Incorporating Life Cycle Assessment at The University of British Columbia

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Glossary

Building Assemblies: Two or more items or products that are grouped together as a unit which performs a function. Typical assemblies are walls, floors, foundations, etc.

Characterization Factor: A factor that converts from materials data to environmental categories such as smog or global warming.

Environmental Product Declaration (EPD): A verified document that uses LCA studies to report the environmental data of products.

International Standards Organization (ISO): Developer and publisher of international standards. Specific standards related to LCA are ISO 14040 and ISO 14044.

Life Cycle Assessment (LCA): The compilation and evaluation of the inputs, outputs, and potential impacts of a product (or system of products), providing quantifiable support for environmental decisions.

Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): A method of producing characterization factors for impact categories using an inventory of stressors collected from different inputs.

Executive Summary

Life-cycle assessment (LCA) offers UBC the ability to further its sustainability and environmental goals in a quantifiable and transparent way. With a new version of LEED® on the horizon now is an ideal time to re-evaluate how sustainability is incorporated into the programs and guidelines affecting new developments on the Vancouver campus.

Current language around LCA's use at UBC is infrequent and misleading, referring instead to life-cycle costing. This apparent lack of consideration is troublesome, as it neglects a major area of sustainability research and progression. UBC has several plans, visions, and policies that extol its goals of a sustainable campus, and LCA is well aligned to be included as a tool for reaching its targets.

Transparent benchmarks created in this study allow for the tracking of sustainability metrics through direct comparisons. This is important in understanding what the actual environmental impacts of developments on campus are, allowing progress to be tracked openly. New projects can be compared to the benchmark to allow The University a way of defining what sustainable means, creating a more proactive way of achieving environmental goals.

Perhaps the greatest opportunity for UBC is in the area of global leadership. With its position UBC has the power to be a prominent player in the North American environmental arena, and by promoting the use of LCA in new developments it is able to guide other universities and private partners towards a more sustainable future, not just a less unsustainable one.

1.0 Introduction

This report serves to address how UBC can further improve its record of environmental accountability and leadership through the incorporation of Whole Building Life Cycle Assessment (LCA) into decisions on campus development and operations. LCA is a method for determining the environmental impacts of a product system, which when applied to buildings allows for the creation of a benchmark that can be used in the evaluation of design choices early on in the decision making process. The information gained by performing an LCA on potential designs lets decision makers weigh options using quantifiable results related to the embodied environmental impacts of new buildings. The potential of using an LCA benchmark at UBC has tremendous potential for creating a way of tracking the progress that UBC is making towards truly being sustainable. With the advancement of other building optimization and efficiency improving strategies reaching saturation the embodied impacts of a building's design are becoming increasingly important in managing environmental impacts. This introduction contains information on the scope of the report followed by a description of the report.

1.1 Scope

To accomplish the goals of this report two main tasks were undertaken:

- A review of The University's policies related to the sustainability of the built environment to determine if LCA is a valid tool for inclusion in future projects.
- The creation of an LCA database of the academic buildings on UBC's Vancouver campus, from which benchmarks have been established for use in comparing different buildings' environmental impacts.

1.2 Project Description

In supporting the case for including LCA in the design conversation surrounding developments at UBC a case study has been undertaken as part of the Civil 498c Life Cycle Assessment course. In this course students over several years have prepared a database of building construction information for buildings at The University and performed an LCA study. Using the database we have been able to make benchmarks for buildings built at UBC. The creation and maintenance of this database would also allow for long term trends in sustainability to be monitored over time to see if progress is truly being made.

The future goals of this course are to further improve the sustainability of UBC's campus by institutionalizing the use of science-based, quantifiable, standards supported methodologies for UBC to reduce its environmental impact. This report will make a case for the inclusion of LCA in UBC's Design Guidelines, and suggest possible uses for the prepared LCA database. To prepare this argument an analysis of the current conversation surrounding sustainability at UBC is presented, with a discussion on how LCA can become ingrained therein. The LCA study of academic buildings undertaken this term is shown with results and discussions related to how the information can be used to guide UBC's design and decision making processes. The report concludes with a section based on the next steps for institutionalizing LCA at UBC, where ideas are presented on ways of incorporating LCA in building design and operations.

2.0 Sustainability at UBC

The University of British Columbia is experiencing a time of tremendous growth which brings with it the requirement to examine how it can better manage that expansion in order to meet its sustainability and climate goals. In 2010 UBC pledged to large reductions in greenhouse gas (GHG) emissions from 2007 levels, as outline in the Climate Action Plan (Sustain.ubc.ca, 2010). Many of the projects underway focus on improving energy efficiency, either through direct production methods, or by improving upon existing systems. And while these programs have proven successful in reducing the amount of GHG emissions, there is still room for improvement in the key area of campus development and infrastructure.

"The University explores and exemplifies all aspects of economic, environmental, and social sustainability"

- The UBC Plan

UBC is steeped in an environment of change. It is something that has been taken as a core principle of the activities that go on at the institution. Sustainability is one such avenue for change, and many commitments towards improving the environmental sustainability of UBC have been made. It has been shown on campus that creating an environmentally aware space has impacts on the awareness of its inhabitants, and can lead to changes in behaviour that align with UBC's Climate Action Plan (Sustain.ubc.ca, 2010; Annualreport.ubc.ca, 2014).

The University has instituted a number of plans that guide its actions as a regional entity located in one of the greenest cities in the world. It has taken a strong stance on the environment, placing a high value on being a leader in the areas of research and implementation of solutions that can positively impact the world we live in. It is in these plans that whole building Life Cycle Assessment can play an active role in meeting the targets set out by the University.

With the Climate Action Plan providing an overarching goal to the actions UBC takes with regards to the environment, other plans provide more detail on how to achieve those goals. In regards to the built environment there are two key documents that direct developers on how to incorporate sustainability into new projects: The UBC Vancouver Campus Plan (The Campus Plan) (Planning.ubc.ca, 2010), and UBC Technical Guidelines (Technicalguidelines.ubc.ca, 2014). These documents support UBC's Policy #5 on Sustainable Development (Universitycounsel.ubc.ca, 2005).

2.1 The Campus Plan

The Campus Plan guides project planners on how to design for the UBC campus with the goal of creating a built environment that adheres to the functional, sustainability, and character objectives of the University. It is motivated by the high level visions and missions set out by UBC in The UBC Plan and CAP.

In The Campus Plan the ways that UBC incorporates sustainability are presented. These methods include:

- LEED® requirements
- Sustainability Best Practice Building Design
- Living Lab Sustainability Opportunities

The incorporation of LCA in these areas would provide The University with a way to reliably track and monitor the progress of these sustainability measures, and provide an opportunity to be a global leader in environmental considerations.

LEED® offers designers a way of classifying their projects according to accepted environmental and energy criteria, and UBC requires that all buildings obtain LEED® Gold (Usgbc.org, 2014). The way this is done is through a system of mandatory and optional requirements, however, in achieving all mandatory credits earns the required Gold rating, so there is little motivation for innovation in design (UBC LEED Implementation Guide, 2013). And when you consider that over 10% of these credits come simple based on density and transit considerations (which apply to any building on campus) it begins to be seen that LEED ratings do not necessarily incorporate the best practices of sustainability. With the advent of LEED v4 new credits have been created for life cycle impact reduction (Usgbc.org, 2014), and there is an opportunity for UBC to re-examine how the mandatory points for campus buildings actually meet its sustainability objectives.

Perhaps LCA is best suited to be discussed in relation to the best practice principles that UBC believes in. It is here that considerations are made by designers early on in the project about decisions that will affect the long term performance of a building. The current conversation revolves around reducing energy use through design principles such as massing and orientation, and does not consider the effects of building materials. There is again an opportunity to re-evaluate how UBC defines sustainability, and incorporate elements of LCA into the decision making process.

2.2 UBC Technical Guidelines

The UBC Technical Guidelines provide recommended standards for building designs not otherwise covered by the Campus Plan. Here again there is reference to sustainability principles focusing on energy efficiency, but not life cycle impacts. Life cycle analysis is presented in the context of learning space guidelines, but not for whole buildings. There is also a discrepancy in the way life cycle costing is discussed with life cycle assessments. Information on quantifying the environmental impacts of a building over its whole life is presented with a reference study (Ospelt, n.d), but the support for its inclusion is not at a sufficient enough level to prompt designers to consider it.

As part of the Technical Guidelines in the Design Process section it is stated that a UBC Technical Sustainability Group advises on sustainability expectations for projects, defining opportunities, expectations, and targets. This stage of the project offers The University the opportunity to incorporate LCA as a cornerstone of its sustainability initiatives. The inclusion of LCA at this level allows for the discussion of University benchmarks to be discussed with design teams, and included for in final design briefs, ensuring that true long term environmental sustainability is considered.

Within the technical guidelines for sustainability there is the mention of selecting materials with recycled and recyclable content, and for using green/sustainable materials certified by a third party (Technicalguidelines.ubc.ca, 2014). This is an important first step, but simply using recycled material does not always promote sustainability related to environmental impacts, and third party certification is a vague descriptor that could be misinterpreted. Here there is the opportunity to include the use of Environmental Product Declarations (EPDs) in the discussion, so that designers begin thinking about their material choices over their life cycle.

2.3 Policy #5: Sustainable Development

It is important to examine where the guidelines and plans discussed in the previous sections originate from in order to better understand how LCA can be included. As such this section will discuss the policy passed by the UBC Board of Governors related to sustainable development.

> *"[UBC]... is committed to improving its performance in sustainability in all areas of operations"* *- Policy #5: Sustainable Development*

Policy #5 again commits UBC to being a leader in sustainability, using targets and objectives to minimize the pollution of air, water, and soil. It states that UBC seeks ways to conserve resources. LCA is perfectly aligned with Policy #5 as a way that UBC can incorporate sustainable developments in a quantifiable and observable way.

Based on the findings of the authors there is substantial evidence that justifies, if not inclusion, at least consideration of incorporating LCA into UBC's sustainability programs. LCA offers The University a way of demonstrating a quantifiable reduction in environmental impacts, which can be directly linked to decisions made during the design of new buildings. UBC's overarching direction with regards to developmental sustainability would be enhanced by the application of LCA in the areas of leadership, conservation, and accountability. Inclusion of embedded material energies allow for the better understanding of the real impacts of projects. Benchmarks creating using LCA studies allow for direct environmental comparisons of building designs. All of these factors align LCA with UBC's vision and goals, and promote UBC's private sector partners to do more.

3.0 LCA Study of Academic Buildings on Campus

Since 2009 the CIVL 498C class has been creating a set of LCAs for a selection of academic buildings on the UBC Vancouver campus. Last year full LCA studies were carried out on a series of 29 buildings. These assessments had a standardized goal and scope in order to make comparative assertions between them. This is a requirement as these studies are to be used in the development of a regional benchmark for the academic buildings at UBC.

3.1 Standardized Goal and Scope

The purpose of these LCAs is to create a regional benchmark for the UBC campus. To create this benchmark all the reports must have a standardized goal and scope. The requirements for a goal and scope of an LCA study are outlined in ISO 14044. The intended applications of the previous studies are to establish a materials inventory and environmental impact reference for a single building and to carry out regional environmental performance comparisons when combined. The studies were carried out because they were seen as an essential part of the creation of a tool that will help inform decision makers. These decision makers such as the UBC Sustainability Office are the intended audience of the studies.

The product system of the studies is the structure and envelope of the academic buildings. The functional unit is a square foot of finished floor area. The studies were cradle-to-gate that included the raw material extraction, the manufacture of construction materials and the construction of the academic buildings and all transportation processes throughout. The impact assessment method chosen was the TRACI method which was developed by the United States Environmental Protection Agency. The impact categories measured in TRACI are: global warming potential, acidification potential, eutrophication potential, human health respiratory effects potential, smog potential, ozone depletion potential, total primary energy use, fossil fuel use and non-renewable energy use. The building takeoffs were done with OnScreen TakeOff software from digital plans. The assemblies of the building that were included are: A11 - Foundation, A21 - Lower Floor Construction, A22 - Upper Floor Construction, A23 - Roof Construction, A31 - Walls Below Grade, A32 - Walls Above Grade and B11 - Partitions. The elimination of assemblies such as HVAC and electrical systems was associated with limitation in the available data and the Athena Impact Estimator (IE). These components were then run through the IE to find the total impacts in the previously mentioned categories. As this was a cradle-to-gate study the timespan considered in the IE was only 1 year.

3.2 Current Study

This year we built off of the results from the individual studies from the previous year to create the benchmark. This was done in several stages.

Stage One

In stage one the building studies were updated to meet the LEED v4 standard for use in life-cycle analysis. LEED requires a 60 lifespan considering all aspects of building construction, replacement of materials and de-construction (Usgbc.org, 2014). To change this we put the models through the IE again but changed the timespan to 60 years. The same impact categories were considered and none of the building assemblies were altered in any other way. These 60 year results were compiled into a class database consisting of

24 buildings. The academic buildings are listed in Table 1 with their original year of construction.

Table 1: Academic Buildings Included

Building	Year Constructed	Abbreviation
Allard Hall	2011	ALRD
Aquatic Ecosystems Research Laboratory	2006	AERL
Centre for Interactive Research on Sustainability	2011	CIRS
Chemical and Biological Engineering Building	2006	CHBE
Chemistry Building	1925	CHEM
Chemistry Building - North	1961	CHEMN
Chemistry Building - South	1959	CHEMS
Civil and Mechanical Engineering Building	1976	CEME
Douglas Kenny Building	1984	KENN
Earth Sciences Building	2012	ESB
Forest Science Centre	1998	FSC
Fred Kaiser Building	2005	KAIS
Frederic Lasserre Building	1962	LASR
Geography Building	1925	GEOG
H.R. MacMillan Building	1967	MCML
Hebb Building	1964	HEBB
Hennings Building	1947	HENN
Henry Angus Building	1965	ANGU
Institute for Computing, Information and Cognitive Systems	1993	ICICS
Mathematics Building	1925	MATH
Music Building	1968	MUSC
Neville Scarfe Building	1962	SCRF
Pharmaceutical Sciences Building	2012	PHRM
Wesbrook Building	1951	WSBK

The buildings were constructed over an 87 year period from 1925 to 2012. The oldest buildings are CHEM, GEOG and MATH. The newest are PHRM and ESB. The average year of construction is 1973 and the median is 1967.

Stage Two

In the second stage of the project we used the database to create benchmarks in all the impact categories. Benchmarks were made for the whole buildings as well as all of their assemblies. Some buildings were egregious outliers in their impacts and had to be excluded from the data set. The biggest outlier is the HENN. It's whole building impacts are over 6 times the benchmark in some impact categories. Upon inspection of its data this is because there is a large amount of Operational Energy Use being counted in the building. This was excluded from the other reports due to a lack of data associated with building operations (e.g. electrical, HVAC, etc). Due to this addition to the HENN report it will be excluded from the benchmark. PHRM will also be excluded. It has very large impact results associated with the manufacture of its construction materials. Since these large impacts lead to results up to 5 times higher than the benchmark in all impact categories it will be excluded from the study.

On the other side of the spectrum there are buildings that have to be excluded for being too low. While low numbers are desirable it is incredibly unlikely that any building in the study would have impacts that are only a tenth of the benchmarks. This is the case in FSC. There is no obvious reason for its low impact results because every process has low impacts associated with it though it is possible it is because the bill of materials is not given in tonnes. MATH is also going to be excluded for low results. Similarly to FSC there is no obvious outlier, it just has low results in every impact category. These two buildings are unlikely to be the lowest impact buildings in the study, especially because MATH was built in 1925. Therefore the results from the previous studies are suspect and cannot be trusted.

After excluding these four academic buildings 20 are left. Across all categories they range from two and half times the category benchmark to a third of it. No individual building has outlying results in any more than three impact categories and none of those outlier are as egregious as the building that were excluded.

3.3 Results

The benchmark totals for the whole building impacts for these 20 buildings is shown in Table 2. A full list of whole building impacts can be found in Appendix A.

Table 2: Whole building benchmarks in TRACI impact categories

Impact Category	Whole Building Benchmark
Global Warming Potential (kg CO_2 eq)	400.0
Acidification Potential (kg SO_2 eq)	2.63
HH Particulate Potential (kg PM2.5 eq)	1.29
Eutrophication Potential (kg N eq)	0.29
Ozone Depletion Potential (kg CFC-11 eq)	1.52×10^{-6}
Smog Potential (kg O_3 eq)	54.65
Total Primary Energy Use (MJ)	7260
Non-Renewable Energy Use (MJ)	6921
Fossil Fuel Use (MJ)	3977

In all assemblies in all buildings the process with the highest impacts associated with it is the manufacture of construction materials. In all impact categories except eutrophication potential it contributes a large percentage of the impacts. In eutrophication potential the process of replacement manufacturing also contributes a significant percentage of the whole impacts and sometimes is the most significant contributor. All buildings in the study are similar in this respect so only one will be illustrated in this report. KAIS will be shown as this example in Figure 1. It shows the manufacture of materials ranging from 58-93% of the total impacts across all categories except eutrophication potential. The replacement materials manufacturing process accounts for 71% of the impacts in that category.

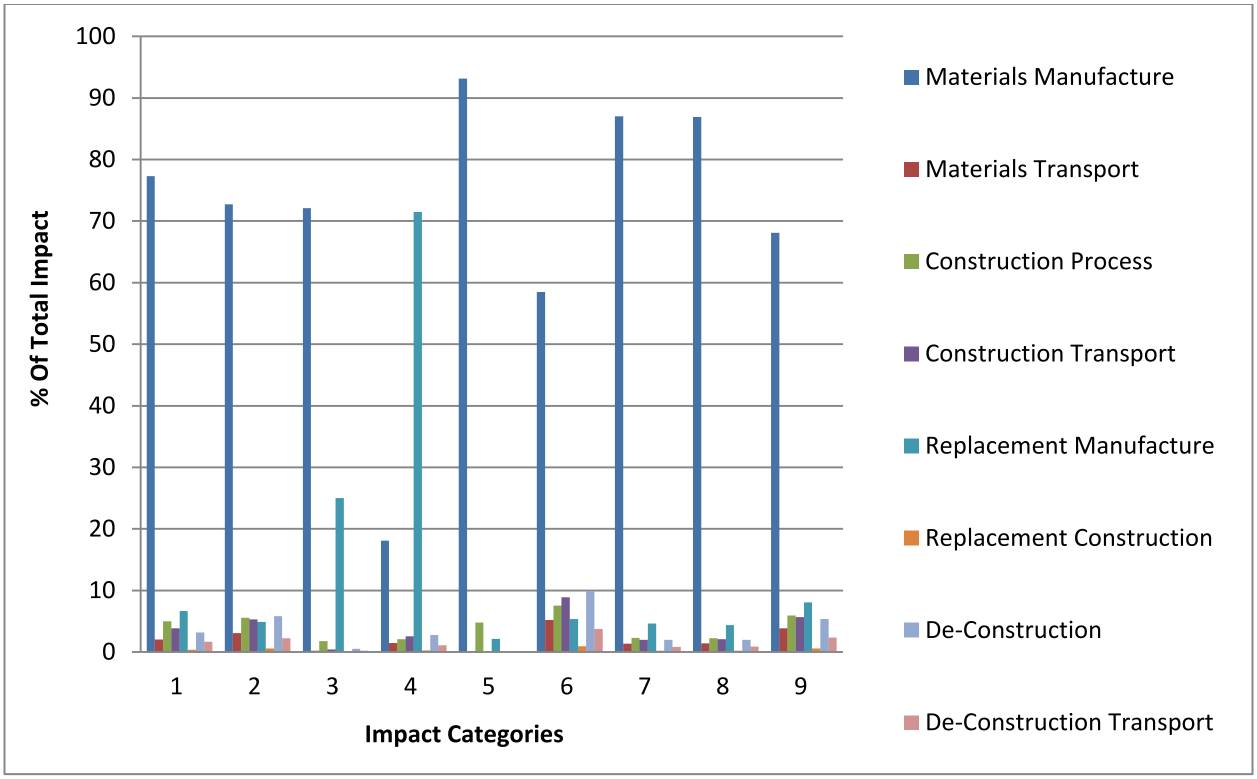

Figure 1: Breakdown of process contributions to whole building impacts of the Fred Kaiser Building

In the above figure the impact categories are as follows:

1 - Global Warming Potential
2 - Acidification Potential
3 - HH Particulate Potential
4 - Eutrophication Potential
5 - Ozone Depletion Potential
6 - Smog Potential
7 - Total Primary Energy Use
8 - Non-Renewable Energy Use
9 - Fossil Fuel Use

3.4 Materials

The materials used in construction of the academic buildings studied did not significantly change over the years. All the buildings have concrete structures with all forms of concrete accounting for 84.4% of the construction materials used. With the addition of rebar and mortar this percentage becomes 93.4% by weight. The most common type of concrete is 30 MPa (flyash av) concrete consisting of 45.4% of all materials by weight. This concrete has been used throughout all eras of building from 1925 until 2011. It has been extensively used in a majority of the 18 buildings it was used in, averaging 54.9% of the whole building by weight.

Concrete's environmental impacts tend to increase as the strength of the mix increases. This can be offset with the addition of a greater percentage of flyash as shown in tables 3 and 4. Table 3 shows the increase and reduction in kg CO_2 equivalent as concrete strength increase and flyash percentage increases. It also includes the percentile amount of the mix of concrete by weight of the total amount of materials in the study. Table 4 shoes the reduction in all impact categories with the addition of more fly ash. All impacts were taken from the Athena IE selecting the Vancouver region and an institutional building type. One m^3 of concrete was selected to have its impacts measured.

Table 3: Global Warming Potential for 1m^3 of concrete mix

Concrete Mix	kg CO_2 eq	Total % of All Materials in Study By Weight
Concrete 20 MPa (Flyash av)	288.95	19.9
Concrete 20 MPa (Flyash 35%)	259.42	1.04
Concrete 30 MPa (Flyash av)	381.52	47.5
Concrete 30 MPa (Flyash 25%)	341.48	3.05
Concrete 30 MPa (Flyash 35%)	318.99	1.84
Concrete 60 MPa (Flyash av)	412.35	0.77

Table 4: Reduction in impacts with the addition of flyash

Impact Category	30 MPa (Flyash av)	30 MPa (Flyash 35%)	% Reduction
Global Warming Potential (kg)	381.52	318.99	16.4
Acidification Potential (kg)	2.73	2.36	13.6
HH Particulate Potential (kg)	0.8	0.7	12.5
Ozone Depletion Potential (kg)	$2x10^{-6}$	$1x10^{-6}$	50
Smog Potential (kg)	70.13	62.47	10.9
Eutrophication Potential (kg)	0.8	0.7	12.5
Fossil Fuel Use (GJ)	2.78	2.5	10.1

The trend towards a greater use of 30 MPa concrete in building design as opposed to 20 MPa concrete has kept environmental impacts relatively higher in the newer buildings. This is illustrated in Figure 2. 20 MPa concrete was favoured until the 1960s when they were both used equally. After 1980 30 MPa concrete became the standard and has only recently given way to higher flyash mixtures. Among the three newest buildings CIRS has higher impacts than the others and this can be attributed to the 60 MPa concrete used. 17.6% of CIRS is 60 MPa concrete by weight.

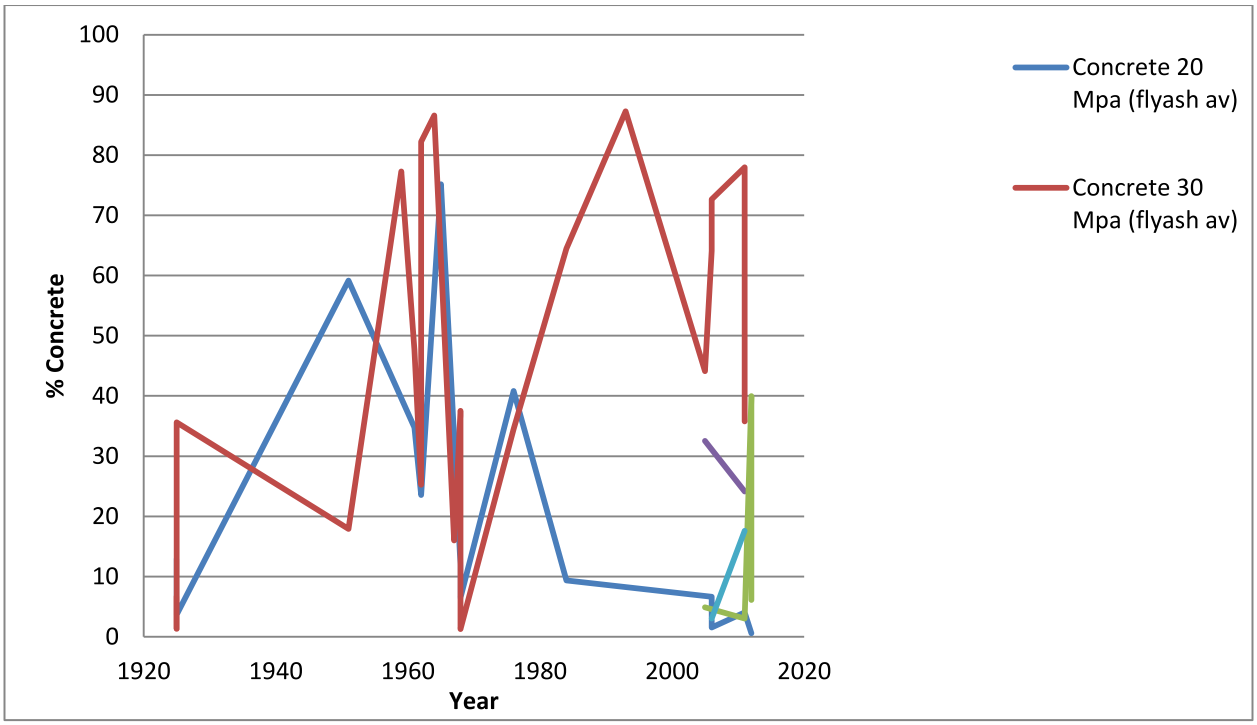

Figure 2: Percentage of concrete in a building by year

3.5 Building Assemblies

Figure 3 shows the global warming potential benchmark for the different building assemblies in the study. Upper floor construction has the highest potential impact with 212 kg CO_2 eq. There is a potential outlier in ICICS with an impact of 754 kg CO_2 eg. This outlier is potentially an error in the database because the material listing for the assembly is much greater than similarly sized buildings. For example HEBB has 300 m^2 more floor space associated with the upper floor construction but 9700 tonnes less of material. Even if ICICS is excluded from A-23 it is still the most impactful assembly with 183 kg CO_2 eq.

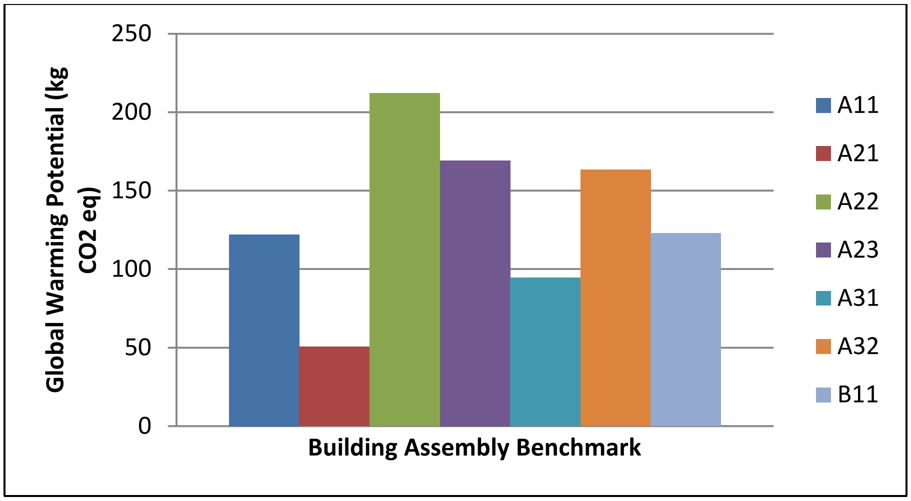

Figure 3: Global warming potential of the building assemblies

The highest remaining buildings are WSBK and MCML and they both have normal flyash concrete and have more mass than standard. MCML also contains precast concrete which has 469.4 kg CO_2 eq for each m^3 which makes it worse than any of the strength-rated concretes. This general rule of thumb of normal flyash and higher masses holds true for other impact categories and their benchmarks.

3.6 Sustainability Program Support

This report can be used in the early stages of design work for academic building on the UBC Vancouver campus. The regional benchmark can be used to achieve points towards LEED credits. LEED v4 awards 3 credits for building life-cycle impact reduction for whole-building life-cycle assessment. The benchmarks developed in this study can be used as a baseline for new projects. UBC currently requires all institutional building projects to achieve LEED gold status (Sustain.ubc.ca, 2010; Usgbc.org, 2014). It currently does not require that LCA be a part of this but with a regional baseline that can be used in design the process becomes easier for developers.

4.0 Next Steps

The implementation of LCA into UBC's building design and operations is an essential factor for progressing the environmental goals and commitments of UBC. Implementation of LCA would further the UBC Green Building's vision to "Pursue regenerative buildings, landscapes, and neighbourhoods that create a healthy, resilient and animated learning environment" (Penny Martyn, 2014). Furthermore, it would provide quantifiable results for the GHG emissions being generated by UBC. UBC has made it a policy to implement a progressive reduction of net GHG emissions. In 2007, B.C. committed that all new public sector buildings or major renovations must target LEED Gold certification. Furthermore, UBC will be putting LEED v4 into effect June 2015. To ease the transition for developers on campus, UBC has produced The UBC LEED Implementation Guide in 2009 and updated it in 2013.

LEED v4, which will be implemented at UBC in June 2015, contains credits for completion of LCA studies and/or environmental product declarations. Under LEED v4 Building Life Cycle Impact Reductions, projects can now earn a maximum of 11 credits using LCA related results. The points are allotted as follows in Table 5:

Table 5: LEED Credits awarded for LCA considerations

LCA Related Category	Points
Building Product Disclosure and Optimization - EPD	2
Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
Building Product Disclosure and Optimization-Material Ingredients	2
Building Life Cycle Impact Reduction	5
Total:	11

Building Product Disclosure and Optimization - EPD

Building Product Disclosure and Optimization-Environmental Product Declarations aims: "To encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. To reward project teams for selecting products from manufacturers who have verified improved environmental life-cycle impacts." (Elixir Environmental, *Life Cycle Assessment*). Projects can exercise 2 separate options worth 1 point each for a maximum of 2 points towards certification. The 2 points are allotted as follows:

Option 1: Environmental Product Declaration

Before delving into the point distribution, let's grab a look at how EPDs work. Environmental Product Declarations are produced following the completion of a life cycle impact assessment for a particular product. The criteria for developing and producing and EPD is governed by standards defined and issued by the International Organization for Standardization (ISO). ISO 14020 describes 3 types of environmental labels. Type I (seal of approval) requires products to meet a predetermined set of criteria, while accounting for life cycle stages. Type II (single attribute claims) can be self-declared by corporations. However, they must release all information necessary to back up their claims. Types III (ecoprofiles and environmental declarations) are the most relevant type of declaration for LCA. Suppliers must provide data for the product life cycle. The data must systematic and be verified independently by a third party.

Option 1 states that projects must use at least 20 different and permanent products that are obtained from a minimum of 5 entirely separate manufactures. The amount that each product is weighted in regards to being wholly acceptable is based on the nature of the product declaration. LEED has placed emphasis on Type III declarations by prescribing more weighting to the products that utilize them. So a product that utilizes a publicly available and critically reviewed (type II) EPD that conforms to ISO 14044 may be valued as one quarter (1/4) of a whole product. It should be noted that ISO 14044 defines LCA requirements and guidelines, which includes: framework, requirements, goal and scope, analysis, assessment, interpretation and reporting criteria. A product that has a type III EPD that is used industry-wide (generically) may be weighted as one half (1/2) of a product. And a product specific type III EPD is counted as a whole product. Please note that the type III EPDs must have a "cradle-to-grave" scope and conform to the following ISO standards:

- ISO 14025 - Environmental labels and declarations
- ISO 14040 - LCA Principles and Framework
- ISO 14044 - LCA requirements and guidelines
- ISO 21930 - Sustainability in Building Construction

(www.usgbc.org/credits, 2014; Rob Sianchuk, 2014)

Option 2: Multi-Attribute Optimization

This option provides points for projects that use products that can demonstrate below industry average in a minimum of 3 of the following impact categories:

- Global warming potential
- Depletion of stratospheric ozone
- Acidification of land and water resources
- Eutrophication
- Formation of tropospheric ozone
- Depletion of non-renewable energy resources

The criteria for Building Product Disclosure and Optimization - EPD LEED points are well defined and prone to complication. The entirety of the details where shown for this particular category to demonstrate the relations to LCA and ISO standards within LEED points. For the sake of brevity the following categories will not delve so deeply into the finer details.

Building Product Disclosure and Optimization - Sourcing of Raw Materials

Sourcing of raw materials also provides 2 options.

Option 1: Raw material source and extraction reporting

This option works very similar to the EPD product reporting. Projects must use at least 20 different permanently installed products from at least 5 different manufactures that have publicly released a report from their raw material suppliers.

Products with self-declared product declarations (type II) are valued as a one half (1/2) of a product. Type III product declarations are counted as a whole product.

Option 2: Leadership Extraction Practices

This option does not utilize LCA but instead relies on a complex series of predetermined standards for various product types.

Building Product Disclosure and Optimization-Material Ingredients

This subcategory follows the same scheme as the previous ones, with 3 options available. However, 2 of the 3 options allow for points for "cradle to cradle" certification

Building Life Cycle Impact Reduction

Option 1: Historic building reuse (5 points)

These points are allotted based on the ability to prove that the building is registered as a historic building and the after alterations are made that it is still eligible for the qualification. Use of LCA is not required for this option.

Option 2: Renovation of abandoned or blighted building (5 points)

These points are allotted based on conserving a certain percentage of the original building surface area. Use of LCA is not required for this option.

Option 3: Building and Material Reuse (2-4 points)

These points are allotted based on the surface area of a new project that reuses certain percentages of surface area for pre-used or salvaged building materials. Use of this LCA is not required for this option.

Option 4: Whole Building Life Cycle Assessment (3 points)

This option provides points for new buildings that in comparison to a baseline building offer 10% **decreases** in at least 3 of the criteria listed below. No point will be allotted if any of the criteria show **increases** of more than 5% in **any** of the criteria.

- Global warming potential (CO2 eq)
- Depletion of stratospheric ozone (kg CFC-11)
- Acidification of land and water resources (kg SO2)
- Eutrophication (kg N or kg phosphate)
- Formation of tropospheric ozone (kg NOx, kg O3 eq or kg ethene)
- Depletion of non-renewable energy resources (MJ)

(http://www.usgbc.org/credits, 2014)

The 11 LCA related credits available as outlined in Table 5 can account for up to 18% of the total points needed to obtain the Gold Certification that UBC is aiming for with all new building developments. If the current trend of increasing involvement of LCA into building accreditation is any indication of the future, UBC needs to implement the proper tools and resources to ensure that it utilizes the methodology in an efficient and technically sound matter.

Currently, the use of LEED at UBC is restricted to institutional buildings. In contrast, all residential buildings constructed on campus are certified using the Residential Environmental Assessment Program (REAP). REAP was developed by UBC, and recently updated during October, 2014 to version 3.0. The overall goal of REAP is to meet the BC building code requirements and outperform similar regional construction in the area. The criteria for REAP is available from the UBC website, and the total amount of points that any new residential building can garner is 200. REAP has varying levels of accreditation much in the same vein as LEED.

UBC's policy is to design for all residential buildings to achieve REAP Gold Certification. Completion of a Life cycle assessment under REAP accreditation is worth a maximum of 4 points. However, completion of a life cycle assessment is completely optional. The requirement for the points is that the building must demonstrate a minimum of 5% improvement from a reasonable baseline building for 3 of the following criteria:

- Global warming potential (CO_2 eq)
- Depletion of stratospheric ozone (kg CFC-11)
- Acidification of land and water resources (kg SO_2)
- Eutrophication (kg N or kg phosphate)
- Formation of tropospheric ozone (kg NO_x, kg O_3 eq or kg ethene)
- Depletion of non-renewable energy resources (MJ)

(Planning.ubc.ca/sites, 2014)

By comparison of impact categories, REAP 3.0 and LEED v4 are identical. However, the expected performance characteristics do not align, as LEED requires 10% improvements in 3 categories plus no more than 5% decrease in performance for any of the remaining characteristics.

4.1 Standardizing Impact Categories

In John Reap, Felipe Roman, Scott Duncan and Bert Bras' 2008 publication *A survey of unresolved problems in life cycle analysis*, they point out that impact categories still vary from organization to organization and that standardization of them would be a large step forward for LCA. In Canada there are two main sets of impact categories employed by the LCA community. The Canadian Life Cycle Impact Assessment Method (LUCAS) was developed by the International Reference Centre for the Life Cycle of Products, Processes and Services (CIRAIG) in attempts to produce impact categories that where more applicable to the Canadian Environment. The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) was developed by the United States Environmental Protection Agency (EPA) and is the most popular in North America. Please refer to the Table 6 below for their respective impact categories.

Table 6: Impact categories for different standards

Impact Categories by Standard		
LEED V.4 / REAP 3.0	LUCAS	TRACI
Global warming potential	Climate change	Climate Change
Depletion of stratosphere	Ozone depletion	Ozone depletion
Eutrophication	Abiotic resource depletion	Water use
Formation of tropospheric ozone	Acidification	Acidification
Depletion of non-renewable energy sources	Smog formation	Smog formation
	Ecotoxicity	Ecotoxicity
Acidification of land and water resources	Humon toxicity	Eutrophication
	Land use	Human health: cancer
	Aquatic eutrophication	Human health: non-cancer
	Terrestial eutrophication	Human health: criteria pollutants
		fossil fuel depletion
		Land use

(LUCAS- A New LCIA Method Used for a Canadian Specific Context, 2007; http://www.epa.gov/nrmrl/std/traci, 2014; www.usgbc.org/credits, 2014)

As it can be seen there exists multiple omissions in the LEED v4 and REAP criteria for impact categories specifically in the area of human health. In order to properly compare the environmental effects of final products, in this case the products being buildings, it is imperative that the same methods of evaluation be utilized. TRACI provides a more thorough framework of criteria and is more widely used throughout North America. It can also be noted that all of the categories specified by LEED are covered in TRACI. Further issues arise from the disparity between residential and institutional buildings. It is unacceptable to host two separate sets of performance characteristics for the same campus. Therefore, it is recommended that new policy be implemented at UBC that requires the completion of an LCA for all new building development (residential and institutional) using the impact characterization outlined in TRACI. Secondly, that UBC standardizes the definition of a "baseline building". Thirdly, that UBC creates a weighting scheme for environmental vs economic benefits. Finally, that UBC produce an LCA implementation guide.

Implementation of this policy will have numerous advantages. Both LEED and REAP require that *if* an LCA study is completed that the selected baseline building should be "reasonable" (Planning.ubc.ca, 2013; Usgbc.org/credits, 2014). In order to progress the advancement of eco-friendly construction and design, the creation of an ever-bar-raising baseline average building is necessary. By performing LCA studies with consistent criteria and execution on all new building designs, UBC will be able to generate quantifiable and comparable performance characteristics for each proposed building on campus, residential or institutional.

4.2 Weighting of Economic and Environmental Results

The impact categories that are defined in TRACE have been selected due to their known contributions to the deterioration of the environment and the human health hazards they inherently possess. Each impact category is defined by a "functional unit" which provides quantifiable performance results as a reference unit. For example, the depletion of stratospheric ozone is measured in kg CFC-11 (http://civl498c.wikispaces.com, 2014). CFC-11 (also known as Green House Gas) is known to deplete the ozone, so the impact category is measured in it. If an alternative chemical also causes similar effects, it is also expressed in CFC-11 using an equivalence factor. The equivalence factor depends on how effective a kg of the chemical in question is in comparison to a kg of CFC-11. In a perfect world, all buildings would be designed strictly for aesthetics and environmental sustainability. However, the current design factors are much more complex than that. Design factors include:

- End user considerations
- Cost

- Land availability
- Environmental considerations
- Permitting Issues
- Etc

While building design is extremely complex, quite often the need for the project arises from end-users, and land availability is typically quite limited. Therefore, in the design stage of a building the two most limiting factors usually are: cost and environmental considerations (at least at UBC). In order to align building design with the values of the university, UBC needs to develop and implement a weighting scheme that evaluates how much emphasis should be placed on each impact category (TRACI is the recommended standard) and how much should be placed on economic performance.

4.3 Developer and Designer Tools

In order to further assist developers and to align their design criteria with UBC's design criteria, a LCA Implementation Guide should be developed. During the building design stage, the construction specifier's role in enforcing environmentally sound designs is crucial. Issues arise when pushing through these designs through purchasing as there is no set standard for processing LCA data in terms of material and process selection throughout the construction process. The *Federal Green Construction Guide for Specifiers* was developed to tackle this issue. It follows the Construction Specification Institute's MasterFormat. MasterFormat is a widely used standard for organizing project specifications, along with its sub-formats: SectionFormat and PageFormat (Applying a Life Cycle Perspective to Federal Construction Specifications, 2005). In 2004, MasterFormat was updated to include specifications for whole project life spans. LCA requirements and sustainable reporting can now be organized according to MasterFormat, Section Format, and PageFormat. *Federal Green Construction Guide for Specifiers* provides model language that aims to assist companies and agencies unfamiliar with LCA. Furthermore, it provides submittal requirements on a Federal level (MasterFormat 04 and LCA, 2005). Making developers aware of tools such as these is imperative to ensuring the completion of a project. The

Federal Green Construction Guide for Specifiers should be included in the LCA Implementation report. Furthermore, developers should be made aware of the possible resources that exist in regards to pre-existing Life Cycle Impact data. There are many available online sources including:

- Athena LCI
- ELCD
- EcoInvent
- GaBi
- US LCI

Each data base possesses its own particularly niche for data type. In order to help developers understand where the best place to access data is, a breakdown of available resources should be supplied. The guide should also include necessary information on the various types of EPDs (Types I, II & III) and the standards that govern them:

- ISO 14025 - Environmental labels and declarations
- ISO 14040 - LCA Principles and Framework
- ISO 14044 - LCA requirements and guidelines
- ISO 21930 - Sustainability in Building Construction

This will ensure that developers are knowledgeable about the products that are being used in design considerations. Lastly, the breakdown for the weighting of economic and environmental characteristics should be supplied so that developers can design to the predetermined standards of UBC.

5.0 Conclusions and Recommendations

Given UBC's position as a global leader it is important that opportunities to improve upon the systems and standards it sets for itself be considered thoroughly. The incorporation of LCA into the fabric of sustainability initiatives for new buildings on campus is one such opportunity. It has been found that there is a great deal of discussion about sustainable developments at The University, with systems set up to guide designers in achieving a satisfactory environmental impact, and review processes for their decisions. LCA exists in these discussions, but it is not a primary motivating factor for decisions.

The LCA study performed on the academic buildings on the Vancouver campus shows the potential for the creation of a University benchmark. Such a benchmark would prove valuable in the evaluation of new projects to determine if sustainability goals are truly being met. The opportunities for tracking real environmental impacts of new buildings across a number of endpoints and indicators are very interesting, and promote a more quantifiable definition of sustainability. This benchmark could be changed based on the desires of The University; it could be a chronological accounting of building's impacts since a certain time, or it could be sequential, showing only the most recent projects to better allow for direct comparisons. In either case the environmental impacts of design choices could be monitored and help to guide future decisions.

In order for UBC to effectively utilize the proposed changes it will need to ensure that it implements LCA for both residential an institutional building developments. Furthermore UBC must be able to supply developers with the necessary resources and client expectations that will enable them to effectively design and develop projects. The necessary resources would include information: on LCA integration with MasterFormat, essential LCI databases such as US LCI, governing ISO standards on LCA and EPDs, available pre-construction LCA tools and economic vs environmental performance decision making criteria.

In light of these conclusions it is recommended that LCA be incorporated into the Design Guidelines and Technical Guidelines for use by designers of new projects at UBC's Vancouver campus. This could come in the form of mandatory LEED points in the Building life-cycle impact reduction category of LEED v4. The language used in these documents should be updated to reflect the differences between life-cycle assessment and life-cycle costing, something that is not apparent now. The creation of a campus wide LCA benchmark has been started through the CIVL 498c course, and should be incorporated into a specific UBC initiative to further refine the data.

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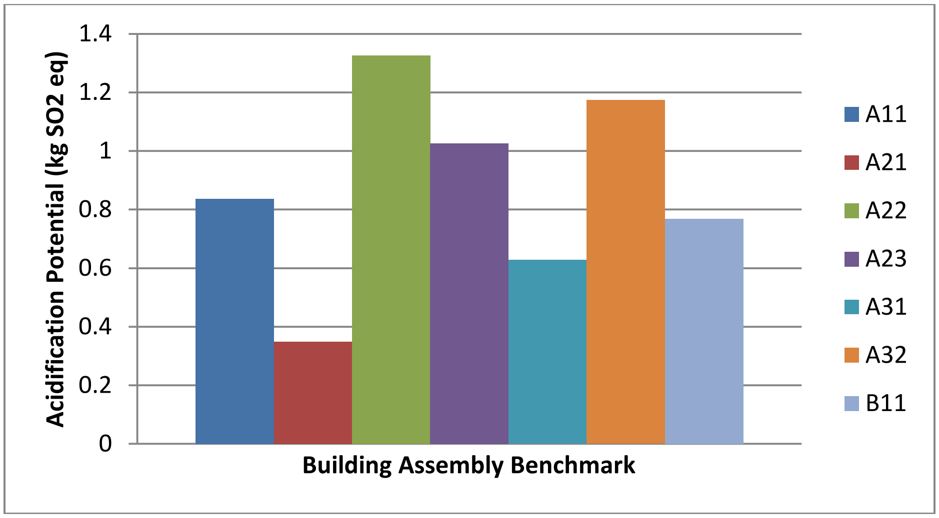
Appendix A - Whole Building Impacts for All Buildings in Study

WHOLE BUILDING									
Building	Global Warming	Acidification	HH Particulate	Eutrophication	Ozone Depletion	Smog	Total Primary Energy	Non-Renewable Energy	Fossil Fuels
AERL	575.1	3.98	2.25	0.42	1.77E-06	75.22	17254	16702	6856
ALRD	326.4	2.21	1.17	0.14	1.64E-06	45.80	7236	6924	2744
ANGU	346.5	2.00	0.92	0.23	2.53E-06	36.52	4128	4053	3365
CEME	186.6	1.16	0.49	0.17	6.33E-07	24.63	2861	2736	2374
CHBE	443.1	2.88	1.34	0.17	1.93E-06	61.64	7183	6840	3689
CHEM	421.8	2.65	1.69	0.62	0.00E+0	57.08	4934	4665	3781
CHEMN	465.3	2.99	1.11	0.22	2.53E-06	63.93	5223	4942	4277
CHEMS	462.2	3.01	1.78	0.29	1.56E-06	63.61	9269	8880	4414
CIRS	415.6	2.92	2.14	0.27	1.44E-06	57.49	14731	14015	3695
ESB	332.5	2.40	1.98	0.24	1.11E-06	44.93	13978	13316	2844
FSC	44.7	0.31	0.10	0.01	2.16E-07	7.59	348	319	315
GEOG	148.5	1.07	0.35	0.76	5.75E-07	20.53	5455	4978	4916

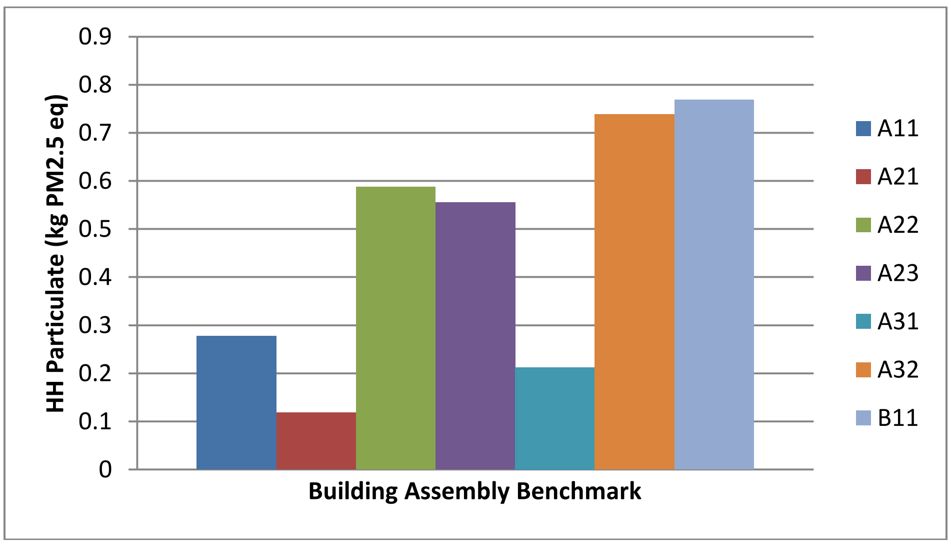
HEBB	339.5	2.31	0.83	0.22	1.36E-06	50.62	4049	3865	3460
HENN	3552.0	5.59	1.70	1.58	2.91E-06	90.54	73390	28267	25222
ICICS	773.6	4.96	2.21	0.51	3.64E-06	104.66	10260	9771	7209
KAIS	311.4	2.09	1.50	0.30	1.11E-06	43.36	7670	7374	2688
KENN	364.5	2.26	1.08	0.23	1.37E-06	46.92	5383	5138	3422
LASR	356.0	2.16	1.04	0.20	0.00E+0	43.49	4527	4314	3443
MATH	101.6	0.77	0.39	0.44	4.58E-07	17.57	2134	1786	1753
MCML	654.5	4.17	1.44	0.18	2.83E-06	90.58	7663	7181	5386
MUSC	247.4	1.63	0.68	0.14	9.33E-07	37.37	3041	2881	2377
PHRM	1886.8	12.69	8.41	0.99	6.80E-06	261.95	50009	47994	15790
SCRF	299.8	2.04	0.71	0.21	1.51E-06	44.78	3558	3358	3078
WSBK	529.7	3.75	1.19	0.24	1.96E-06	79.81	6804	6493	5520
BENCHMARK	566.0	3.00	1.52	0.37	1.70E-06	61.28	11295	9033	5109

Appendix B – Building Assembly Benchmarks

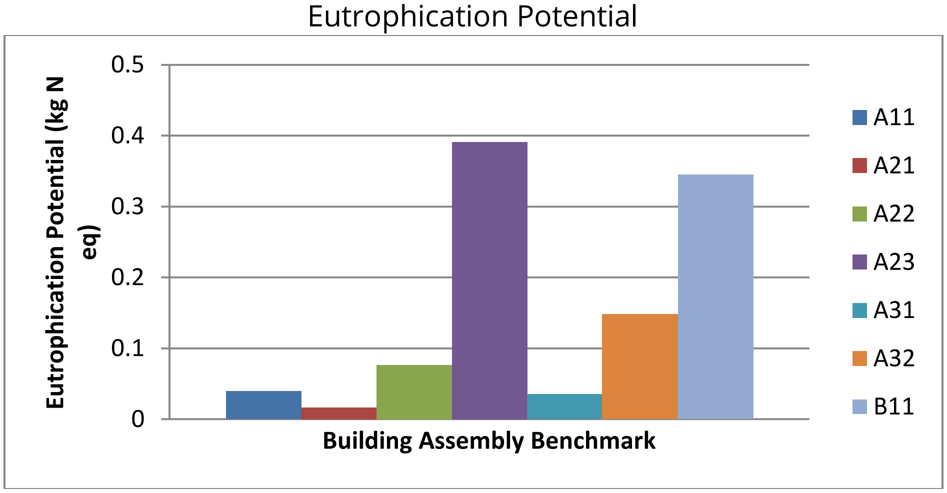
Acidification Potential

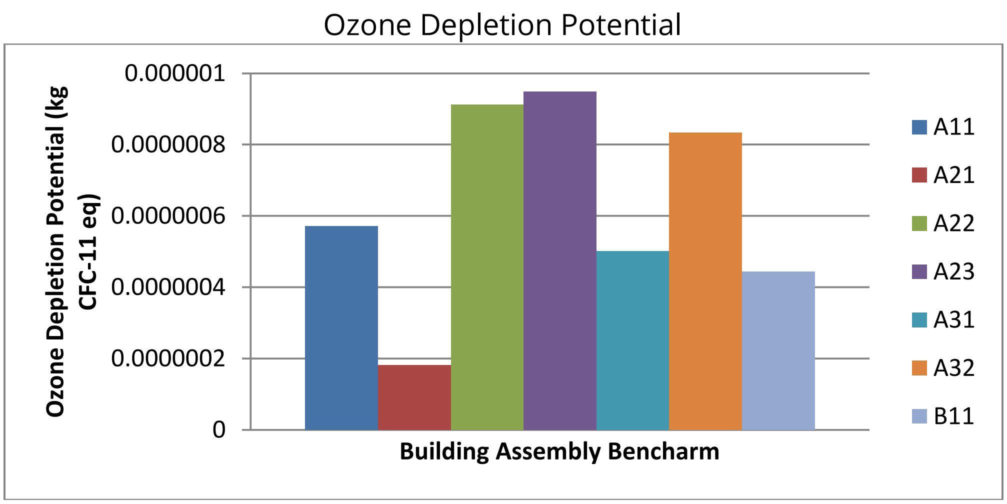


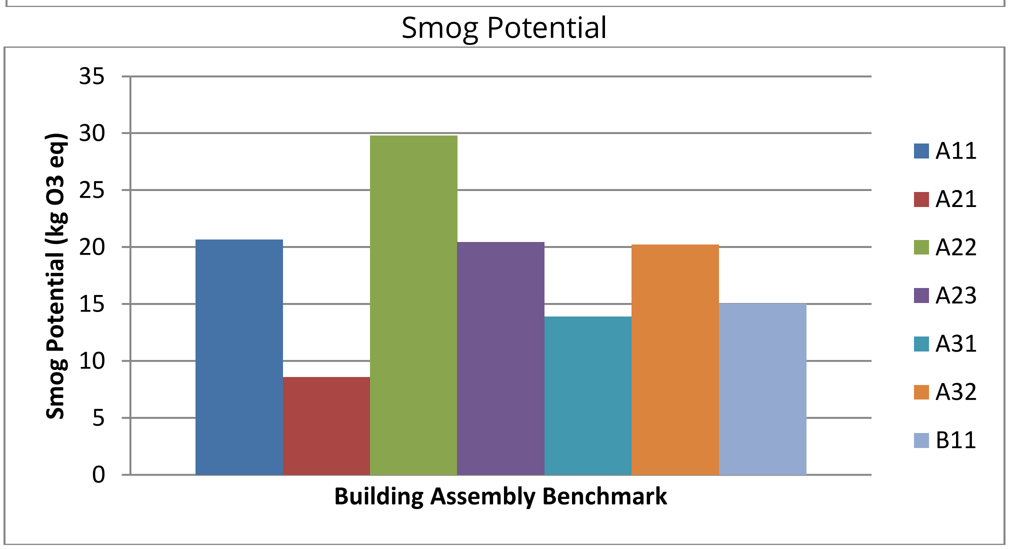
HH Particulate Potential

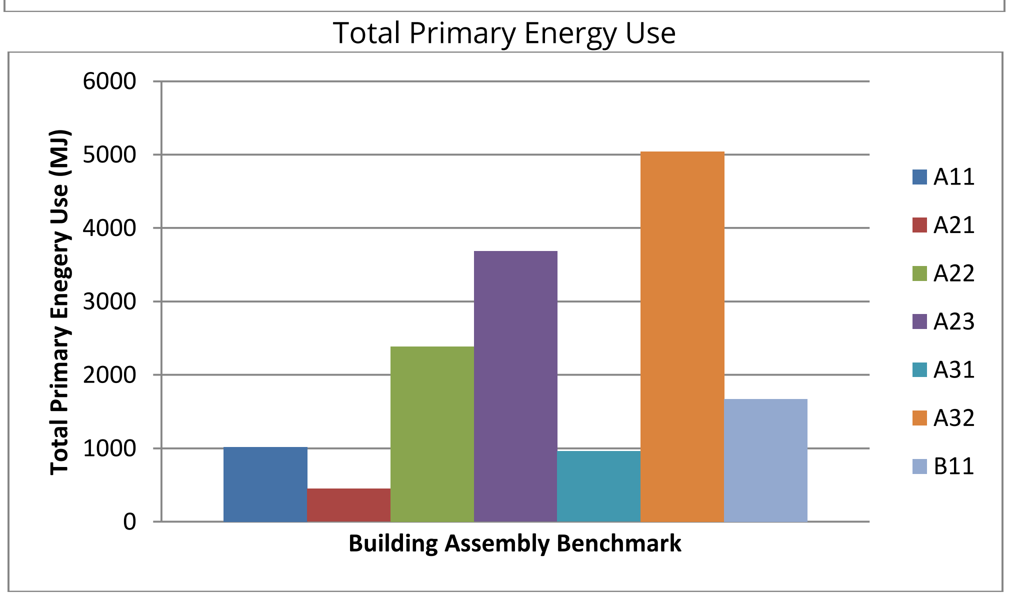


Eutrophication Potential

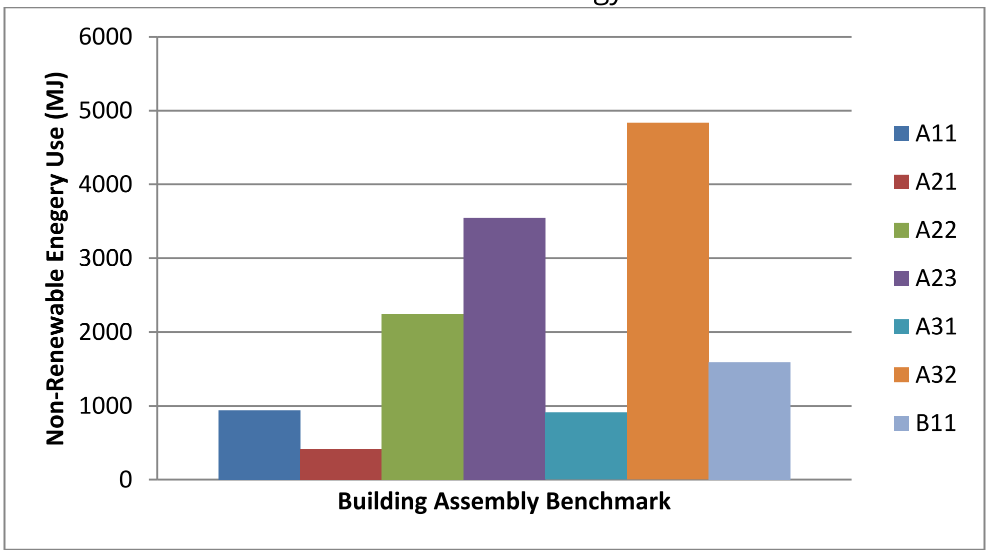



Ozone Depletion Potential
Ozone Depletion Potential (kg CFC-11 eq)
0.000001
0.0000008
0.0000006
0.0000004
0.0000002
0
Building Assembly Bencharm
A11
A21
A22
A23
A31
A32
B11

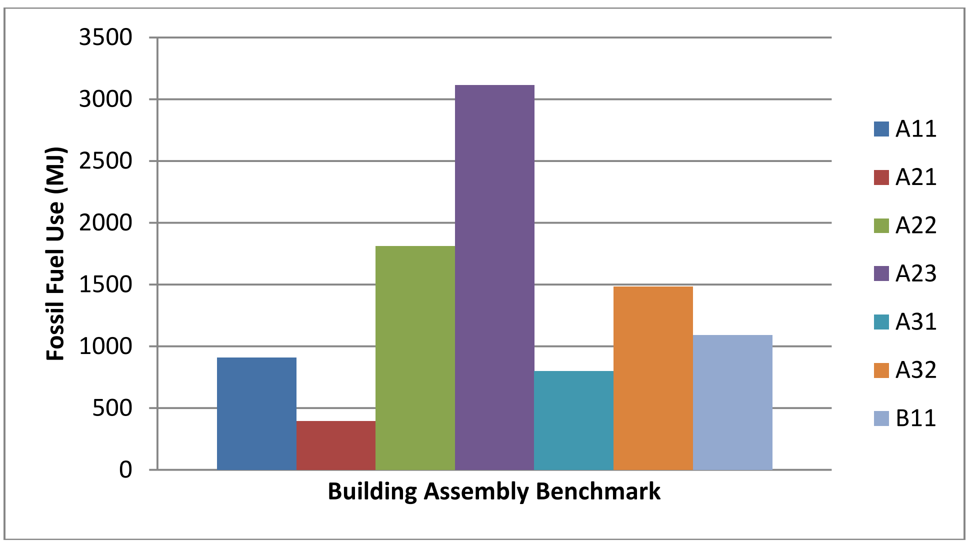

Smog Potential
Smog Potential (kg O3 eq)
35
30
25
20
15
10
5
0
Building Assembly Benchmark
A11
A21
A22
A23
A31
A32
B11


Total Primary Energy Use
Total Primary Enegery Use (MJ)
6000
5000
4000
3000
2000
1000
0
Building Assembly Benchmark
A11
A21
A22
A23
A31
A32
B11

Non-Renewable Energy Use



Fossil Fuel Use



Appendix C – Bill of Materials for Study

Material	Weight (tonnes)	% of Total Weight
#15 Organic Felt	138.49	0.0522
1/2" Gypsum Fibre Gypsum Board	0.41	0.0002
1/2" Moisture Resistant Gypsum Board	28.59	0.0108
1/2" Regular Gypsum Board	321.02	0.1209
1/2" Gypsum Fibre Gypsum Board	87.38	0.0329
1/2" Moisture Resistant Gypsum Board	50.81	0.0191
1/2" Regular Gypsum Board	642.02	0.2419
3 mil Polyethylene	1.11	0.0004
5/8" Fire-Rated Type X Gypsum Board	71.02	0.0268
5/8" Moisture Resistant Gypsum Board	6.16	0.0023
5/8" Regular Gypsum Board	517.03	0.1948
5/8" Fire-Rated Type X Gypsum Board	270.15	0.1018
5/8" Gypsum Fibre Gypsum Board	0.31	0.0001
5/8" Moisture Resistant Gypsum Board	198.99	0.0750
5/8" Regular Gypsum Board	578.36	0.2179
6 mil Polyethylene	13.26	0.0050
8" Concrete Block	12337.98	4.6479
Air Barrier	0.17	0.0001
Aluminum	247.46	0.0932
Aluminum Window Frame	46.92	0.0177
Ballast (aggregate stone)	4049.88	1.5256
Blown Cellulose	6.82	0.0026
Cedar Wood Bevel Siding	2.27	0.0009
Cedar Wood Shiplap Siding	116.27	0.0438
Cold Rolled Sheet	7.89	0.0030
Concrete 20 MPa (flyash 35%)	2583.84	0.9734
Concrete 20 MPa (flyash av)	54889.86	20.6777
Concrete 30 MPa (flyash 25%)	7589.75	2.8592
Concrete 30 MPa (flyash 35%)	4563.98	1.7193
Concrete 30 MPa (flyash av)	120515.89	45.3999
Concrete 60 MPa (flyash av)	1907.98	0.7188
Concrete Brick	1889.04	0.7116
Concrete Tile	8.35	0.0031
Double Glazed Hard Coated Air	28.66	0.0108
Double Glazed Hard Coated Argon	5.85	0.0022
Double Glazed No Coating Air	262.65	0.0989
Double Glazed Soft Coated Argon	10.95	0.0041
EPDM membrane (black, 60 mil)	9.35	0.0035
Expanded Polystyrene	35.57	0.0134
Extruded Polystyrene	120.58	0.0454
FG Batt R11-15	60.92	0.0229
FG Batt R20	0.15	0.0001
Fiber Cement	13.76	0.0052
Galvanized Decking	83.23	0.0314
Galvanized Sheet	281.50	0.1060

Galvanized Studs	410.65	0.1547
Material	Weight (tonnes)	% of Total Weight
Glass Facer	1.45	0.0005
Glazing Panel	1157.97	0.4362
GluLam Sections	192.28	0.0724
Hollow Structural Steel	152.27	0.0574
Joint Compound	267.49	0.1008
Laminated Veneer Lumber	59.23	0.0223
Large Dimension Softwood Lumber, kiln-dried	324.94	0.1224
MBS Metal Roof Cladding - Commercial (26 Ga.)	17.18	0.0065
MBS Metal Wall Cladding - Commercial (24 Ga.)	16.45	0.0062
MDI resin	0.04	0.0000
Metal Wall Cladding - Commercial (26 Ga.)	27.57	0.0104
Metal Wall Cladding - Residential (30 Ga.)	0.66	0.0002
Metric Modular (Modular) Brick	3603.88	1.3576
Modified Bitumen membrane	322.97	0.1217
Mortar	18114.94	6.8241
MW Batt R11-15	36.35	0.0137
Nails	41.07	0.0155
Natural Stone	38.77	0.0146
Ontario (Standard) Brick	783.25	0.2951
Open Web Joists	80.96	0.0305
Oriented Strand Board	33.75	0.0127
Paper Tape	2.79	0.0011
Polyethylene Filter Fabric	1.81	0.0007
Polyiso Foam Board (unfaced)	39.81	0.0150
Precast Concrete	14150.89	5.3308
PVC Membrane 48 mil	0.00	0.0000
Rebar, Rod, Light Sections	8607.67	3.2426
Roofing Asphalt	786.75	0.2964
Screws Nuts & Bolts	31.83	0.0120
Small Dimension Softwood Lumber, kiln-dried	377.16	0.1421
Softwood Plywood	125.19	0.0472
Solvent Based Alkyd Paint	0.81	0.0003
Solvent Based Varnish	0.23	0.0001
Spandrel Panel	26.87	0.0101
Stucco over metal mesh	58.76	0.0221
Stucco over porous surface	567.27	0.2137
Type III Glass Felt	97.23	0.0366
Unclad Wood Window Frame	14.73	0.0055
Vinyl Siding	0.81	0.0003
Water Based Latex Paint	23.16	0.0087
Welded Wire Mesh / Ladder Wire	123.23	0.0464
Wide Flange Sections	130.57	0.0492

Appendix D – Author Reflections

Kris Hellens

I feel that sustainability is a word that everyone is becoming more aware of, but not enough people understand the meaning of. It is used frequently as a marketing term rather than a true environmental claim, which is misleading and dangerous. I took this course because I wanted to better understand the science of sustainability, rather than just the concept, and I believe that the course has been successful in that regard. Through the topics covered I have gained a much better understanding of the processes behind the claims so that I will be able to make better decisions in the future when faced with situations where environmental claims can be made. Learning to think in terms of systems rather than products is something that every engineer should be doing, and the risks of not doing so are becoming increasingly more apparent. In thinking about LCA everything becomes part of some bigger product system that extends both forwards and backwards in time. I have learned that LCA as a tool gives people an easy to understand metric that can be directly compared across possible choices; I feel that the environmental claims become much more consequential when looked at this way.

Prior to this course I was aware of city plans such as Greenest City 2020 that place an emphasis on the marketing definition of sustainability. I was aware of LEED® and how it works, with a point score coming from a wide variety of possible areas. I wasn't as critical of these things as perhaps I should have been, because both now seem to simply pay lip-service to sustainability through superficial actions that are hard to verify the impact of. This is still important to increase the number of people considering sustainability, but more quantifiable results need to be included in the conversation. LCA can offer that in a meaningful way.

That's what I have enjoyed about the final project – the feeling that I am working towards making a difference. Writing a persuasive report where the audience is actually in a position to make changes is something that has not been available through most of my educational experience, and I found it made the project much more interesting to work on. I think the biggest revelation I had while working through this course is how simple getting useful results from an LCA study is; the science behind the processes is kept away from end users, so as not to confuse issues, and the presented results seem clear. This is an incredible strength of the field, as even preliminary results can offer decision makers enough information to pursue truly sustainable choices.

I feel that is my biggest take away: the ability to confidently recommend LCA to people who have the ability to make decisions.

CEAB Graduate Attributes:

	Graduate Attribute		
	Name	**Content Code**	**Comments**
1	Knowledge Base	IDA = introduced, developed & applied	Throughout the course we used engineering fundamentals taught in previous courses. New knowledge was given specifically related to LCA, tested on and developed, and then applied to the final project.
2	Problem Analysis	IDA = introduced, developed & applied	This course introduced the concept and theory behind an LCA study, which can be used to solve complex engineering problems. The final project then applies these theories to the analysis of the situation at UBC.
3	Investigation	I = introduced	Much of the science behind an LCA study requires investigation and analysis, but while this was introduced in the course it was not an area of focus. The focus was on applying the results of these investigations that have already been performed by others.
4	Design	N/A = not applicable	While the material of the course can help when deciding between design options it does not inherently require design applications.

5	Use of Engineering Tools	IDA = introduced, developed & applied	New tools were introduced and developed for applications in LCA studies. These tools were extensively applied, with the results being adapted for use in the final project. The limitations were well documents and presented.
6	Individual and Team Work	DA = developed & applied	Projects and assignments throughout the term gave the opportunity to work in teams.
7	Communication	DA = developed & applied	Issues related to an LCA study were required to be communicated in the final report, requiring the development and application of relevant communication skills.
8	Professionalism	A = applied	This was applied in the final project, where the concepts developed in the course were used to speak to an organization's goals and missions.
9	Impact of Engineering on Society and the Environment	IDA = introduced, developed & applied	This was the main goal of the course, and has been thoroughly introduced, developed, and applied throughout all aspects of lectures, assignments, and projects.
10	Ethics and Equity	A = applied	Engineering ethics were applied in the final project where the limitations and concerns related to the conclusion and recommendations were given.
11	Economics and Project Management	I = introduced	Some elements of the economics of projects were introduced, but it was not a focus.
12	Life-long Learning	DA = developed & applied	Showed how knowledge bases change over time, leading to an understanding that constant edification is required.

Dave Klassen

Previous Exposure to LCA

Before I enrolled in CIVL 498c: Life Cycle Assessment, my exposure to the very concept of life cycle assessment (LCA) was introductory at best. In CIVL 400: Construction Engineering and Management, as part of the course, my professor made sure to touch on the concept of LCA, just so the class was aware of it. The material covered in CIVL 498c has been quite thorough and was more than sufficient enough to give me:

- an understanding of the current issues surrounding industry wide implementation of LCA methodology
- working knowledge of the applicable standards and governing bodies of LCA
- the skills needed to complete a life cycle analysis using applicable tools

In order to transfer the knowledge needed for me to gain this set of skills and knowledge, the course had to cover many topics in regards to LCA. The following section is a summarization of the topics covered in this course.

Life Cycle Assessment Summarization

Life Cycle Impact is an ISO (see ISO 14040 & 14044) defined process that evaluates processes and systems in regards to their environmental impacts. LCI follows three distinct steps:

1. Goal and Scope
2. Inventory Analysis
3. Impact Assessment

In the goal and scope stage of the project, the users are defined and the purpose of the survey is established (eg. will it be used for comparative assertions?). In the inventory analysis stage the process flow diagram is established. The process flow diagram includes all of the distinct stages of a product from start to finish (cradle to grave) and includes inputs and outputs (materials, by-products etc.). In order to complete this stage, detailed information about all the processes involved in the product needs to be gathered including all materials being used, energy use, etc. Essentially the inventory analysis environmental impacts are evaluated in regards to impact categories**.** Impact categories will vary depending on standard being utilized. In Canada and the United States of America the tool for the reduction and assessment of chemical and other environmental impacts (TRACI) is one of the most used standards. The impact categories as defined by TRACI are as follows:

- Ozone depletion
- Global warming
- Acidification
- Cancer

- Non-cancer
- Eutrophication
- Smog Formation
- Ecotoxicity
- Fossil Fuel Use
- Land use
- Water use

The parameters are selected based on their known contribution to the deterioration of the natural environment. For example, acidification potential is the potential for a product or system to cause acid rain. SO2 has been identified as the chemical largely responsible for acid rain when it is released to the environment. Therefore, acidification potential is measured by the amount of SO2 released to the environment throughout the life of a product in kg (kg SO2). This unit is known as a characterization factor. Other characterization factors are selected using similar logic as well. Energy use is measured in Mega Joules, etc.

Using these parameters, the product or system is evaluated as a function unit. For example the functional unit for steel pipe would be /kg of m3. The end result of a LCA study is the measurement of each impact category in regards to the functional unit of the product.

So why do we use LCA?

The term "from cradle to grave" was used in the last segment to describe the evaluation of a product from the very initial stages of creation to the end of the product life cycle. LCA takes a "cradle to grave" approach to environmental assessment. Furthermore, it's results give quantitative measures of impacts of known environmental disturbers.

Reasons for Selecting Course

Through UBC I have completed 3 rounds (or 20 months) of co-op work experience. My work experience has varied greatly, from performing materials testing on large scale infrastructure projects through a consulting firm, to being employed in the tailings and water department of a copper mine. However diverse, all of my work experience has brought me to one distinct conclusion: that once I graduate from school, I want to work for a construction firm as field engineer with the hopes of one day pursuing a career in project management. I enrolled into CIVL 498c because I believe that it is highly relevant for the career of my choice. The certain aspects of the course that attracted me to it where:

- The integration of project management techniques and environmental responsibility
- Gaining further knowledge of the intricacies of construction methods
- The chance to evaluate a career option related in a non-traditional manner to the construction industry

CEAB Graduate Attributes

In order to complete CIVL 498c, I had to utilize many personal attributes, many of which align with CEAB graduate attributes.

	Name	Content Code	Comments
1	Knowledge Base	IA = introduced & applied	A number of knowledge bases were drawn upon during the course. CIVL 400 Construction Engineering and Management has been particularly important for understanding the methodology of completing quantity takeoffs, and understanding the factors that have to be accounted for during the construction phase of projects.
2	Problem Analysis	IDA = introduced, developed & applied	The activity of note that utilized this attribute was an analysis of a building where we were asked to formulate feasible and quantifiable means of lowering the environmental impacts of an existing building owned by UBC.
3	Investigation	IDA = introduced, developed & applied	Numerous assignments throughout the course have promoted investigative techniques. An assignment was completed that involved two miniature scale LCA studies that involved different products that were designed for the same task. Comparative assertions were concluded from the studies and an investigation of the causes of difference in performance was completed. Furthermore, the final project has involved large quantities of data that has been amalgamated from different sources, for the purpose of creating baselines and tracking performance characteristics of buildings on campus.
4	Design	N/A = not applicable	

5	Use fo Engineering Tools	IDA = introduced, developed & applied	This course has introduced and encouraged the use engineering tools on many levels. I was given in depth knowledge of the various LCI databases that currently exist, and what type of information they specialize in. I was instructed on how to access them, and how to apply their results to LCA. The Athena database was especially focused on. Furthermore, two LCA evaluation tools were introduced. A run through of the abilities of Talley was given and we were also shown how to manipulate the program. The Athena Impact Estimator was the most highly used tool however. Plenty of background information was given on the workings of the software. Moreover, we were required to familiarize ourselves with inputting information and analyzing the results it produced.
6	Individual and Team Work	DA = developed & applied	While most of the course work was completed as an individual, the final project has been a highly involved team effort.
7	Communication	IDA = introduced, developed & applied	The final project is the main driver for the use of communication skills in this course. In order to communicate the results of numerous LCA studies, my team and I have had to determine the most effective means of conveying results. Furthermore, we will be presenting our results to an administrative employee of UBC who is charge the green building program on campus. This has proved particularly challenging in the method of approach of how to effectively convey LCA results to an individual who is not well versed in the field. Finally, the methodology and framework for developing environmental product declarations was introduced.
8	Professionalism	I = introduced	Applicability of LCA results in regards to human health was covered, and how many of the results of LCA are applicable to government legislation. An example of this would be how the max concentrations of particulate matter smaller than 2.5 microns (PM2.5) are regulated by the government and how to calculate these results using LCA methodology.

9	Impact of Engineering on Society and the Environment	IDA = introduced, developed & applied	The entire goal of LCA is to provide quantitave measures for the impact of engineering projects. In regards to providing useful and accurate tools for assessing the social and environmental impacts of engineering projects, this has been the most relevant course I have taken at UBC. The course provided information on how to complete an LCA during its various phases: goal and scope, inventory analysis and impact assessment. Furthermore, in order to avoid weighting biases and promote less misinterpretation of results, "mid point" assessments are encouraged over "end point" assessment.
10	Ethics and Equity	N/A = not applicable	
11	Economics and Project Management	I = introduced	The course syllabus included a guest speaker who presented on the topic of project management. The course also covered the similarities and differences of life cycle costing.
12	Life-long Learning	I = introduced	In order to promote sustained learning upon graduation, numerous resources and sources of learning were supplied. These include: The Life Cycle Assessment Alliance, The Hitch-hikers Guide to LCA, the guiding standards organization: ISO and many more.

Kyle Schurmann

PREVIOUS EXPERIENCE

I have had very little previous experience or exposure to Life Cycle Assessment prior to this class. It had been mentioned in previous classes such as CIVL 400 but I can't recall anything specific.

INTEREST IN COURSE

I was interested in this course because it seemed like a quantitative way to back up sustainability claims. There have been many instances in my academic career when professors have said things are more sustainable but have never backed it up with numbers. This course seemed like a way to do that and I am very happy it turned out to be that way.

I am interested in a more sustainable future and to have a class that demonstrates tools for doing that is just what I wanted. I am a little disappointed it took until a fourth year technical elective to get to this stage though.

SPECIAL THOUGHTS

I feel like this project was the breakthrough for my understanding and take-aways from this class. Getting inside the database and finding all the reasons for impacts to be what they were, and evaluating reliability of the data was actually a lot of fun. While I never felt lost in this course and felt my LCA understanding was good, I now believe it to be much greater. I have always felt like I learned better doing projects than sitting in lectures and this course is no exception.

CEAB GRADUATE ATTRIBUTES

Name	Content Code	Comments
Knowledge Base	D = developed	My knowledge base on sustainable design and practice was greatly increased with this class.
Problem Analysis	N/A = not applicable	

Investigation	DA = developed & applied	I did most of the work with the database for this final project and there was a lot of data to be investigated and interpreted. Finding conclusions in this large data set was sometimes challenging so it was rewarding to synthesize everything into meaningful conclusions.
Design	N/A = not applicable	
Use of Engineering Tools	I = introduced	The use of ATHENA was good and we were shown more thorough programs (eg GaBi). My Excel skills also improved in dealing with the database.
Individual and Team Work	A = applied	The final project was broken into 3 stages with the first two being done individually and the final being team based. In addition to the team course work I feel there was a good mix of individual and team based work in this class.
Communication	IDA = introduced, developed & applied	I almost feel like I learned a new language with this class with all the LCA terminology we were introduced to and then became fluent in ourselves.
Professionalism	I = introduced	
Impact of Engineering on Society and the Environment	IDA = introduced, developed & applied	This was the first class I took that would put actual number on environmental impacts. See my interest in course section for more comments.
Ethics and Equity	N/A = not applicable	

Economics and Project Management	N/A = not applicable	
Life-long Learning	D = developed	I now feel like LCA is something I'll always be interested in as well as looking for new ways to quantify sustainability claims.