new university building, 2003)*

Lighting is another big component that contributes to energy use. LCA would propose several ways of effective and efficient lighting. However, the energy saving process would not be successful without serious considerations of academic use of the facilities on campus. For example, shutting down computers would be feasible at the start of the semester but not so much during exam period since more frequent uses would be expected. Also, frequent on and offs would consume more energy rather than putting computers on standby mode. Lighting can be dimmer in general but not in study areas. In general the operation of the buildings, i.e. energy use, should be saved without significant compromises for school activity and students' life.

1.3 Fleets and Fuel Use

Vehicles operating on campus have reduced the number of trips they make per day and use biodiesel in all diesel vehicles. Several electric cars are also put in use. This greatly reduces air emissions and use of fossil fuels and it's a crucial part of the LCA study.

It is necessary to plan most efficient routes for buses to connect the major buildings and residences. The serviceability of the buses would thus be guaranteed and would not cause unnecessary detours around the campus. Peak Hours of different bus routes can be studied. For example, more students would take buses to go to class, i.e. academic buildings, in the morning than the afternoon while more students would take buses to grocery stores and food courts in the evening.

We must encourage people to use public transits that are provided by UBC, but do not increase emissions and use of fuel significantly. Biking is also encouraged on campus.

This component of Action Plan generally deals with GHG emissions and energy use, thus affecting Global warming potential and Fossil Fuel consumption.

Biomaterial is used to replace fossil fuels for heating and power. The renewable fuel generates energy without compensating other energy sources and gives a net zero energy footprints. Life cycle assessment recognizes this by reducing fossil fuel consumption. Despite the significant increase in the total floor area and enrolled students, UBC reduces water consumption and emission and only has an insignificant increase in energy consumption. By 2050, UBC would have used renewable energy to power the entire campus and thus be a net zero campus.

1.4 Food

Food production outputs a great amount of GHG. In fact, the production is responsible for 18% more GHG emissions when compared to transportation emissions. The reduced food production and less waste would be considered great results from the LCA study[7]. The recycling site and organic decomposition site would be located such that it would be closest to most waste sources. Due to the site of the campus and university's responsibility to provide catering services at various locations over the campus, it is necessary to set up several wastes sites or transportation centers that would carry the wastes to closest sites. Effective management in food wastes would significantly reduce the UBC environmental impact.

1.5 Water management and use

Water is associated with great environmental issues. The use of water would cause great environmental impact to the planet but the delivering process would cost considerable amount of energy due to water density and the necessity of water in daily life. Out of all the water available on earth, only a small proportion is potable and that water needs to go through various industrial processes such as purification,

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[7] (*A review of life cycle assessment (LCA) on some food products, 2008)*

iodization and etc.[8]. The process can cause many impacts that are important in the LCA study, Ozone Depletion Potential, Eutrophication Potential and Acidification Potential. To better manage water to reduce environmental impacts, several measures such as to set the most water concentrated facilities at lower floors. The delivering of water can also be done with more efficient pipe system. The locations of buildings do matter. The bigger the campus, the more power needed to deliver water to designated buildings.

At the same time, wastewater would cause exactly the same problem or even a larger problem. Wastewater commonly denser and is often mixed with other wastes. The treatment of the wastewater would also cause great environmental impact. Buildings, especially residential buildings, should take wastewater seriously and carefully choose treatment center.

Heated water for academic and residential buildings in UBC is another major source of energy input. Great amount of energy is lost during the delivering process. This can be remediated by replacing used pipes or the entire hot water system. This way, energy is saved and the system is able to maintain the same level of hot water use.

1.6 Recycle

Recycling infrastructure for buildings is specified in technical guidelines. Reduction in wastes by recycling significantly reduces the environmental impact of UBC buildings. It is also associated with eutrophication potentials.
At UBC, recycle stations serve all buildings, not garbage bins. This has specified the destination of recycling and is a more definite solution for recycling.

[8] (WULCA, 2014)

2.0 LCA Study of Academic Buildings at UBC Vancouver Campus

UBC Vancouver campus buildings were assessed for 9 different environmental impact categories. Each impact categories has been analyzed in the following sections to give a better understanding of the numbers in UBC LCA database.

2.1 Global Warming Potential

Building	A11 Foundations kg CO_2 eq/m^2	A22 Upper Floor kg CO_2 eq/m^2	A23 Roof Construction kg CO_2 eq/m^2	A32 Walls Above Grade kg CO_2 eq/m^2
MCML	674.36	353.72	283.23	116.56
HEBB	173.44	186.90	123.32	177.28
CHEMN	46.76	281.11	166.84	108.04
CHEMS	32.79	350.71	259.61	135.81
ALRD	207.06	118.43	47.99	206.34
FSC	159.51	174.31	222.32	80.72
CHBE	89.28	192.19	290.34	341.28

Table 2 Global warming potential per useable area

In Table 1,highlighted elements show high global warming potential per usable area. As seen from the data generated by the Impact Estimator, A11, A22, A23 and A32 are the elements that have relatively larger global warming potential per usable academic building space. A11 foundation element of MacMillan Building (MCML) has significantly large global warming potential even when compared with those large values. This can be explained after investigating the material used by this particular element of MCML. Concrete and rebar are the common materials used in the construction of building's foundation, but apart from the fact that MCML used way higher volume of concrete per m^2 of foundation, it was also built using many other building materials in the table below.

Material	Mass/ Tonnes
5/8" Regular Gypsum Board	8.0295
6 mil Polyethylene	0.5238
Concrete 20 MPa (flyash av)	19376.8711
Joint Compound	0.7788
Nails	0.0073
Paper Tape	0.0089
Rebar, Rod, Light Sections	20.4612
Welded Wire Mesh / Ladder Wire	3.4939

Table 3 Material used in the construction of A11 element of MCML building

Apart from that, upper floor element (A22) generally has higher global warming potential than the lowest floor (A21) because of the larger volume use of concrete per m^2 and the use of rebar in the upper floor construction. For example, Westbrook Building (WSBK) uses 0.24 and 2.11 tonnes of concrete per m^2 for the construction of the lowest floor (A21) and upper floor (A22) elements respectively. And upper floor elements used 362.757 tonnes of rebar for construction purpose.

The research finding shows that ICICS Building has the highest global warming potential of 773.55 kg CO2 equivalent caused by the usable academic spaces of the building. A22 is the element that contributes the most to this hazard. It is understandable as it uses up to 3.44 tonnes of concrete for every m^2 of construction. Furthermore, 675.54 tonnes of rebar was also used for the construction of the upper floor that has an area of 3543 m^2.

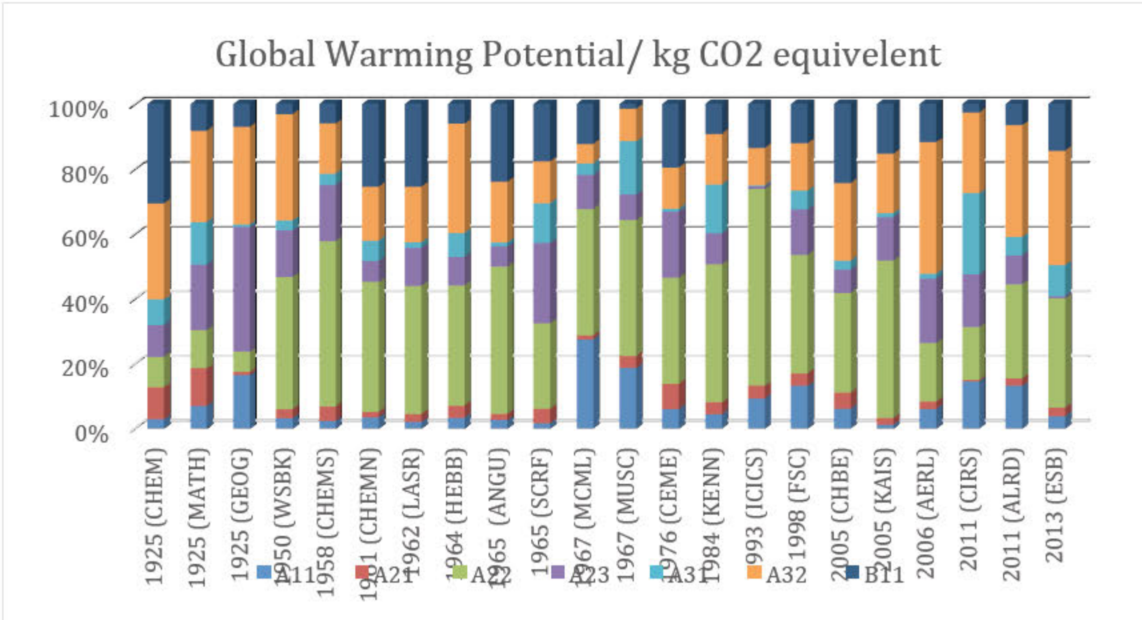

Figure 1 Percentage distribution of global warming potential by each element

As seen from the graph above, A22 and A32 are the elements that cause most damage to the global warming crisis, followed by A23 and B11. While A11, A21 and A31 are the elements that have the least global warming potential hazard.

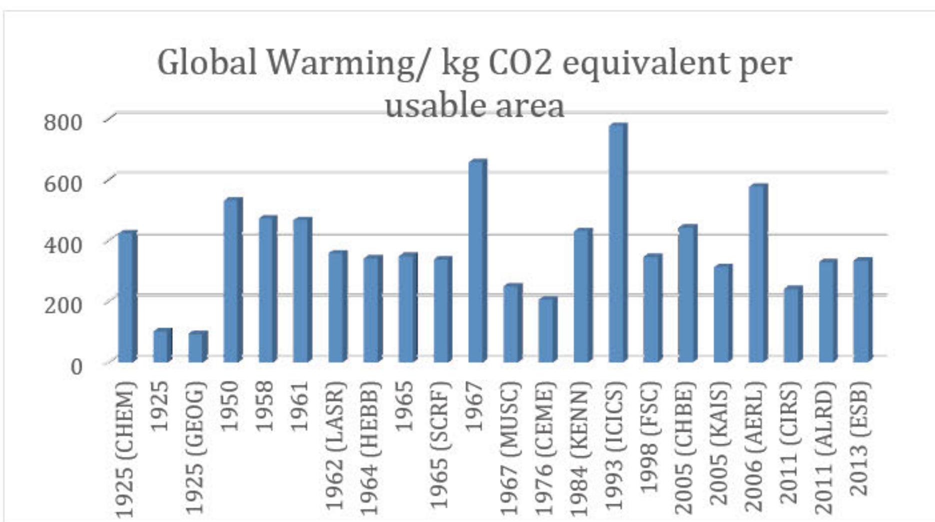

Figure 2 Global Warming Potential per useable area of building

The three buildings (CHEM, MATH and GEOG) were constructed in the year of 1925. Both MATH and GEOG buildings have global warming impact of approximately 100 kg CO2 equivalent per usable area, while CHEM has significantly higher value of 421.8 kg CO2 equivalent per usable area.

Then there is a peak at the year of 1950 and going down to year 1965, there is a decreasing trend from 529 to 336 kg CO2 equivalent per usable area. In 1967, another peak value of 654 kg CO2 equivalent per usable area of MCML building is recorded. There it goes down the slope to a value of 205 in the year of 1976 before rising up to another peak of 774 kg CO2 equivalent per usable area of ICICS building, which was built in the year of 1993. Buildings built between 1998 and 2013 shows a series of fluctuation of up and down trends.

Analyzing data generated by the Impact Estimator, the global warming impact is generally caused by the large volume use of concrete and rebar rod as shown in the examples above. To further alleviate the global warming impact caused by the building, implication of technology to reduce the hazard generated during the manufacturing process of these building materials is vital. Use of more environmentally friendly materials such as wood is also recommended.

2.2 Acidification

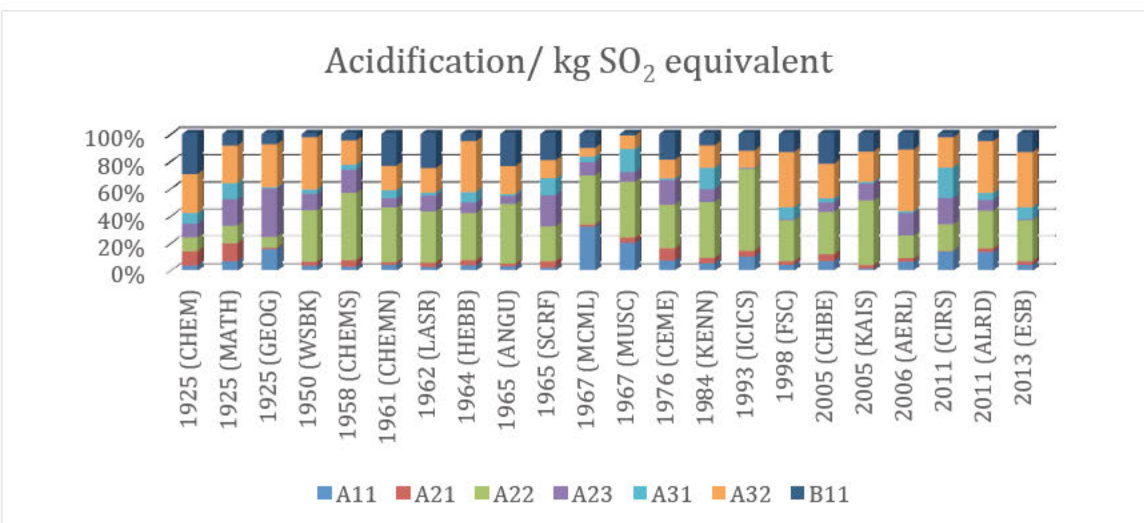

Figure 3 Percentage distribution of acidification potential by each element

The percentage distribution of acidification impact category is produced using the data generated by the Impact Estimator. Study shows that the upper floor element (A22) has the biggest share among other elements that contribute to the worsening acidification problem. For ICICS building, A22 element has 59% of the total acidification potential of the building. Compared with the lowest floor element (A21) of ICICS building that only has 4% percentage distribution, much more materials were used for the construction of A22 element. Concrete 30MPa, Rebar and ballast (aggregate) are the materials, which were used abundantly and this directly increases the acidification potential of A22 element.

A11 and A21 and A31 elements have the least contribution to the acidification. ANGU building has 2% share for both A11 and A21 elements, and 1% for A31 element. The use of concrete and rebar per m2 for the construction of the mentioned elements are fairly low. Though there are other materials that were being used such as nails, joint compound and paper tape but the quantity is just a fraction of tonne.

Generally, concrete and rebar are the building materials that are used in large quantity. As the amount of concrete or rebar being used increases, the acidification hazard will increase significantly, therefore we can conclude that the abundant use of these materials is the main source of acidification.

A21, Area = 2151m2	
4% Acidification Potential	
Material	Mass Value/ tonnes
6 mil Polyethylene	0.5952
Concrete 30 MPa (flyash av)	1083.1531
Rebar, Rod, Light Sections	1.5383
Welded Wire Mesh / Ladder Wire	3.3802

A22, Area = 3543m2	
59% Acidification Potential	
Material	Mass Value/ tonnes
#15 Organic Felt	22.3441
Ballast (aggregate stone)	367.8132
Concrete 30 MPa (flyash av)	12203.4424
Extruded Polystyrene	21.182
Galvanized Sheet	2.6667
Hollow Structural Steel	5.7262
Polyethylene Filter Fabric	0.4557
Rebar, Rod, Light Sections	675.5415
Roofing Asphalt	45.2027
Screws Nuts & Bolts	0.2584
Wide Flange Sections	-0.6583

Table 4 Material used in the construction of A21 and A22 elements of ICICS building

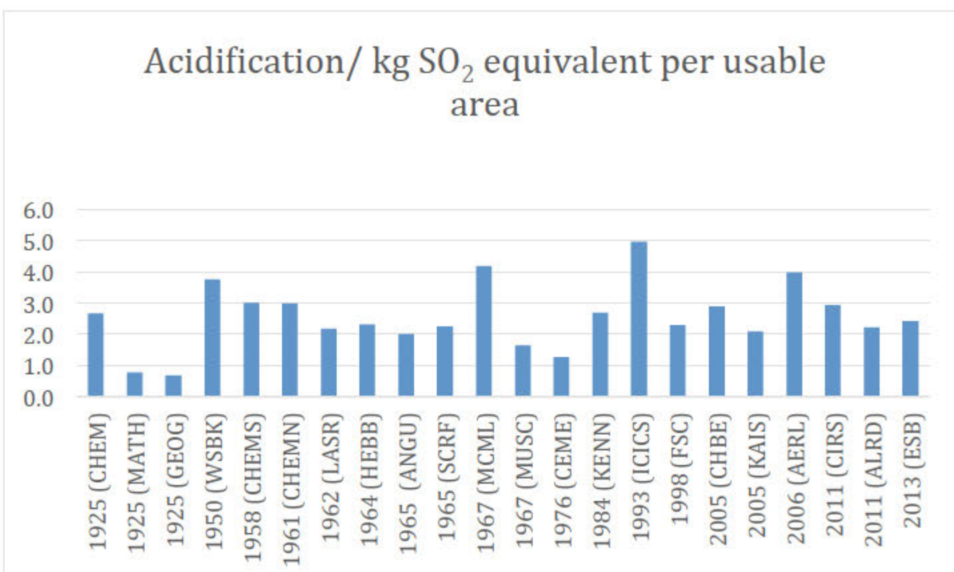

Figure 4 Acidification potential per useable area of building in chronological order

CHEM building has significantly higher acidification than MATH and GEOG buildings though they were built in the same year. Then from the year of 1950 to 1965, there is a decreasing trend from 3.75 kg SO2 equivalent/m² to 2.00 kg SO2 equivalent/m². The value of acidification goes up to a peak at the value of 4.17 kg SO2 equivalent/m² by MCML building. ICICS building, which was built in the year of 1993 has the greatest acidification potential of 4.96 kg SO2 equivalent/m². Starting from year 2006, there is sign of decreasing trend from 3.98 to 2.40 kg SO2 equivalent/m² by the year of 2013.

2.3 HH Particulate

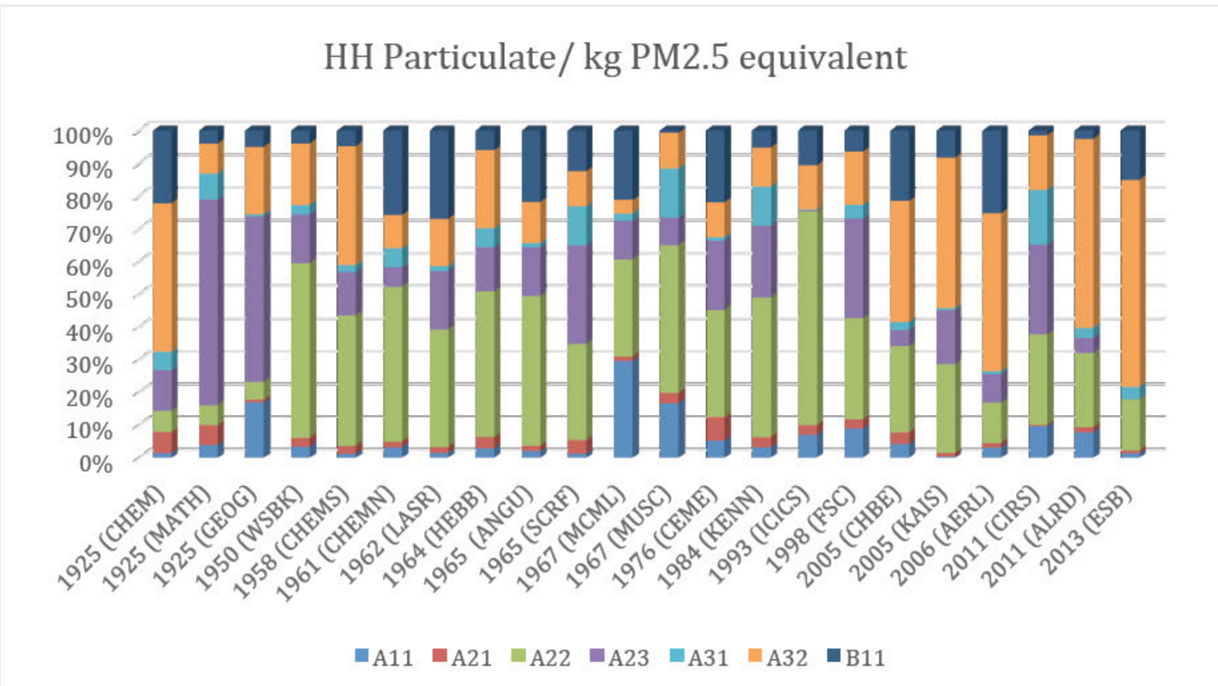

Figure 5 Percentage distribution of HH Particulate potential by each element

The analysis of the percentage distribution of HH particulate potential shows that A22 and A32 are the primary elements that contribute to this environmental issue. This is caused by the larger quantity of concrete and rebar used in those elements, which is very similar to the case of global warming potential. A11, A21 and A31 are the elements that have the lowest impact on HH particulate issue.

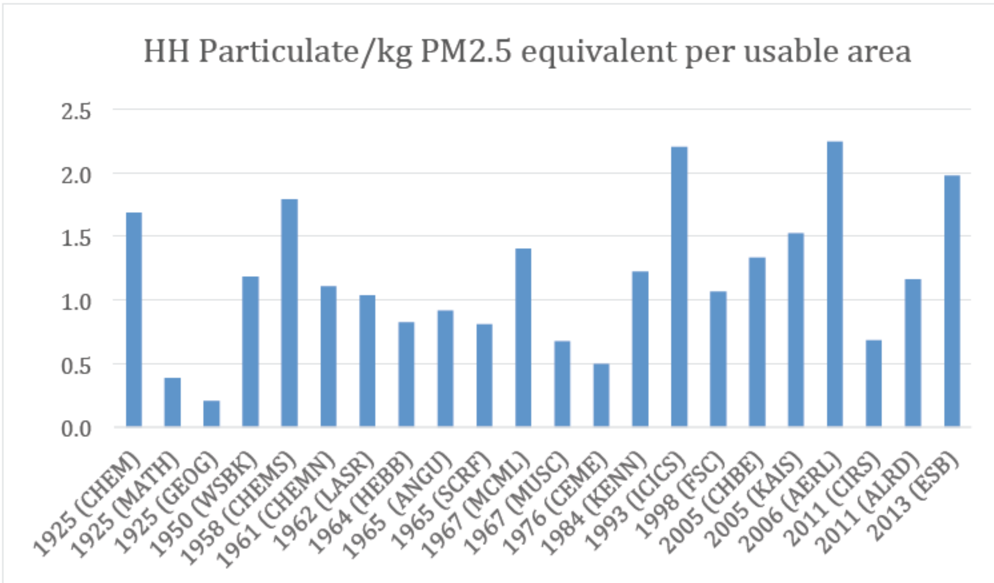

Figure 6 HH Particulate per useable area of building in chronological order

ICICS and AERL are the buildings that have the highest HH particulate potential hazard of 2.20 and 2.25 kg PM 2.5 equivalent/m^2respectively. There is decreasing trend shown in the buildings between year 1958 and 1965, dropping from 1.80 to 0.81 kg PM 2.5 equivalent/m^2. However, the buildings that were built recently show a significant increase from 0.69 to 1.98 kg PM 2.5 equivalent/m^2 in just over three years period.

2.4 Eutrophication

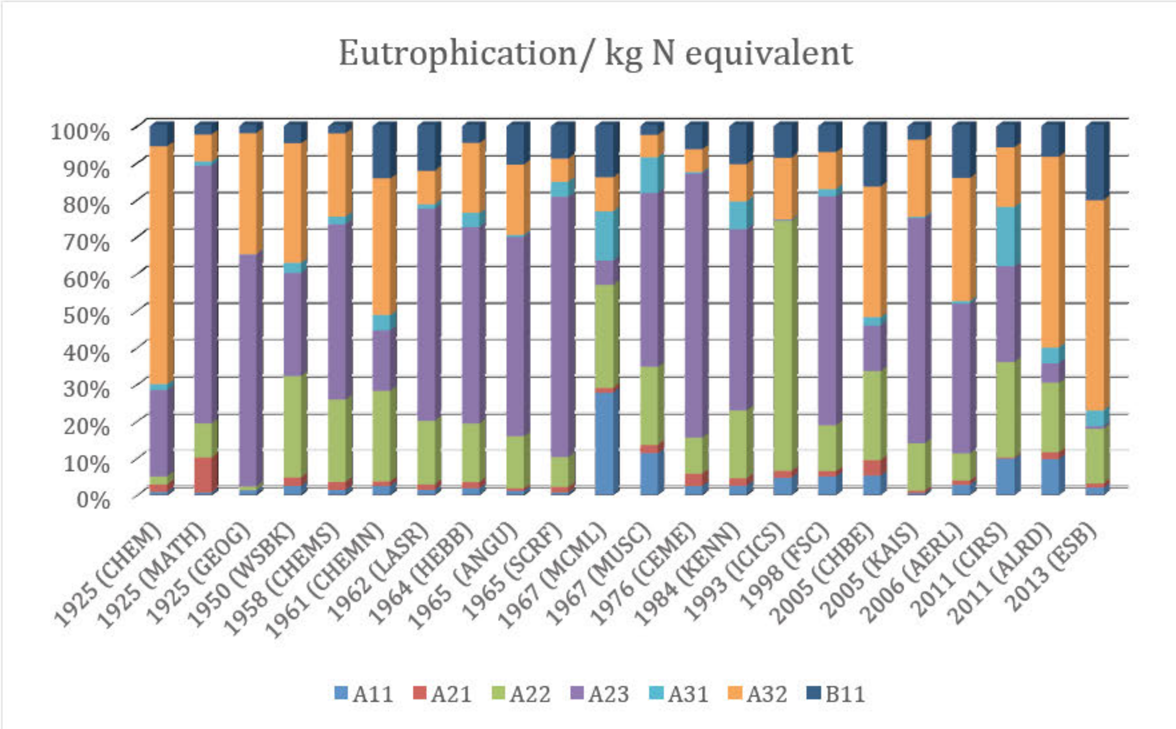

Figure 7 Percentage distribution of eutrophication potential by each element

Most of the buildings have large percentage of eutrophication hazard contributed by A23 and A32 elements. SCRF has 70% share of eutrophication from A23 element. Although A22 element has much larger amount concrete and rebar in its construction, but it only has 8% contribution to the eutrophication hazard of SCRF building. The large eutrophication potential of A23 element could be possibly caused by the use of ballast (aggregate stone), roofing asphalt, Gypsum board or organic felt which are used in quite an amount after concrete and rebar. A point to add is that the total amount of building materials used for A22 is larger than A23 element.

A22	
8% Eutrophication Potential	
Material	Mass Value/ tonnes
Concrete 30 MPa (Flyash average)	2273.0726
Rebar, Rod, Light Sections	95.3335

A23	
70% Eutrophication Potential	
Material	Mass Value/ tonnes
#15 Organic Felt	13.4724
1/2" Moisture Resistant Gypsum Board	26.7481
6 mil Polyethylene	0.4294
Ballast (aggregate stone)	147.8491
Concrete 30 MPa (Flyash average)	1427.3635
Extruded Polystyrene	6.9764
Galvanized Sheet	3.2158
Nails	1.3899
Rebar, Rod, Light Sections	60.0397
Roofing Asphalt	99.0373
Type III Glass Felt	19.3939

Table 5 Building materials used in the construction of A22 and A23 elements of SCRF building

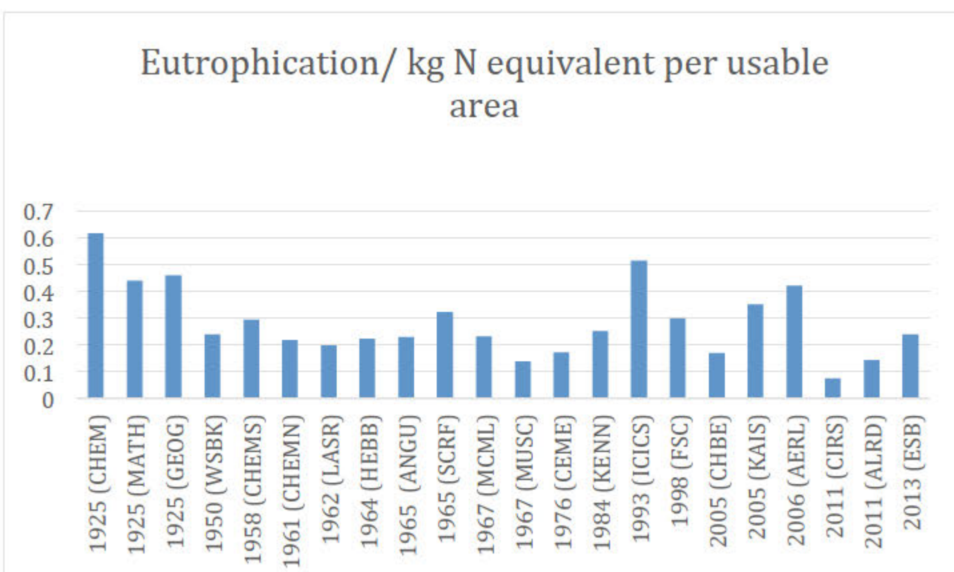

Figure 8 Eutrophication potential per useable area of building in chronological order

There is series of up and down of the eutrophication of buildings built between year 1925 and 2013. From 1925 to 1965, the eutrophication level goes down from 0.62 to 0.22 kg N equivalent/m^2. Then it goes up again from 0.14 to 0.51 kg N equivalent/m^2 between year of 1967 and 1993. This increasing trend is also seen between 2005 to 2006 and 2011 to 2013.

2.5 Ozone Depletion

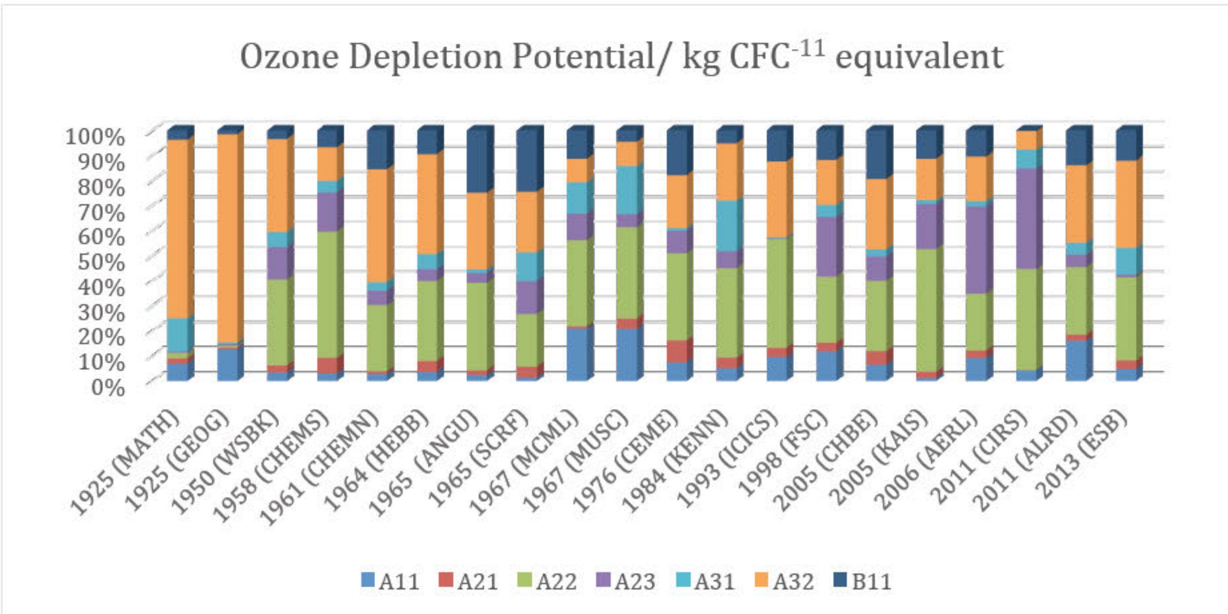

Figure 9 Percentage distribution of ozone depletion potential by each element

There are only 20 buildings that will be studied in the analysis of ozone depletion potential due to the fact there are incomplete data for CHEM and LASR buildings. The investigation shows that A22 and A32 are once again the two elements that contribute to most of the ozone depletion of a building. HEBB building has 32% and 40% of its ozone depletion potential from A22 and A32 elements respectively. The reason why A22 upper floor element has higher ozone depletion potential than A21 lowest floor element is that much more amount of concrete was used for the construction of A22 element. Apart from that, 213 tonnes of rebar was used for the construction of A22 element.

	A21	A22
Material	Mass /tonnes	Mass /tonnes
Concrete 30 MPa	462.9208	3407.0026
Welded Wire Mesh	1.7156	-
Rebar, Rod, Light	-	213.2708

Table 6 Material used in construction of A21 and A22 elements of HEBB building

A11 foundation also used much lesser materials (concrete and rebar) than A22 element, therefore the abundant use of these materials explain why the A22 element contributes the most to the ozone depletion issue.

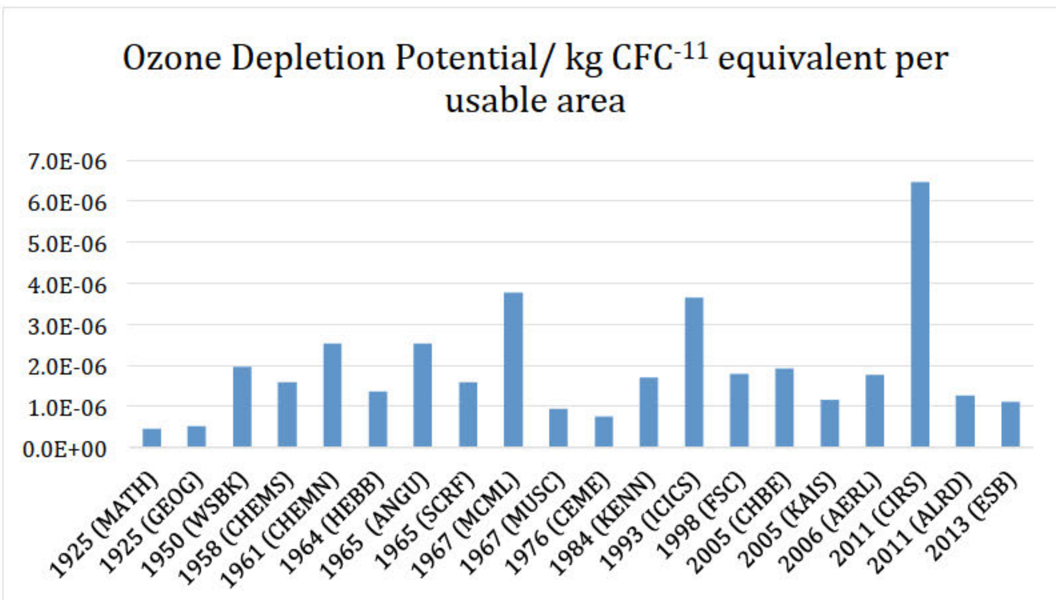

Figure 10 Ozone depletion potential per useable area of building in chronological order

Between 1925 and 2006, the ozone depletion of the academic buildings being studied are in the range of 4.58 x10^{-7} and 2.53 x10^{-6} kg CFC^{-11} per usable area except that there are two buildings (MCML and ICIS) that have much larger value than the other buildings. CIRS building, which was built in 2011 has exceptionally high value of 6.47 x 10^{-6} kg CFC^{-11}/m^2. While ALRD and ESB buildings, which were built in 2011 and 2013 respectively have fairly low ozone potential of about 1.2 x 10^{-6} kg CFC^{-11}/m^2.

2.6 Smog Potential

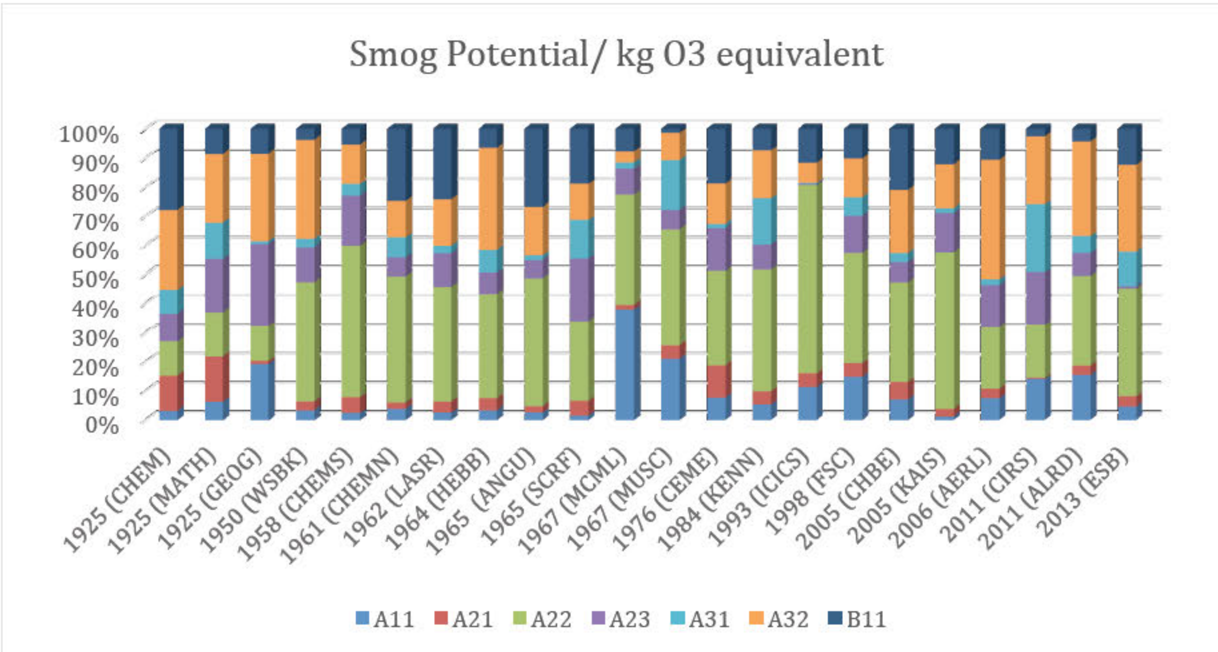

Figure 11 Percentage distribution of smog potential by each element

Generally, most of the smog hazard potential is contributed by A22 element, followed by A32 element. While A11, A21 and A31 are among the elements that have the least smog potential.

A22 element of CHEMS building that contributes to 52% of the building's total smog potential has a value of 130000 kg O3 equivalent while the A22 element of HEBB building that was only built from two materials, concrete and rebar has smog potential of 104000 kg O3 equivalent.

Material	A22 of HEBB / tonnes	A22 of CHEMS / kg O3 eq
Concrete 30 MPa (flyash av)	3407.0026	3948.0427
Rebar, Rod, Light Sections	213.2708	288.4612
8" Concrete Block	-	95.2448
Mortar	-	122.28

Table 7 Material used in the construction of A22 element of HEBB and CHEMS building

The quantity of use concrete and rebar is comparable between the A22 elements of these two buildings. However, A22 of HEBB building which was only made up of concrete and rebar has significant influence on the smog hazard of the buildings, therefore we can conclude that concrete and rebar are the key materials that affect the smog potential of building.

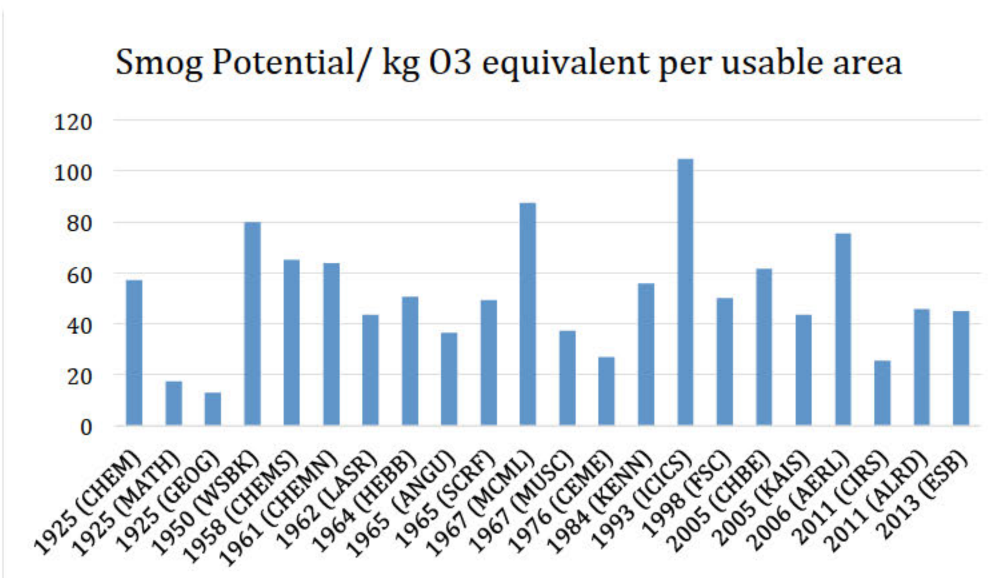

Figure 12 Smog potential per useable area of building arranged in chronological order

ICICS building, which was built in the year 1993, has the highest smog hazard of 104.7 kg O3 equivalent per usable academic area. There is a decreasing trend from year 1950 to 1965 with fluctuation. Then, the value of smog potential drops from 87.5 kg O3 equivalent of MCML building which was built in the year of 1967 to 27.0 kg O3 equivalent of CEME building (constructed in the year of 1976). What follows then is a positive slope up to the peak of 104.7 kg 03 equivalent (ICICS building which was mentioned earlier). ESB building, which was built in year 2013 has a close value of smog potential with ALRD building (constructed in year 2011). However, CIRS that was also built in the year of 2011 shows a fairly low value of just 25.4 kg 03 equivalent when compared with ALRD and ESB buildings.

2.7 Total Primary Energy

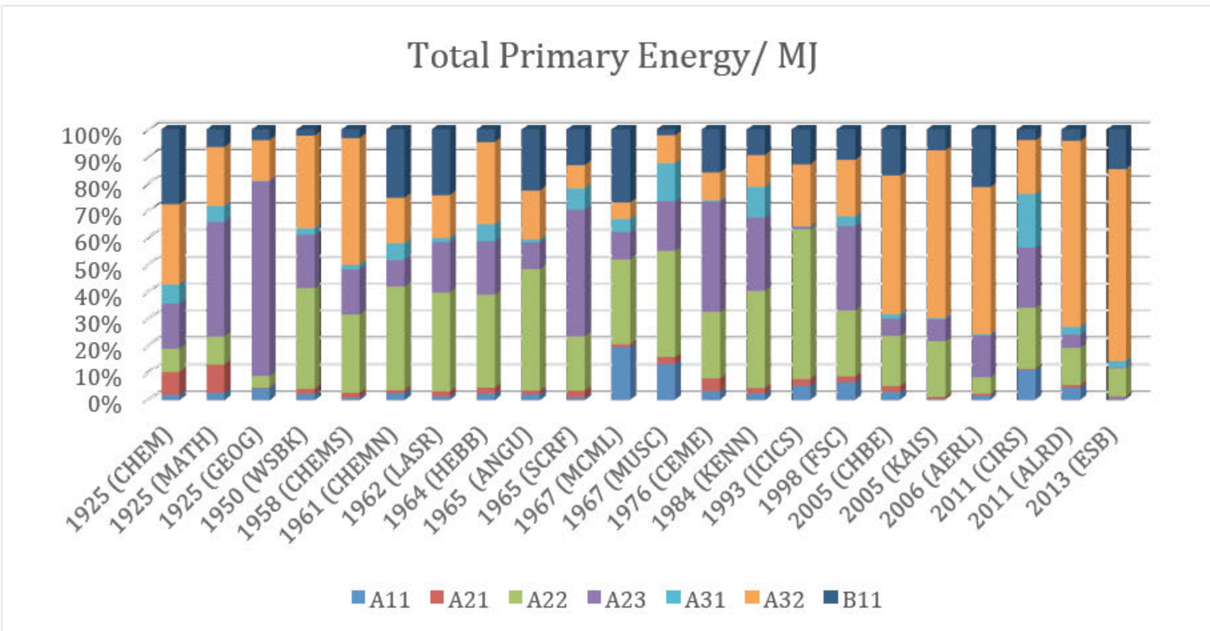

Figure 13 Percentage distribution of total primary energy used by each element

Analysis performed shows that A22 and A32 elements once again are the main contributors to the primary energy usage in addition to other impact categories. A32 element of KAIS building has a total of 63200000 MJ usages. It only used 160.4 tonnes of concrete 30MPa, 4.33 tonnes of rebar. Other materials, which were used abundantly, are aluminum (37.6 tonnes) and glazing panel (198.7 tonnes).

A22 element of KAIS building has 21000000 MJ total primary energy usage which has great amount of concrete 30 MPa up to 10781 tonnes and 449.3 tonnes of rebar.

Therefore the large total primary energy usage of A32 elements is possibly caused by aluminum or glazing panel that were used.

A11 and A31 are the elements that have the least impact on the total primary energy usage.

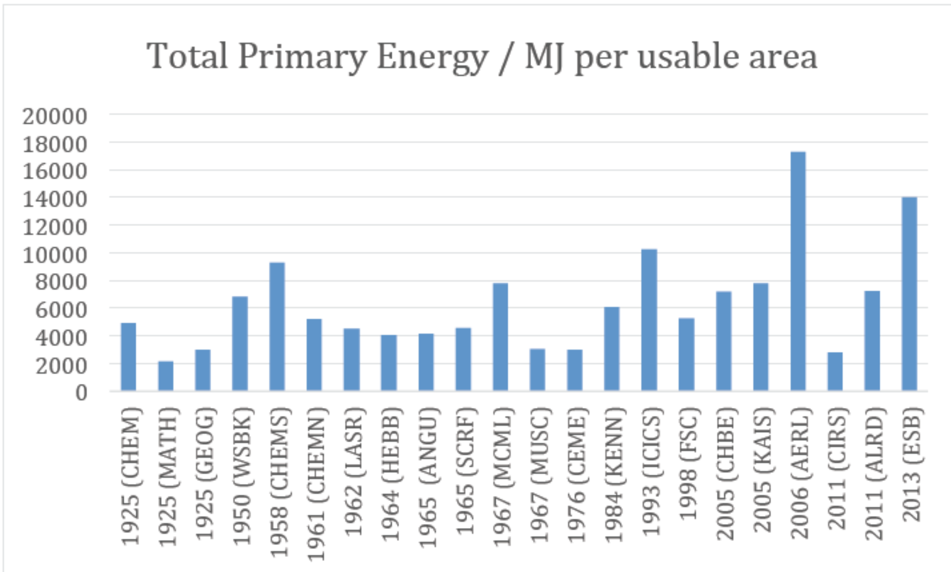

Figure 14: Total primary energy used per useable area of buildings in chronological order

The total primary energy usage for buildings built between year 1925 and 2005 are fluctuating in the range between 2134 to 10259 MJ per usable area. The highest total primary energy used per usable academic area is recorded at 17262.43 MJ by AERL building. Then the trend in the recent years is that there is an increasing trend from 2800 MJ per usable area to approximately 14000 MJ per usable area (ESB building).

2.8 Non-Renewable Energy

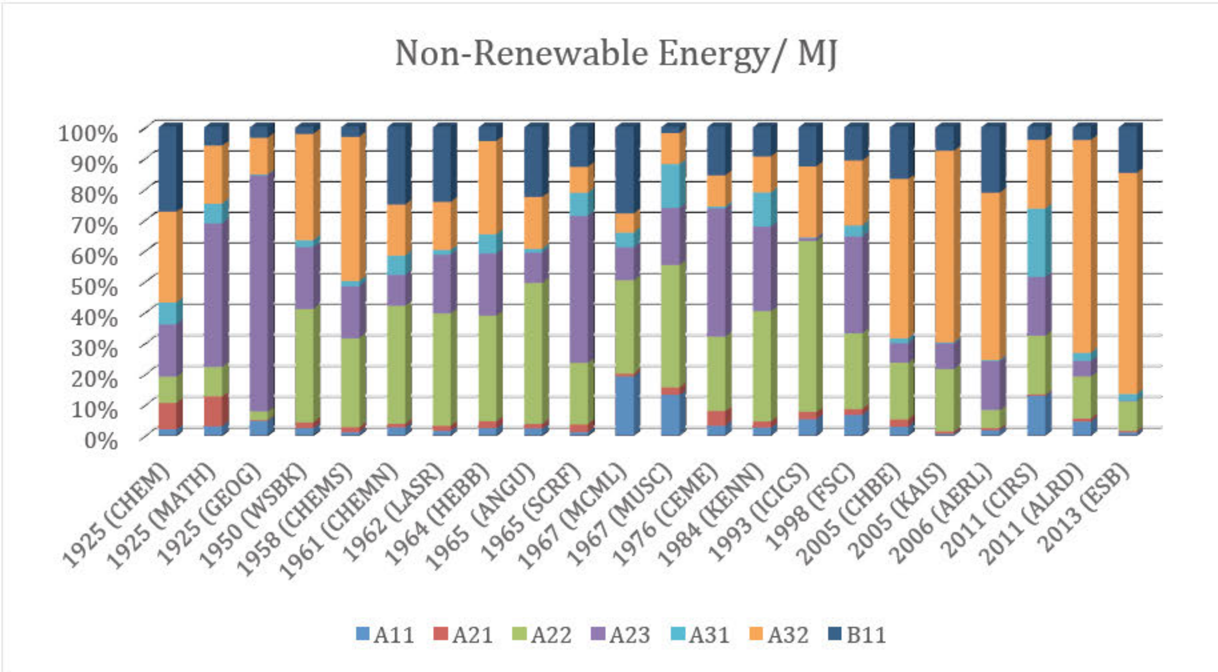

Figure 15 Percentage distribution of non-renewable energy used by each element

A11, A21 and A31 elements have generally low usage of the non-renewable energy while A22 and A32 elements unsurprisingly the two highest elements that consume lots of non-renewable energy. Study on the A22 element of both ICICS building and SCRF building which consumed 30900000 MJ and 4280000 MJ respectively shows that the concrete and rebar are the main building materials that use up such large amount of non-renewable energy.

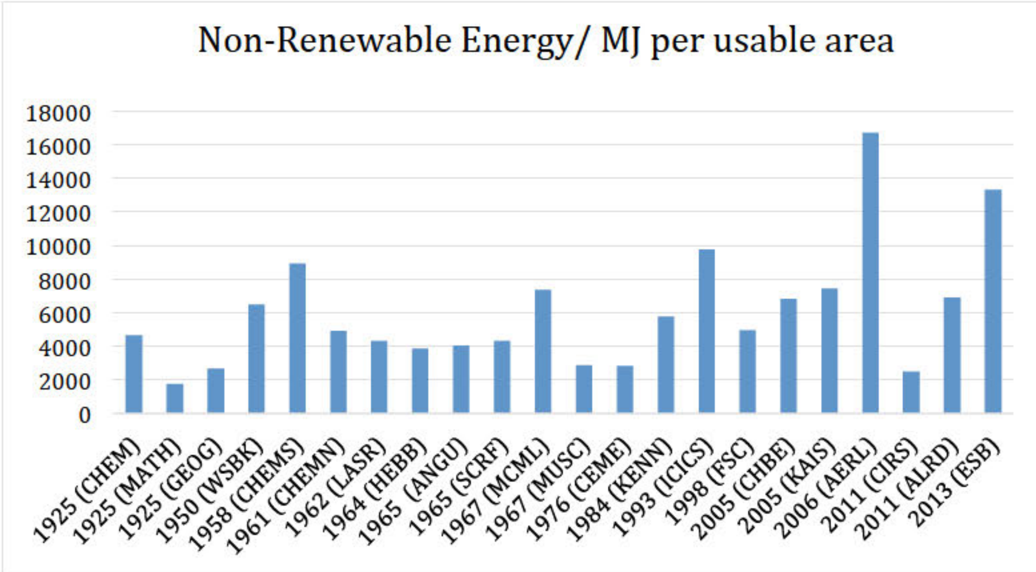

Figure 16 Non renewable energy per useable area of building in chronological order

Between 1925 and 2005 the non-renewable energy used per usable area fluctuates between 1786 and 9770 MJ/m^2 with a decreasing trend between year 1958 and 1964. AERL building uses up the largest amount of non-renewable energy at 16711 MJ/m^2. Then there is a positive slope from year 2011 to 2013, rising up to a value of 13316 MJ/m^2.

2.9 Fossil Fuel Consumption

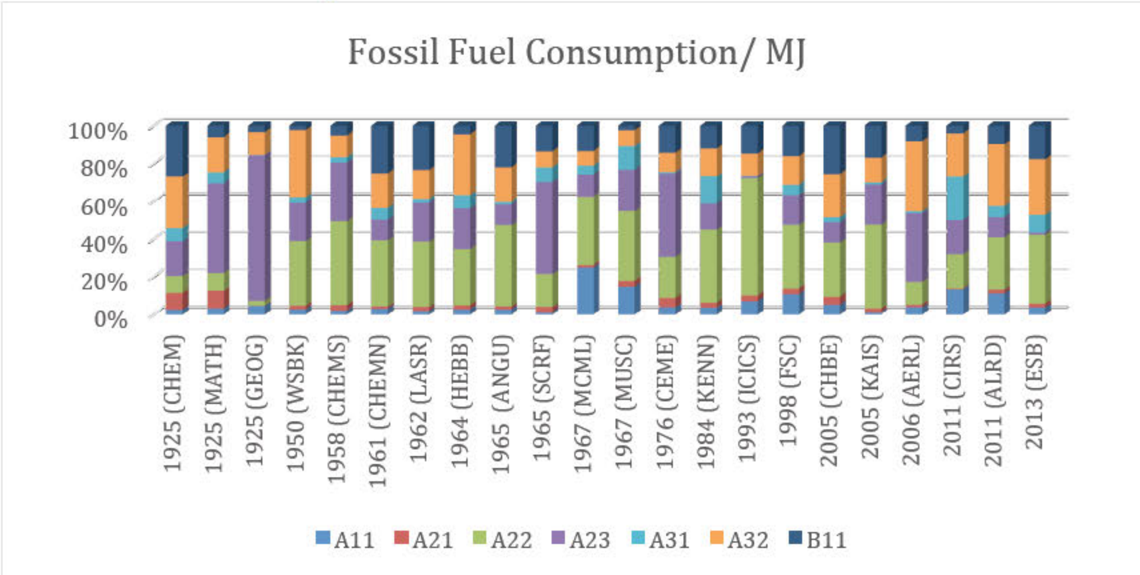

Figure 17 Percentage distribution of non-renewable energy used by each element

A11, A21 and A31 are again consume the least fossil fuel among all the other elements, while A22, A23 and A32 elements use up large amount of fossil fuel. To illustrate which building material has bigger impact on the amount of fossil fuel consumption, A23 element of CIRS building and MATH building will be the subject of study. CIRS used a total of 494 tonnes of concrete, 129 tonnes of Glulam sections, 26 tonnes of rebar and other materials in small quantity. While MATH building used 238 tonnes of ballast (aggregate stone), 25 tonnes of Cedar wood shiplap siding and 32 tonnes of roofing asphalt. As a result the fossil fuel consumption of CIRS is 2071360 MJ which is unexpectedly lower than that of MATH building that used lesser building materials to construct. Therefore, we deduce that the use of ballast, roofing asphalt and Cedar wood will consume much more fossil fuel than concrete, rebar and Glulam sections.

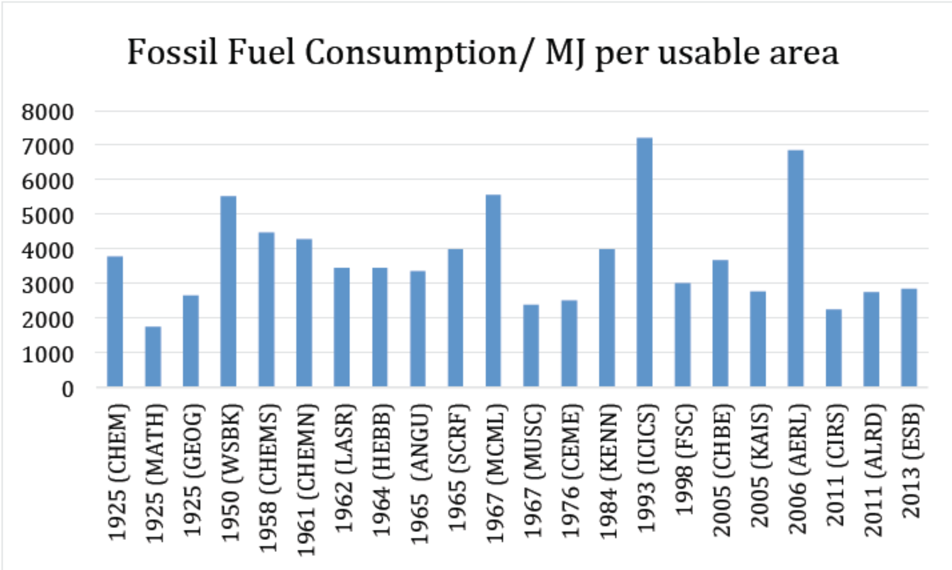

Figure 18 Fossil fuel consumption per useable area of building in chronological order

The fossil fuel consumption of WSBK building (built in year 1950) is 5520 MJ/m^2 and from there it decreases to 3442 MJ/m^2 in year 1962 before going on a positive slope to a value of 5556 MJ/m^{2}of MCML building which was constructed in 1967. Between year 1967 and 2013, the fossil fuel consumption of building is in the range of 2250 MJ/m^2 and 3985 MJ/ m^{2}except that there are two buildings with significantly large value of 7209 MJ/m^2 (ICICS building) and 6858 MJ/m^2 (AERL building) which were built in year 1993 and 2006 respectively.

2.10 Discussion

Analysis on the life cycle impact assessment result of the 22 UBC academic buildings shows that different building materials have different degree of impact on the nine environmental impact categories being studied. Concrete and rebar are the most abundantly used building materials in some of the elements of UBC buildings and the use of these materials in large quantity directly results in much higher impact on global warming, acidification, HH particulate, ozone depletion, smog potential and non-renewable energy usage.

Apart from concrete and rebar, there are also other building materials that have great impact on certain impact categories. For example, investigation on the impact assessment shows that the use of ballast (aggregate stone) will result in much higher acidification potential of a building. While the construction of element using ballast (aggregate stone), roofing asphalt, Gypsum board, and organic felt has large eutrophication potential. However, in-depth study is needed to verify which exact building material is the main culprit of eutrophication problem.

Usage of aluminum and glazing panels in the construction will increase the total primary energy used, and this is understandable as the extraction of aluminum from its ore, bauxite requires large amount of energy in addition to other unit processes. Furthermore, ballast (aggregate stone), Cedar wood shiplap siding and roofing asphalt are among the building materials which consume large amount of fossil fuel compared to concrete and rebar.

This information obtained from the analysis will be very useful in the future planning of UBC buildings to have them certified through LEED, achieving environmental sustainability. In order to achieve 3 LEED points for newly constructed building, it must have at least three impact categories that shows a minimum of 10% reduction in the following impact categories

1. Global warming potential
2. Depletion of the stratospheric ozone layer
3. Acidification of land and water recourses
4. Eutrophication
5. Formation of tropospheric ozone
6. Depletion of non-renewable energy resources

The identification of materials that have huge influence on certain impact categories through the analysis of the life cycle impact assessment enables UBC to make use of this useful information. As an implication of this knowledge for example, we can reduce the usage of less environmentally friendly building materials and replace them with more sustainable materials to achieve LEED points.

However, the most recent building (ESB) which was built in the year of 2013 still has not achieved the maximum environmental friendliness and sustainability, therefore much more in-depth study is needed to improve the efficiency of the building throughout its life cycle.

3.0 Next Steps for Institutionalizing LCA at UBC

3.1 Modeling Tools

After rationalizing use of LCA in UBC buildings and analyzing the summary of environmental impacts and materials used in academic building designs, it is time to institutionalize LCA such that in the future, decision makers in UBC will implement LCA as part of the building's pre-construction research.
Before getting into further details, it is important to ask the question: why should UBC institutionalize LCA in the first place? The answer is, to assist UBC's policy makers (i.e. Project services, Property trust, etc.) in making informed decisions in establishing guidelines for both future building constructions and renovating or demolishing existing buildings.

The first step in institutionalizing LCA on UBC campus is to choose a modeling tool that best suits UBC's requirements. UBC requires a tool that can provide them transparent, reliable and user-friendly information. LCA results are highly sensitive to the data used and the assumptions made. That is why the interpretation of the results is only possible if all steps of the LCA procedure are transparent. Moreover, the modeling tool must use a reliable database that is updated frequently to provide its users with the most up-to-date data of common materials[9]. As a general requirement, the user friendliness of the software is also of importance.

[9] (Schaltegger, 1996)

Athena impact estimator for buildings is a modeling tool that best suits UBC's requirements. Athena institute constantly tries to provide as much transparency as possible regarding the data and the inner workings of the impact estimator software and that is why much of their data are available in reports downloadable on their website[10]. Additionally their data are the result of "on-going research since the inception of the Athena Institute, and is periodically updated as funding allows – either from their core funds, or according to client requests[11]." With UBC's growing technology in building sciences and their sustainable approaches in construction methods, having up to date information is what has made the impact estimator the suitable option. As a basic requirement, it is necessary for the modeling tool to have a user-friendly interface such that the program can be used on a normal computer and no extra programs or libraries are required to run the software. Although Athena impact estimator satisfies these requirements, it is still difficult for non-technical users to work with the program. It is proposed that the Athena impact estimator to be used in combination with another, simpler and more user friendly software interface, so the combination can provide the non technical users, especially managers and decision makers with an interface that allows different LCA scenarios to be built instantly on all types of devices (i.e. cell phones, iPads, etc.) and the results are generated in graphical and intuitive manner. Creating such an interface is not difficult and can be done with funding from UBC student fees and donor fundraisings.

It is worthy to note hat Athena institute had developed EcoCalculator- a simpler version of Impact estimator- for an easier life cycle assessment for building design teams. The program is an excel sheet with predefined assemblies for a quick assessment[12]. However, Athena institute has recently announced that the EcoCalculator tool is out of date. Their website states:

[10] (Athena Sustainable Materials Institute, 2014)
[11] (Athena Sustainable Materials Institute, 2014)
[12] (Athena Sustainable Materials Institute, 2014)

"We developed the EcoCalculator as an entry-level LCA tool, to make life cycle assessment especially accessible for building design teams. It was created in partnership with the Green Building Initiative, specifically for the Green Globes rating system but available to anyone. Green Globes has changed its LCA credit to an approach more suited to the Impact Estimator. Similarly, we are encouraging all EcoCalculator users to switch to the Impact Estimator – it's got so much more to offer while still easy to use. See our tutorials on this web site to get started. Meanwhile, the EcoCalculator is still available but slightly out of date (it is out of step from the Impact Estimator by three revision cycles). We are currently considering the future of the EcoCalculator [13]. "

Therefore, it is evident that there is a need for a simpler and more easily understood program. Use of the proposed software in conjunction with Athena impact estimator will allow any end-user to run an intricate LCA tool and generate easily understandable results for everyone.

3.2 UBC Database

In order to be able to institutionalize LCA at UBC campus, it is important to understand how UBC gathers the information necessary to perform the assessment and how these information are processed to create a comprehensive database that includes the impacts that UBC buildings have on the environment in nine categories. Global warming, acidification, HH particulate, eutrophication, ozone depletion, smog potential, primary energy consumption, non-renewable energy sources and fossil fuel consumption are the nine categories that are analyzed in UBC's building database.

UBC uses two primary sources of information to obtain the amount of material used in a building, construction and architectural drawings and architectural construction assemblies.

Construction drawings are used to determine precise volumes of concrete in footings, slabs, columns, walls and other structural and building elements. Moreover

[13] (Athena Sustainable Materials Institute, 2014)

architectural drawings are used to identify the location and placement of specific wall, floor slab, ceiling finish, acoustic finish, partitions and other assemblies[14].

The second source of information, the architectural construction assemblies, is mainly used to identify the materials in a specific assembly. It is used to "determine the envelope and barrier characteristics for the roof, exterior walls, floor and interior partition assemblies[15]."

A software tool called On-Screen Takeoff was used to determine material quantities, from the above drawings. In 2013, CIVL 498C students used the OST program to manually measure the structural drawings in order to get the amount of material used in the buildings. In case of lack of data in the drawings, the students either made an assumption or in some cases used the building's 3D model. Once the takeoffs were complete, they were exported to Impact Estimator[16].

Athena impact estimator was chosen as the best software for UBC as was discussed in section 3.1. The information from OST was inputted into IE in six different assembly groups, foundation, walls, columns and beams, floors, roof and extra basic material[17].

Foundation assembly group consists of two main assemblies, concrete slab on grade and concrete footing (including stairs). Similarly walls were grouped in either exterior or partition walls. In case of columns and beams, "the impact estimator calculates the sizing of beams and columns based on the following inputs: number of beams and columns, floor to floor height, bay size, supported span and live load". As for floors, the impact estimator uses floor width and span, concrete strength, fly ash content and live load as inputs. Roof assembly is modeled similar to floors. In the case where the building under study featured a specific type of material (e.g. hollow structural steel (HSS)), they were inputted into the IE under Extra basic materials.

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[14] (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
[15] (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
[16] (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
[17] (Sianchuk, 2009)

After exporting building information from On-Screen Takeoff to Impact estimator, the information is processed by the Athena Life Cycle Inventory (LCI) and US LCI database to produce the building's impacts on the environment[18].

- Athena LCI database is used for structural material such as concrete, steel and wood. It contains detailed information on the building's envelope such as cladding, insulation, barrier products, paint, gypsum board, roofing products and windows[19]. This database is managed by ASMI and it is not publically available. Athena researchers updating maintain the database industry averages on material such as concrete and lumber[20]. Other data such as demolition and end of life processes, Athena membership fees and research grants are utilized[21].
- US LCI database is a publically accessible database with a wide variety of information, however impact estimator only uses this database for energy consumption impacts[22].

These databases process building information and using category indicators, convert the data to impact categories. For example, every kilogram of Portland cement used in the building is multiplied by 0.95- the global warming category indicator- so that the impact of that 1 kg of cement can be quantified into how many kg of CO_2 equivalent is released to the environment[23].

It is important to note that the reliability of LCA results is greatly dependent on the reliability of the inputting data. Therefore, as newer versions of On-Screen Takeoff program is released, it is recommended to repeat the takeoff procedure regularly in order to increase the accuracy of the data. For further accuracy in the data, for newer UBC buildings, it is suggested to input the data into IE using both 2D

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18 (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
19 (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
20 (Athena Sustainable Materials Institute, 2014)
21 (Athena Sustainable Materials Institute, 2014)
22 (Life Cycle Assessment of the Aquatic Ecosystems Research Laboratory, 2013)
23 (Bushi, 2014)

(construction/architectural drawings) and 3D (BIM models) information and compare the results to eliminate any errors that might occur due to the programs or other factors.

Since UBC database is mainly used as a benchmark for future constructions, it is recommended that the LCA studies be repeated regularly. In addition to increased accuracy of newer On-Screen Takeoff versions, Athena and US LCI database update their inventory data periodically. Newer material and methods are added regularly to keep up with the latest material and techniques used in the construction industry. Therefore updating the UBC database periodically becomes an important factor in creating a reliable and accurate database to be used as a reference for future projects.

However the main step in institutionalization of LCA n UBC is utilizing the database appropriately. The main purpose of the database is to create a reference building for future UBC constructions. If each new building is compared to the reference building and the performance of the new building is better than the reference building, after several years, the reference building will improve significantly because the database is constantly updated with better and newer buildings built on campus. Additions of newer buildings to UBC database will not only improve performance of individual buildings, but will improve the sustainability of the entire campus.

3.3 Decision making

LCA can be a useful tool in informing decision makers on what factors are contributing to damaging the environment. Furthermore, it provides insight about which impacts are contributing more than others so that decision makers can conduct further detailed analysis to minimize the impacts and optimize the design.

Nevertheless, there are two main limitations with applying LCA as an input for strategic decision-making on UBC campus. First limitation is that LCA considers all impacts to be of the same importance. Some regions, due to local policies, require more attention to be paid to some impacts. Similarly, in UBC, more emphasis is being put on reducing green house gases. UBC's climate action plan aims to reduce green house gases by 100% before 2050 when compared to 2007 [24]. This action plan puts more emphasis on global warming category results from the assessment. A solution to this limitation is to multiply the results of each impact category by a weighting factor that represents the relative importance of that category. This method can be useful since the weighted LCA results (i.e. normalized results multiplied by importance factor) can be summed up to produce a single value, which represents the total impact of the structure. This allows decision makers to easily compare the results of different buildings to compare the performance of proposed design with existing buildings on campus.

Furthermore, it is easier and clearer for decision makers to communicate LCA results with one number rather than comparing 8 different category numbers for each building [25]. Although we must be very careful in choosing the correct weighting factors for UBC based on its goal and scope, since unsuitable factors can greatly influence the results of the LCA.

The second limitation with institutionalizing life cycle assessment at UBC is that LCA excludes cost and investment concerns. Currently, financial and environmental issues are assessed separately. The main focus of studies done on UBC buildings are assessing cradle to grave life cycle of buildings and life cycle costing (LCCA) is done separately in the early design stages. UBC also offers an LCCA toolkit to be used as a template in coordination with project manager and technical services[26]. For an effective LCA institutionalization, an integrated analysis is required to combine financial and environmental concerns. The primary goal is to determine a

[24] (UBC Sustainability, 2014)
[25] (Brilhuis-Meijer, 2014)
[26] (UBC Technical Guidelines, 2014)

sustainable and cost effective design, based on an assessment that is benefiting from both LCA and LCCA results. This method can help UBC support strategic decision-making.

3.4 Communication and education resources

In order to be able to fully institutionalize Life cycle assessment in UBC, we must first overcome the main issues that are currently preventing growth of LCA. The three main issues concerning the progress of LCA on UBC campus are the credibility and lack of proper education and communication.
For any type of procedure that is being introduced in a community, it has to be reliable enough for the people to accept it and expand their use. LCA is no different from this concept. For institutionalization of LCA on UBC campus, it is essential for both the internal (project services, property trust) and the external community (Vancouver citizens, LEED officials, etc.) to be able to trust the results of LCA. As opposed to the past, where there had been lack of transparency on several aspects of LCA studies[27], it is important to make sure that all procedures and steps involved are clearly understandable and transparent to the community. If people can count on accuracy and correctness of the steps involved and the reliability of the data in an LCA, they are more likely to accept it. Availability and quality of necessary steps are the two main points that can help us institutionalize LCA more effectively.

Another reason that might prevent institutionalization of LCA is the lack of proper education and communication with the UBC community. It has not been long since the first session of CIVL 498c has been introduced in 2009 [28].

Today, many of UBC project designers are concerned with designing the buildings to achieve LEED certificates. Although LEED requirements do contribute to a more

[27] (Frankl, 2001)
[28] (Sianchuk, 2009)

sustainable design, it is best to complete it with a comprehensive LCA study to not only achieve a greener building based on LEED'S criteria (sustainable site development, water efficiency, energy efficiency, material selection, indoor environmental quality)[29], but to have a comprehensive cradle to grave assessment, meaning all the impacts from the initial stages of resource extraction to the end of the building's life cycle (i.e. demolition) be analyzed, to design a more sustainable and cost effective building. This ideal scenario where both LEED and LCA are integrated in building design can only be achieved if the right people are educated about the benefits of LCA. These "right people" are today's students that will become designers and decision makers in UBC's future campus design team. Civil 498c has taken the first steps in introducing students at UBC to LCA, but still not many students know about it. If civil 498c were to be offered as a core coarse in the civil engineering curriculum instead of a technical, more students will be exposed to LCA. Additional lectures and seminar must also be held on regular basis so that other students from other faculties can also be informed.

Additionally, a consistent education needs to be provided from what is being learnt in the studies done in this coarse. Not only students, but also decision makers and project services executives need to be informed of how campus buildings are currently operating. Most people don't know how the buildings truly behave and they assume that because the term "green" is put behind the project, that it must be a sustainable structure. Although these green buildings might be environmentally friendly in some aspects, they will have a lower than average behavior when the cradle to grave assessment is done. Therefore the current UBC building database can be used as a reference for all the future UBC campus buildings and just like UBC's LEED green building policy, designers should be required to do a comprehensive LCA during the initial design phases.

[29] (US Green Building Council, 2014)

No matter how much effort is put in choosing the best modeling tool or creating the most accurate and reliable database, if people don't know about LCA, they are not going to ask for it. Sufficient education to students and current executives is the key component in the successful institutionalization of LCA in UBC.

Conclusion

This paper focuses its discussion on three main sections.

- To rationalize the institution of environmental life cycle assessment (LCA) in UBC building design and operations.
- Report on the LCA study carried out in CIVL 498C and where it can be used by UBC sustainability programs
- Propose how UBC should approach the institution of LCA in building design and operations.

Institutionalizing LCA will help UBC building design and operations by supporting different sustainability programs such UBC Climate Action plan, Sustainability guidelines and etc. by providing sufficient scientific information to reduce impacts that are caused by transportation, recycling, water management, etc. Moreover, improvement in energy usage and global warming potential is achieved through management and reduction of electricity use.

Detailed analysis of UBC Vancouver camps buildings indicated that concrete and rebar are the most abundantly used building materials in some of the elements of UBC buildings and the use of these materials in large quantity directly results in much higher impacts. Also Usage of aluminum and glazing panels in the construction will increase the total primary energy used, and further
Investigation shows that use of ballast (aggregate stone) will result in much higher acidification potential of a building, while the construction of elements using ballast, has large eutrophication potential.

Lastly, further recommendations are made to facilitate successful institutionalization of LCA at UBC in the future. It is suggested a user-friendly software be made to be used in combination with IE. Also with newer UBC constructions, the database should be updated with newer building's information to improve the overall sustainability of the campus. Weighting procedures and integrated financial-environmental analysis is a useful tool for accelerating the decision making process. Lastly, it is noted that sufficient education and information is required to spread the word about LCA. This will increase the demand for such analysis, which will be beneficial for all parties involved.

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Annex A- Author Reflection

Maryam Abolghassem Tehrani

1) Previous exposure with sustainability and LCA :

   Before this course I had no exposure to LCA, however three of the course from the civil engineering curriculum had introduced the concept of sustainability.

   - APSC 201 “Technical Communication”: researched and wrote a paper on the solar aquatic wastewater treatment system in UBC’s CIRS building. Also, conducted an interview with Alberto Cayuela to research the feasibility of green building institutionalization in large communities.
   - CIVL 201 “Civil Engineering I”: concept of sustainable design was introduced. We also designed a bridge on Cambie and west Broadway corridor, which featured sustainable features such as storm-water harvesting and photovoltaic panels for electricity.
   - CIVL 300 “Construction Engineering and Management”: a guest lecture by Eesmyal Santos Brault on implementing sustainability features in existing buildings in Vancouver
   - CIVL 445 “Engineering Design and analysis I” : In this course, we are repurposing Emily Carr university’s building on Granville island. The new building contains many green features such as green roofs, sustainable water management systems, etc. the project is aimed to be certified for a LEED gold certificate.

2) Highlights of the coarse:

   - It was interesting to see the interaction between the environment and man made structures and how changing minor details an have a huge impact on the environment.
   - The most interesting part to an LCA study is that it is science based and there are fats to support he results of the LCA. It is easier to spread the message of LCA and convince people to adopt it as part of the design phase.
   - The coarse mainly focused on LCA studies in UBC campus. This is particularly interesting since it gives me the opportunity to directly change the future of my university’s campus. Expanding the use of UBC database as a reference for future developments will make each building better than its one before.
   - I understood that just because the term “green” is used in a certain portion of a project, it doesn’t mean that it is overall environmentally more sustainable. LCA’s cradle to grave

approach allows the entire lifecycle of the project to be examined and if the overall impacts were lower than a benchmark, then it should be labeled as a sustainable structure.

3) Expectation before this coarse
Although time wise, it was more practical to focus on the results of the LCA and use the data from last year students, it would have been more useful for us to do the assessment from scratch. It would have been better if we had learnt the on screen takeoff program so we can do an LCA from scratch for our future projects. Currently I am taking CIVL 445, where we are redeveloping Emily Carr University's building. We are adding green features to the structure to be certified as a LEED gold building. However, if we had learnt to use floor plans and 3D models to take off material quantities and afterwards we used the impact estimator to assess the project, it would have been much more helpful in designing a more sustainable structure.

4) CEAB graduate attributes

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 were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.**
Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A = applied	The coarse utilized mathematics for impact calculations and benchmark development. Also chemistry and physics concepts were applied to demonstrate the relation between material and environmental impacts
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.	ID = introduced & developed	the engineering problem in this coarse was to assess UBC campus buildings to create a benchmark for future constructions. Solving the problem included quantifying the impact of structures in terms of different impact categories.

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.	D = developed	Analyzing the impact estimator data and modifying it to reach a better, more sustainable structure that behaves better than the benchmark building was developed. Valid conclusions were also made based on the results of the analyzed and modified data from the impact estimator.
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.	DA = developed & applied	In final project stage2, there are some design components where raw data are modified to make the building under study, perform better by changing its assemblies in the impact estimator.
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.	IA = introduced & applied	Modern engineering tools such as Impact estimator and SimaPro were demonstrated and used to solve he engineering problems involved in the course.
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	Final project stages 1 and 2 were done individually whereas stage 3 was done In groups of three to develop the skills to be able to work in a group
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.	DA = developed & applied	The final project report provided the opportunity to comprehend and write effective reports to be used by professionals. Also the final presentation will facilitate in communicating complex engineering concepts with the profession and with the society

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	The course introduced the importance for engineers to understand the long term implications associated with engineering decisions in the context of environmental impacts.
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 aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	IDA = introduced, developed & applied	The main focus of this course was on the impacts of engineering products and structures on the environment. It also developed the understanding of the interactions that engineering has with the economy by introducing life cycle costing. Uncertainties in the methods and software were also analyzed
Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A = applied	In the final project, credit is given to cited references to comply with professional ethics in engineering profession.
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.	I = introduced	Introduction to the concept of life cycle costing demonstrated that the LCA is more effective when it is accompanied by a life cycle costing analysis.
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	The course gave me an in-depth understanding of sustainability and methods behind a life cycle assessment, which will allow me to apply my knowledge in future projects.

Alvin Kong Jit Sieng

I am an exchange student from the University Of Hong Kong (HKU) and one of the best things that I really enjoy during my period of study at the University of British Columbia is that I get to learn about this new knowledge-life cycle assessment. Life cycle assessment is something that I had never heard of before I enrolled into this course unlike sustainability. Sustainability has emerged as an environmental goal to alleviate the current global environmental crisis which is worsening day by day. Pursuing engineering degree program at the University of Hong Kong, I received formal education about sustainability though a course named "Engineering for sustainable development", learning about the environmental issues and how the utilization of technology can help to increase the efficiency of buildings which in returns reducing the carbon footprint on the environment. Apart from just educating students about sustainability through in-class lessons, HKU does put sustainability into practice and the newly built Centennial Campus in the year 2012 is the proof to that statement. Installed with solar panels, wind turbines, motion-sensor lighting system and other green features, HKU Centennial Campus receives LEED Platinum certification for high performance green buildings.

Life cycle assessment (LCA) is compilation and evaluation of the inputs, outputs and potential impacts of a product system or product throughout its life cycle (from cradle to grave). The study of life cycle assessment knowledge in this course has been eye-opening and the assignments given in the class have successfully met its aim, enabling students to have better understanding about this new knowledge. The first assignment, which was summarizing the key points of any five articles from the White Paper, enlightened my mind with many mind-blowing facts. Many people including myself have the misconception that recycling is environmentally friendly as it avoids the fate of these recyclable materials from ending up at landfill, but this is not necessarily true as the life cycle assessment result shows that it does more harm to the environment if the source is at far distance from the recycling facility. Apart from that, invitation of guest speakers sharing their experience working on life cycle assessment provides us a clear picture of the application of life cycle assessment on real life situation.

Being assigned to perform analysis on the LCA study of academic buildings at UBC Vancouver Campus has given me the opportunity to work closely with all these data generated by Athena Impact Estimator software. During the period of time when I was working on the final project Stage 1 and 2, I was actually puzzled and confused by the massive amount of data in that Excel sheet, I had a hard time figuring of how one value was related to another. Therefore, I think it will be very helpful if more time is spent on explaining those figures before working on the Stage 3, so that the students really know what they are doing. However, I am really glad that I understand how life cycle assessment works and how the unit processes within the system boundary of the building will have effect on the environment. The identification of building materials that have high potential on specific impact category made possible by the analysis carried out on the LCA study will be very useful for UBC to create buildings that are more environmental friendly in the future, and I do hope that my investigation will help in shaping a better future of UBC campus.

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 were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.**
Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	ID = introduced & developed	Life cycle assessment is a new knowledge to me as I have come across this term before I enrolled into this course. This class introduced me about this powerful engineering tool and also the class materials, assignments have fulfilled its aim which is to enable students master the Impact Estimator software and perform analysis on the results to explain the impact assessment of building during its service life.
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.	DA = developed & applied	This course does help me to develop better in investigation work especially the final project as explained in the problem analysis section.
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.	DA = developed & applied	Analyzing the impact estimator data and modifying it to reach a better, more sustainable structure that behaves better than the benchmark building was developed. Valid conclusions were also made based on the results of the analyzed and modified data from the impact estimator.
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.	N/A = not applicable	

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	In order to understand how life cycle assment works, Athena Impact Estimator is a very good tool to see how building materials affect the environmental impact categories. I was introduced to this software and now I am able to use the software on my own to perform analysis on LCA study.
Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	A = applied	Stage I and II required individual effort to accomplish while Stage III demanded more of a team work to produce a fine piece of final report.
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	This is very crucial especially in the stage 3 of final project as it is a group work and therefore good communication will ensure the delivery of ideas of other temamates in order to work efficiently.
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.	IA = introduced & applied	I was introduced to how life cycle assessment helps the building industry in green building designs. In fact, many big companies have implied LCA study on their products to study their environmental impacts.

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 aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	DA = developed & applied	LCA definitely plays a big role in the future as the result generated will have information about the environmental impacts which gives clue on how a product will affect the environment.
Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	N/A = not applicable	
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.	N/A = not applicable	
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.	N/A = not applicable	

Dewei Kong

My primary understanding about LCA is limited to manufacturing process and the end of service life, i.e. recycling, of the products and services. However, LCA includes so much more that covers the entire "life" for any product or service. It gives an index and categories to follow and these are most important and relevant environmental impacts we have today.

Most activities would have at least one of impacts listed. This gives a very systematic way of organizing information related to environmental friendly. Most importantly, LCA poses a very important question to manufacturer, designer, architects, construction companies and etc., who claim to give environmental friendly products and services, "what exactly do you help to achieve sustainability and support the environment". The title of "environmental-friendly" is no longer free to use and abused. It awards companies and individuals with serious concern about environment and careful implementation of the concept of sustainability while they are providing the market with best products and services.

LCA is a great tool to evaluate sustainability and environmental impacts. However, it is not very accessible to average people. It contains too complicated terms and jargons that general public, also the majority population without related education, cannot understand, let alone use LCA in daily life to choose and purchase services and products. Yes, we have a special organization and system to award LCA related achievements but this is not enough. Without the general recognition from the public, LCA study is greatly limited and not fully utilized.

While the solution is not easy to find and hardly perfect in this case, there could be improvements. First would be the approval from all major countries and government agencies that LCA should be included for evaluation of sustainability and environmental impacts. Second, scholars and organizations should have developed a tailored or simplified version for the public. And at the same time, they carry the responsibility to better inform the public about LCA findings and achievements.

Graduate Attributes

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 were addressed during your class experience. Reflect on the experiences you got from the games, lectures, assignments, quizzes, guest speakers organized for the class, and your final project experience.
Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IA = introduced & applied	A lot of calculation and spreadsheet is used in the first two stages of the projects in order to apply the LCA index. Other knowledge include the use of previous knowledge in structural engineering that gives information about how construction work is done and what material is used.
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.	DA = developed & applied	In the final project, connection needs to be drawn from the current environmental projects going on UBC campus to the LCA application. The understanding of LCA is tested as well as the understanding of the reports and proposals
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.	I = introduced	In stage two, a set of data is given and to be manipulated in order to give a clear comparison between the studied building and the campus average.
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.	IA = introduced & applied	The second part of stage two involves changing the design components of the building. This involves the use of the Athena software. However, this task has not specified exactly how such redesign should be done but need our own understanding and ideas.

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	Athena is a big part of the course and it is crucial to understand the software and apply our LCA study. However, I feel that disproportionate time is given during the course for this program. I, personally, need more help about this program and meeting the professor and the TA is not enough.
Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	IA = introduced & applied	The schedule of the course makes it very difficult to meet up with group members. I happen to like the style that group members gathered to complete the task together and teammates contribute and help each other with their content. However, currently the project is done in a way that each member is given a part of the project and complete on his own. I find it is not very conducive for the development of the project and understanding of the course.
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.	IDA = introduced, developed & applied	The final report includes a lot of understanding of the material and application of the LCA concepts.
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.	I = introduced	Engineers does carry great responsibility to the society about its well-being because engineers has their hands on almost everything people use and live with in the modern society. In LCA, environment is the issue that engineers should always consider while they work.

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 aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	I = introduced	While LCA does include various aspects of urban life but this course is for civil engineering student and only a limited range of LCA is concerned. Moreover, real life business is not greatly discussed and it is hard to make connection.
Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	N/A = not applicable	In the final project, credit is given to cited references to comply with professional ethics in engineering profession.
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.	I = introduced	Very weak connection between LCA study and economic aspect of real life application is established during my study of the course. While UBC is implementing it in real life and a lot of study is based on UBC, it does not come close to the majority business in real life.
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.	ID = introduced & developed	Examples and achievements in LCA are given for better understanding of this field of study. Furthermore, tests based on LCA technical terms and element construction format is very useful for civil engineering student to apply LCA in their future career.