CIVL 498c – Stage 3

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Executive Summary

Life Cycle Assessment (LCA) is a methodology to evaluate environmental impacts with all the stages of a product from cradle-to-grave. It is widely acknowledged as one of the optimal decision support tools being utilized by stakeholders in green building design and construction processes. The main purpose of this study is to assess the environmental performances of buildings at UBC through interpreting LCA results, understand the current use of LCA at UBC, and propose the approaches to develop LCA at UBC.

This report explains the methods and steps undertaken to complete the LCA study for 22 buildings on campus. The performances of each building are determined by applying Athena Impact Estimator modeling software, in term of 9 categories: climate change, ozone depletion, acidification, smog formation, eutrophication, HH particulate, total primary energy, non-renewable energy, and fossil fuel consumption. The performance results are sorted into major element groups, including A11 Foundations, A21 Lowest Floor Construction, A22 Upper Floor Construction, A23 Roof Construction, A31 Walls Below Grade, A32 Walls Above Grade, and B11 Partitions. The report summarizes which building have the most and least impact for each building element and the entire building as a whole. It also compares the bill of materials for each building to determine the trends in high and low impact elements.

This reports also reviews ongoing projects associated with LCA at UBC. It is proved that LCA is contributed to sustainable development lowering environmental footprint. However, it is recommended to enhance the quality of LCA database and LCA modeling in order to better standardizing the institution of LCA at UBC.

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1.0 Introduction

Sustainable decision-making is made based on anecdotal experience or prescriptive based on criteria, constraining opportunities to innovate by overlooking the realities of the outcomes of these decisions in the real world. In order to consider the outcomes of decision making on the environment and human health, designers are increasingly using LCA(APEG, 2013). This report is aim to introduce how LCA work to improve sustainability at UBC from past to future. By looking into how various sustainability programs can be supported by LCA's application and doing research and calculation on specific buildings with Athena Impact Estimator, students can simply compare outcomes against transparent benchmarks to achieve desired targets. In addition, future trend of institutionalizing LCA is also discussed in this paper. In order to clearly state the research and calculation results, three main sections are involved, including context for use of LCA at UBC, LCA study and Academic Buildings at UBC Vancouver campus, and future steps for institutionalizing LCA at UBC.

2.0 Context for Use of LCA at UBC

Life cycle assessment (LCA) is technique to assess environmental impacts associated with all the stages of a product's life from cradle-to-grave. LCAs can help avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential impacts associated with identified inputs and outputs and interpreting the results to help make a more informative decision. Most of the planning decisions made on sustainability were based on intuition, a tool like LCA is needed to help quantify impacts. LCA is a solid professional framework for people to involve in the field. It only requires general understandings to analyze the outputs. However, applying only LCA to assess inputs is not always enough to get comprehensive information. A toolkit including various sustainability programs is developed. UBC is taking this LCA technique associated with other sustainability programs to design and improve eco-friendly buildings on campus, including:

- Climate Action Plan
- Vancouver Campus Plan Part 3 Design Guidelines
- Technical Guidelines
- UBC RFI Evaluation Criteria
- LEED v4

2.1 LCA and Climate Action Plan

UBC developed its Vancouver Campus Climate Action Plan by leading campus-wide consultation and stakeholder working groups to develop targets and strategies for emission reductions. This program mainly focuses on reporting annual GHGs in operations.
LCA assesses inputs and produces outputs with respect to various impact categories by quantifying impacts, including global warming potential.

Buildings contribute more than half of all Vancouver's total greenhouse gases emissions every year and detached houses are the biggest culprits. It is crucial to reduce possible GHGs emission source while making planning decisions.

LCA is applied to support Climate Change Action Plan by directly providing quantifiable information of greenhouse gas emissions. If any adjustment is needed to achieve target, LCA can be used to make decisions about which raw materials produce less GHGs that should be used. LCA's application with accurate data can help predict and reach UBC's Climate Actions Plan goal of reducing GHG emissions by 100 percent by 2050.

2.2 LCA and Vancouver Campus Plan Part 3 Design Guidelines

These Campus Plan Design Guidelines are for the use of consultants as a guide; staff undertaking in-house project design or reviewing capital projects, project sponsors and members of the broader UBC community (Vancouver Campus Plan Part 3, 2010). This Plan provides detailed design rationale regarding structural and aesthetic requirements. In order to integrate sustainable best practices in designing buildings, all environmental, social and economical impacts should be considered. All building projects on the UBC campus must be designed to achieve LEED Gold certified standards or approved equivalent and some additional requirements. In addition, Sustainability Best Practice Building Design Guidelines and UBC Climate Change Action Plan are also applied to measure the level of sustainability.

LCA is not used as reference for this plan. However, LCA's application can help designed buildings and landscapes to achieve targets (for UBC Climate Change Plan) and obtain credits (for LEED Gold certified standards). As long as accurate data is applied, designers and engineers can change planning decisions based on how each material during its life cycle contribute to the environment. LCA would be a powerful tool to quantify environmental impacts with respect to each impact category and avoid wasting energy and human resources.

2.3 LCA and Technical Guidelines

Buildings are not only one of the largest contributors to resource depletion and climate change; they are also the most visible and enduring elements of an organization's commitment to sustainability (UBC Technical Guidelines, 2010). Various design guidelines and sustainability programs, such as BEES, ATHENA and Life Cycle Analysis, are applied to set for design requirements. LCA is used for setting design requirements as well. LCA produces outputs with specific numbers; by calculating benchmarks, designers and engineers are able to compare results with standards within each sustainability programs. By changing inputs and production methods, adjustments can be made if any requirements were not met.

2.4 LCA and UBC RFI Evaluation Criteria

RFI Evaluation Criteria outlines various key issues and constraints. Different evaluation strategy is applied to find solutions for the issues. Among all the evaluation strategies, life cycle assessment of project options counts for 5/100(UBC RFI, 2013). This assessment requires an effective, multi-discipline team for an accurate result. A good assessment results can score a high rating mark. LCA is powerful as it can be used to make decisions at preliminary stage of a designed building. All building products can be assessed before designed as part of a building. By comparing the results with similar construction products through the whole life cycle, designers can choose more environmental friendly material for a better result.

2.5 LCA and LEED v4

LEED has recognized the value of incorporating LCA into its rating system for its better-reviewed assessment of building materials and assemblies. As long as the LCA basis of LEED credits can be practical and use consistent methodology with a consistent scope, LCA into LEED project will significantly influence related industry. All suppliers, database providers and LEED clients will be motivated to help design and construct location appropriate buildings with low environmental impacts.

Incorporating sustainability programs with LCA can holistically assess building materials and assemblies; In order to achieve targets, more practical design guidelines can be set up by following the requirements. Using LCA and other guidelines and plans motivate designers to create a material and location appropriate building with low environmental impact.

3.0 LCA Study to Academic Buildings at UBC Vancouver Campus

3.1 Methods

3.1.1 CIVL 498c student project

The CIVL 498c student project is an ongoing study that began in 2008. The Goal of study is to assess the environmental impacts of the buildings on the UBC Point Grey Campus using Life Cycle Assessments – the results from the LCAs were added to a database for the buildings at UBC. The information from the LCAs will be used to create multiple benchmarks for buildings and building elements will be created for different impacts. Information on elements and the impact categories selected is described in the next section.

3.1.2 2014 Class

The 2014 Class studied 24 buildings (Complete list of buildings located in Appendix), all located on the UBC Vancouver Campus. Each student was assigned its own building and was responsible for completing two stages that focused on the environmental impacts of the respective buildings.

The first stage was to complete a life cycle impact assessment (LCIA). The life cycle impact assessment is the final phase of a Life Cycle Assessment; it is the part where potential environmental impacts are evaluated. The impact assessments were completed using Athena Impact Estimator for Building Software. The Athena software is a helpful for LCAs for buildings – its takes the information from the material takeoffs for a building and quantifies the impacts that are associated with the particular materials. Athena uses TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) as its impact methodology. The impact methodology determines the impact categories and the methodology used to determine the impacts from the information from the life cycle inventory analysis (which is the material takeoff in the case of a building). TRACI is the most popular methodology used in North America, and includes the following impact categories: climate change, ozone depletion, acidification, smog formation, eutrophication, HH particulate, total primary energy, non-renewable energy, and fossil fuel consumption. Impact assessments were completed for the entire building and separately for the building elements (or reference flows). The building elements included the foundation, lowest floor construction, upper floor construction, roof construction, walls below grade, walls above grade, and partitions. To complete the impact assessment, we used the Inventory Analysis completed by CIVL 498c students from last year. After completing the impact assessments, students added their results to a database, which was used for the next stage of the 2014 class project.

The main goal of the second stage completed was to create an environmental impact benchmark for the buildings at UBC. Using the information from the database created during the first stage benchmarks was determined. The average impacts for each building element and entire buildings were calculated and used as the building benchmark. In addition to the impact benchmarks, a material mass benchmark was created for buildings and each element. After benchmarks were established, students were able to compare their results from stage 1 to the benchmark to see how impactful their results were relative to rest of the buildings on campus and to see if their building would qualify for LEED Points as per LEED's "Building Life-Cycle Impact Reduction – Option 4." LEED Points would be awarded if a building showed 10% reduction in at least 3 of the impact categories (one of which must be global warming potential), while not having a greater than 5% increase in any category when compared to the established benchmark.

3.2 Results

The table below summarizes which buildings have the most and least impacts for each building element and the entire building as a whole. Tables with details on the impacts for all elements and buildings can be seen in Appendix A.

Table 1 Low and High Impact Building Elements

ELEMENT	Low Impacts	High Impacts
A11 Foundations	Kaiser, Neville Scarfe, CEME, Chemistry South	CIRS, Hebb, ICICS, Geography
A21 Lowest Floor Construction	MacMillan, Chemistry North, Wesbrook, Henry Angus	ICICS, Chemistry, Allard Hall, CHBE, Pharmacy
A22 Upper Floor Construction	CIRS, Chemistry, Allard Hall, Neville Scarfe	MacMillan, Wesbrook, Chemistry South, Chemistry North
A23 Roof	Hennings, CEME, Allard Hall,	Neville Scarfe, AERL, CHBE,

	CIRS, Henry Angus	Chemistry South
A31 Walls Below Grade	ICICS, Henry Angus, CEME, Lasserre, AERL, Math	MacMillan, Chemistry, Allard Hall, CHBE
A32 Walls Above Grade	CIRS, CEME, Douglas Kenny, FSC	Wesbrook, CHBE, Pharmacy, Kaiser, AERL
B11 Foundations	CIRS, Geography, Math, CEME, MacMillan	Neville Scarfe, Lasserre, Pharmacy, Kaiser, ESB
Building	CEME, Kaiser, Neville Scarfe, Allard Hall	Wesbrook, ICICS, MacMillan, AERL, Chemistry North

3.3 Discussion

After determining low impact and high impact buildings for each element, the bills of materials were examined to determine trends in high impact and low impact elements. Trends for each element are discussed below. Complete Bills of Materials for each element analyzed can be seen in Appendix B.

3.3.1 A11 Foundations

There wasn't much of a difference in the material selection for the high impact and low impact elements – all of them had 30 MPa Concrete with rebar reinforcement. However, the amount of materials used did differ. The low impact foundations were much more mass efficient – meaning the total mass per square meter of foundation produced was much lower for the lower impact foundations. The results are summarized in the table below.

Table 2 Material Mass for High and Low Impact Foundations

Low Impact Foundations		High Impact Foundations	
Building	**Tonnes/m^2**	**Building**	**Tonnes/m^2**
Neville Scarfe	0.123	**ICICS**	1.258
Chemistry South	0.214	**Geography**	1.620
Kaiser	0.128	**CIRS**	0.706
CEME	0.185	**Hebb**	0.218

AVERAGE	0.163	**AVERAGE**	0.951

It’s clear that the low impact buildings had a much lower materials mass per square meter; however, the reason why is unclear. These building may just require less structural capacity in their foundations or they may have just been more efficiently designed.

3.3.2 A21 Lower Floor Construction

When comparing the materials used in the lower impact and higher impact lower floor construction there was a difference in materials selections between the two. The lower impact elements all used 20 MPa Concrete, while the higher impact tended to use 30 MPa concrete. Also, the mass efficiency was much better in the lower impact buildings.

Table 3 Material Mass for High and Low Impact Lower Floors

Low Impact Lower Floor Construction		High Impact Lower Floor Construction	
Building	**Tonnes/m^2**	**Building**	**Tonnes/m^2**
MacMillan	0.251	**ICICS**	0.506
Chemistry North	0.196	**Chemistry**	1.346
Wesbrook	0.257	**Allard Hall**	0.302
Henry Angus	0.308	**CHBE**	0.489
AVERAGE	0.253	**Pharmacy**	1.059
		AVERAGE	0.740

3.3.3 A22 Upper Floor Construction

When comparing the material selections for the high impact and low impact assemblies, there wasn’t a difference – they were all mostly constructed with concrete, with 20MPa or 30MPa strength. After examining the material mass per square meter, the low impact assemblies were much more mass efficient.

Table 4 Material Mass for High and Low Impact Upper Floors

Low Impact Upper Floor Construction		High Impact Upper Floor Construction	
Building	**Tonnes/m2**	**Building**	**Tonnes/m2**

CIRS	0.180	**MacMillan**	1.838
Chemistry	0.365	**Wesbrook**	2.254
Allard Hall	0.613	**Chemistry South**	1.691
Neville Scarfe	0.645	**Chemistry North**	1.441
AVERAGE	0.451	**AVERAGE**	1.806

As you can see from the table, the lower impact floor construction's average material mass per square meter is approximately 75% less than the high impact counterpart.

3.3.4 A23 Roof

Two of the roofs with low impacts (Hennings and Henry Angus) have ballast-roofing systems. While Allard Hall's and CIRS' roofs were primarily concrete. The High impact buildings were primarily constructed of concrete too, but were much heavier.

Table 5 Material Mass for High and Low Impact Roofs

Low Impact Roofs		High Impact Roof	
Building	**Tonnes/m2**	**Building**	**Tonnes/m2**
Hennings	1.555	**Neville Scarfe**	1.338
Allard Hall	0.150	**AERL**	0.871
CIRS	0.353	**CHBE**	1.275
Henry Angus	0.460	**Chemistry South**	1.232
AVERAGE	0.630	**AVERAGE**	1.179

3.3.5 A31 Walls Below Grade

When comparing the materials in low impact and high impact walls below grade, there was one trend that was apparent. For the low impact buildings, nearly 100% of the material was concrete; the high impact buildings tended to have larger quantities of other materials like Gypsum Boards, Mortar, Concrete Blocks, and Galvanized Studs. Below is a table with the percentages of concrete in the walls below grade for the high and low impact walls below grade.

Table 6 Percent Concrete and Material Mass for High and Low Impact Walls Below Grade

Low Impact Walls Below Grade			High Impact Walls Below Grade		
Building	**Percent Concrete**	**Tonnes /m^2**	**Building**	**Percent Concrete**	**Tonnes/m^2**
ICICS	97.4%	0.216	**MacMillan**	83.7%	0.307
Henry Angus	98.9%	0.527	**Chemistry**	64.9%	0.802
CEME	98.5%	0.471	**Allard Hall**	90.1%	0.140
Lasserre	95.9%	0.315	**CHBE**	91.9%	0.905
AERL	98.2%	0.387	**AVERAGE**	82.6%	0.538
Math	94.0%	0.374			
AVERAGE	97.1%	0.382			

It appears that walls below grade that are constructed with greater than 94% concrete, while minimizing material mass/m2 have the lowest impacts.

3.3.6 A32 Walls Above Grade

Similarly to walls below grade, the lowest impact walls above grade are constructed with concrete making up nearly 100% of the material. The high impact walls above grade were either constructed with concrete, mortar, and bricks; aluminum and glazing panels; or a combination of the two. The table below shows percent of assembly that is concrete and the material mass per square meter.

Table 7 Percent Concrete and Material Mass for High and Low Impact Walls Above Grade

Low Impact Walls Below Grade			High Impact Walls Below Grade		
Building	**Percent Concrete**	**Tonnes /m^2**	**Building**	**Percent Concrete**	**Tonnes /m^2**
CIRS	98.4%	0.188	**Wesbrook**	30.1%	0.980
CEME	93.3%	0.299	**CHBE**	74.6%	1.247
Douglas Kenny	95.0%	0.299	**Kaiser**	38.6%	0.115
Neville Scarfe	96.8%	0.299	**Pharmacy**	0%	0.209
AVERAGE	95.9%	0.271	**AERL**	11.0%	0.644

	AVERAGE	30.9%	0.639

The lighter high impact walls, Kaiser and Pharmacy, were assembled with aluminum and glazing panels. While the heavier high impact walls, Wesbrook and CHBE, were assembled with Concrete, Mortar, and bricks/blocks. While AERL which falls in the middle of the two weight classes was assembled with a combination of mortar, bricks, concrete, aluminum, and glazing panels. Out of all the assemblies, Pharmacy had the largest impacts by a wide margin. It appears that constructing walls above grade that are around 95% concrete, with material mass per square meter less than 0.300 tonnes / m2 have the lowest impacts. While walls above grade that use combinations of mortar, blocks, aluminum, and glazing panels have the highest impacts.

3.3.6 B11 Partitions

For Partitions, the high impact materials look to be mortar and block/brick assemblies. These materials were the mostly utilized materials in three of the four high impact buildings (Neville Scarfe, Pharmacy, and Kaiser) examined. These results agree with the results for walls above and below grade. The other high impact partition, Earth and Ocean Sciences Building (ESB), was primarily assembled with concrete and gypsum board, which aren't considered high impact materials, but did have considerable amount of glazing panel and aluminum (44.9 tonnes and 8.5 tonnes respectively) which were considered high impact materials for walls above grade.

As for low impact partitions, three of the four buildings had gypsum board as its most used material. The assemblies with large amounts of gypsum board resulted in very lightweight partitions (approximately 0.03 tonnes/m2). Other low impact partitions, from CEME, used concrete, mortar, and blocks, but with less mass per square meter than the high impact assemblies just mentioned.

Table 8 Partitions mass per square meter

Low Impact Partitions		High Impact Partitions	
Building	**Tonnes/m2**	**Building**	**Tonnes/m2**
CIRS	0.0239	**Neville Scarfe**	0.4756
Geopraphy	0.0306	**Pharmacy**	0.4023
Math	0.0417	**Kaiser**	0.1443
CEME	0.2401	**ESB**	0.0712
AVERAGE	0.0841	**AVERAGE**	0.2734

3.3.7 Rules of Thumb

Rules of thumb for each element are essentially the “does and don’t” for designers who are interested in minimizing impacts of their buildings. The Rules of thumb are summarized in the table below.

Table 9 Rules of Thumb

ELEMENT/ REFERENCE FLOW	Low Impact	High Impact
A11 Foundations	Materials: Concrete	Materials: Concrete
	Material Mass/m^2: approximately 0.25 tonnes/m^2	Material Mass/m^2: approximately 0.25 tonnes/m^2
	Comments: the foundations with the lowest impacts had a much smaller material mass per square meter. However, this could indicate that they had more efficient designs, or just that their foundations required less structural capacity. Therefore, results are inconclusive.	
A21 Lower Floor Construction	Materials: 20 MPa Concrete	Materials: 30 MPa Concrete
	Material Mass/m^2: approximately 0.25 tonnes/m^2	Material Mass/m^2: approximately 0.75 tonnes/m^2
A22 Upper Floor Construction	Materials: Concrete	Materials: Concrete
	Material Mass/m^2: approximately 0.45 tonnes/m^2	Material Mass/m^2: approximately 1.8 tonnes/m^2
A23 Roof	Materials: Concrete, Ballast	Materials: Concrete
	Material Mass/m^2: approximately 0.63 tonnes/m^2	Material Mass/m^2: approximately 1.18 tonnes/m^2
A31 Walls Below Grade	Materials: Concrete - wall systems made with approximately 97% concrete	Materials: Mortar, Concrete Blocks, Metric Modular Bricks
	Material Mass/m^2: approximately 0.38 tonnes/m^2	Material Mass/m^2: approximately 0.54 tonnes/m^2
A32 Walls Above Grade	Materials: Concrete - wall systems made with approximately 96% concrete	Materials: Mortar, Concrete Blocks, Metric Modular Bricks, Aluminum, Glazing Panels
	Material Mass/m^2: approximately 0.27 tonnes/m^2	Material Mass/m^2: approximately 0.64 tonnes/m^2
B11 Partitions	Materials: Gypsum Board, Concrete	Materials: Mortar, Concrete Blocks, Metric Modular Bricks, Aluminum, Glazing Panels
	Material Mass/m2: approximately 0.084 tonnes/m2	Material Mass/m2: approximately 0.27 tonnes/m2

3.4 Sustainability Program Support

This vast database filled with the LCA results has the potential to be one of UBC's best tools for their sustainability programs. UBC prides itself on creating green built environments; this is evident in all the programs they have in place mentioned in the 'Context for use of LCA at UBC' section above. The CIVL498c database has an opportunity to increase the efficiency of these programs.

3.4.1 Climate Action Plan

The climate action plan focuses on GHG emissions, which is related to the impact category Global Warming Potential in the context of LCA. UBC has the opportunity to benchmark the global warming potential for new proposed building designs against existing buildings. Also, UBC could use the database and try further their best practices for designs, by identifying materials and structure with the lowest impacts and trying to mimic that when designing new buildings on campus.

3.4.2 LEED v4

For new buildings on UBC, I think it would logical for making the Building Life Cycle Impact Reduction Option 4 mandatory. It would be most effective if instead of using a baseline building for comparing impacts of the proposed design, to use a benchmark from the data in the CIVL498c database. This would make the three LEED points achieved in option 4 more meaningful as designers looking for these points are also in charge of designing the baseline building. This seems to be a conflict of interest, as this leaves opportunity for designers to manipulate the baseline building to make their proposed design look less impactful and reach desired reductions. Using a benchmark from the database, like CIVL498 students did in stage 2, eliminates this opportunity for manipulation. Achieving option 4 will also support the other sustainability programs at UBC; for example, this would make new building at UBC have minimal Global Warming Potential, which would directly support UBC's Climate Action Plan.

4.0 Next Steps for Institutionalizing LCA at UBC

LCA is one of the most functional assessment tools to evaluate and reduce environmental impact by buildings. It has been increasingly accepted in project design and operation for sustainability developing purpose. For the sake to incorporate LCA at UBC, we have explored several aspects with regard to LCA application, including LCA modeling tools, LCA database, LCA decision making and LCA education resource.

4.1 LCA Modeling Tools

LCA modeling tool is the modeling software to present life cycle inventory analysis (LCI) and life cycle impact assessment (LCIA), and eventually interpret the results in relation to defined goal and scope. There are various LCA modeling tools have been developed to assist in project managing and building operations. LCA modeling tools can be classified based on application to life cycle stages. It is noted that not all the LCA tools are capable to conduct cradle-to-grave LCA analysis (Bayer, Gamble, Gentry, &Joshi, 2010). Therefore it is very important to introduce suitable LCA modeling at UBC for project designing, construction and operations.

4.1.1 Athena Impact Estimator

In this study, Athena Impact Estimator (IE) is the primary modeling tool utilized through the project. It provides inventory profile for whole building and individual assemblies, such as foundations, walls, floors and roofs. Athena Impact Estimator (IE) is appropriate for detailed design stage. It enables the designers to know environmental effects generated by the proposed design, and make adjustments based on bill of materials and associated impacts. It also evaluates the environmental impacts associated with material manufacturing and building construction phase (Bayer, Gamble, Gentry, &Joshi, 2010).

4.1.2 Building for Environmental Economic Sustainability

Building for Environmental and Economic Sustainability (BEE) measures the environmental performance of building through all the stages in life cycle, including raw material acquisition, manufacturing, transportation, installation, maintenance and operation (Lippiat & Boyless, 2001). It provides environmental and economic comparison between competing products that are functionally equivalent with similar modeling considerations (Lippiat & Boyless, 2001).

4.1.3 ENVEST®

ENVEST® is a simplified modeling tool for use in pre-design stage. It reveals both environmental and financial impacts based on basic design information, such as gross building area and floor plan. It allows users to optimize their designs in the early stage.

4.2 LCA Databases

There are many LCA databases available developed by different institutions. It is crucial to apply appropriate database for inventory analysis. The following are three data collections suggested for use at UBC.

4.2.1 LCI Databases

LCI database is key to LCA analysis. It contains material and energy use, as well as emissions for commonly used products and processes (Bayer, Gamble, Gentry, &Joshi, 2010). LCI database is region-specific because elementary flow for each unit process and resulting energy may vary in different regions. As for UBC, databases for North America are applicable, such as ATHENA database and US LCI database. LCA database reflects industry average in aid to manage UBC buildings and assemblies.

4.2.2 Impact Assessments

Impact Assessments are the output from a given process or product expressed in term of ecological impact category. Impact assessments vary and are dependent on the LCA tools used. For Example, the impact categories generated from ATHENA IE are Global Warming Potential (GWP), Acidification Potential, HH Particulate, Eutrophication Potential, Ozone Depletion Potential, Smog Potential, Total Primary Energy, Non-Renewable Energy, and Fossil Fuel Consumption; the impact categories generated from ATHENA EcoCalculator are Global Warming Potential, Embodied Primary Energy, Pollution to Air, and Weighted Resource Use. It depends on the users to select the most important impact categories in concern.

4.2.3 Environmental Product Declarations (EPDs)

EPDs are third-party verified documents quantifying environmental impact of a product or system based on LCA. It allows comparison of multi-impact information among equivalent products. Besides those impact categories generated through impact assessments, EPDs can also include other impacts that are particular interest to the discloser, such as toxicity risk and corporate social responsibility (UL Environment, 2014)

4.3 LCA Decision Making Methods

Incorporating LCA into decision-making can be approached through following methods.

4.3.1 Benchmarking

Benchmark is a participatory and iterative tool to provide frame of reference in LCA study. It allows decision makers and intended audience to make comparative assertion of products in regard to various categories.

In the project of CIVL 498C, benchmarks in term of each environmental impact on whole building level and by element are created among 22 buildings on campus.

By comparing the results through LCA of each building to the campus benchmarks, we are able to evaluate performance of each building, and figure out the potential improvements existing in current operations. However, there are several other ways that benchmark can be performed to guide better decision-making.

Benchmarking can be developed in peer groups. That means a building at UBC is compared to other buildings serving similar functions. For example, the performance of Math building at UBC is compared to the benchmark of numerous institutional buildings on university campus in Vancouver. This approach provides holistic basis for comparison, and lead decision maker to assess the building performance at UBC from a broader scope.

Benchmarking can be developed against the best in class (Bayer, Gamble, Gentry, & Joshi, 2010) . That means each building at UBC is compared to one most sustainable building on campus. This approach provides a sound benchmark at a higher level.

Alternatively, benchmarking can be developed in past performance. That means the current performance of one building is compared to its historic data (Bayer, Gamble, Gentry, & Joshi, 2010). This approach addresses performance variation over a specific time.

Moreover, current limitation is the lack of benchmark data established by governmental authorities (Bayer, Gamble, Gentry, &Joshi, 2010). It will be beneficial to decision makers applying LCA at UBC if the limitation is overcome.

4.3.2 Weighting

Weighting method is to multiply the impact category indicator results by the weighting factors and add together to form a total environmental performance score (Bayer, Gamble, Gentry, & Joshi, 2010). Weighting is helpful in decision making because it converts different impact categories into one single value result. This value is easily understood by decision makers and can be used in early product development process (Matterson,2012). However, there are several issues of the appliance of weighting method. First, The selection of impact category for product comparison is subjective to the decision makers based on their interest. Secondly, the weighting system has not been adequately established and still unapproved by many LCA experts. Therefore more study and generalizations is required to make weighting results more reliable.

It is recommended to allow weighting method across impact categories at UBC. Through reading one single indicator, stakeholders and researchers can quickly examine the outcomes of one building by applying different materials or resources . Then they can make improvements as necessary. They can also make comparison between two or more products in term of environmental performances. Additionally, in order to achieve more representatively scientific weighted values, it is necessary to have a group of professional LCA experts to create a consistent weighting set for campus based on numerous study and tests.

4.3.3 Integrated Financial-Environmental Analysis

LCA estimates resulting environmental impacts on a wide range of categories. It can provide ecological footprint related to resources, energy, pollutants and material. However LCA is limited to include cost and investment analysis for strategic decision-making (Klemes,2012). LCC (Life Cycle Costing) is a tool to provide decision support in building design and building system based on financial benefits (Bayer, Gamble, Gentry, &Joshi, 2010). LCC analyzes all relevant costs and revenues involved in activities in life cycle, including initial investment and future cost, and determines the cost-effectiveness between different alternatives.

Thus appliance of both LCA and LCC as integrated financial-environmental analysis generates more holistic decision-making. Through integrated financial-environmental analysis, decision makers not only can manage environmental impacts but also choose the most suitable option for budget control.

4.4 LCA Communication and Education Resources

In purpose to approach the institution of LCA at UBC, it is fundamental to get more faculties and students involved in LCA development.

It is recommended to establish a UBC LCA council. The objective is to lower environmental footprint of buildings at UBC and to lead a sustainable campus. UBC LCA council is responsible for conducting the development of LCA on campus, and standardizing the LCA process, including selecting LCA modeling tools and LCA databases to be used, and decision-making among various design options.

Education is an effective way to reinforce awareness of LCA application on campus. UBC could promote more courses and programs related to LCA, such as CIVL 498C. By doing this, students can obtain great understanding of LCA and how LCA functions to improve environmental performance of buildings. Moreover, LCA database should be able to be accessed through UBC library for university students, architects, and project decision makers. Readily available data is convenient for both education and industrial purpose. It can also improve data quality and transparency.

5.0 Conclusion

LCA is currently the best tool for quantifying environmental impacts from a certain product. It is particularly useful for determining impact related to buildings because they are on the most impactful products created by mankind. Cradle-to-grave LCAs takes a holistic approach to determining impacts by looking at the entire life cycle, including resource extraction, construction, operation, demolition, and disposal.

One of UBC priorities when building new buildings on their campus is to have minimal impacts. To make sure green buildings are being built, UBC has established numerous sustainability programs. LCA has been incorporated in their Climate Action Plan, UBC Technical Guidelines, UBC RFI Evaluation Criteria, and LEED v4 (LEED is not a UBC program, but all new buildings are required to achieve LEED Gold).

UBC also began a pilot project class, CIVL 498c, in 2008 and continues today where students are able to participate in an ongoing LCA study of the UBC buildings. The study continued in 2014 where students performed a LCA on 22 buildings at UBC, created a database of all the results, and created environmental impact benchmarks.

The database was used in this report to identify the building elements in the UBC buildings that have the lowest and highest impacts. In general, the lower impact designs were mass efficient concrete structures. The high impact designs tended significant quantities of mortar, concrete blocks, modular bricks, aluminum, and glazing panels. In general, the elements designed with low mass efficiency had high impacts.

Because of LCAs effectiveness and superiority to other environmental impact methods, UBC should institutionalize it. UBC has an opportunity to be trendsetter in environmental communities by making LCA the standard at their campus. To institutionalize LCA, UBC needs to make it one of their primary decision tools with respect to building designs. LCA can effectively used for benchmarking, while LCA weighting is still being debated if it is currently an effective tool, but has the potential to be useful with set standards. Also, the establishment of a LCA council could be useful at UBC. The council can be responsible for using LCA to analyze proposed designs and to reduce environmental impacts.

In addition to LCA being used as tool for UBC building construction and design, LCA should have a more significant presence in the education curriculum. Teaching the premise of LCA in lower level classes in the engineering, architecture, and environmental departments would help spread the awareness of LCA among students, and eventually industry. It could also increase the popularity of CIVL 498c.

APPENDIX A – Impact Tables

A11 - Foundations

Building	Global Warming Potential	Acidification Potential	HH Particulate	Eutrophication Potential	Ozone Depletion Potential	Smog Potential	Total Primary Energy
	kg CO2 eq	kg SO2 eq	kg PM2.5 eq	kg N eq	kg CFC-11 eq	kg O3 eq	MJ
Hennings	92.5	0.7	0.2	0.0	0.0	16.3	798.0
ICICS	188.7	1.302	0.413	6.09E-02	9.25E-07	32.17	1,446
CIRS	134.1	0.752	0.260	2.74E-02	1.15E-06	14.07	1,221
Neville Scarfe	18.7	0.128	0.042	5.98E-03	9.01E-08	3.15	146
Hebb	173.4	1.179	0.399	5.48E-02	8.17E-07	28.79	1,406
Chemistry North	46.8	0.318	0.110	1.48E-02	2.16E-07	7.76	386
Wesbrook	37.9	0.263	0.095	1.26E-02	1.58E-07	6.61	340
Henry Angus	45.1	0.260	0.106	1.06E-02	3.28E-07	5.37	438
Geography	267.6	1.806	0.624	8.41E-02	1.17E-06	44.42	2,331
Chemistry South Wing	32.8	0.224	0.074	1.04E-02	1.57E-07	5.50	261
Chemistry	41.2	0.280	0.111	1.32E-02	0.00E+00	6.90	427
Earth Science (ESB)	92.5	0.646	0.215	3.11E-02	4.10E-07	16.30	798
Allard Hall	37.9	0.268	0.085	1.32E-02	1.58E-07	6.98	336
CEME	25.0	0.174	0.055	8.33E-03	1.18E-07	4.39	197
CHBE	89.3	0.611	0.198	2.87E-02	4.32E-07	15.10	692
Lasserre	33.4	0.234	0.080	1.14E-02	0.00E+00	5.97	290
Kaiser	16.5	0.115	0.039	5.51E-03	7.36E-08	2.90	142
Douglas Kenny	63.3	0.433	0.141	2.03E-02	3.05E-07	10.66	493
AERL	104.2	0.714	0.228	3.37E-02	5.04E-07	17.80	814
Average	**81.1**	**0.545**	**0.183**	**2.51E-02**	**3.69E-07**	**13.22**	**682.2**

A21 Lowest Floor Construction

	Global Warming Potential	Acidification Potential	HH Particulate	Eutrophication Potential	Ozone Depletion Potential	Smog Potential	Total Primary Energy
Building	kg CO2 eq	kg SO2 eq	kg PM2.5 eq	kg N eq	kg CFC-11 eq	kg O3 eq	MJ
Henn	63.0	0.5	0.1	0.0	0.0	11.54	550.1
MCML	31.0	0.223	0.070	1.08E-02	1.26E-07	5.68	289.2
ICICS	78.1	0.539	0.176	2.48E-02	3.70E-07	13.02	646.2
SCRF	56.7	0.393	0.127	1.81E-02	2.70E-07	9.46	468.6
HEBB	37.5	0.257	0.084	1.20E-02	1.79E-07	6.27	297.7
Chemistry North	22.6	0.159	0.054	7.73E-03	9.79E-08	4.06	193.2
Wesbrook	32.1	0.231	0.071	1.19E-02	1.29E-07	5.38	313.5
Henry Angus	36.1	0.209	0.080	8.34E-03	2.79E-07	4.26	334.4
Geography	50.8	0.344	0.118	1.61E-02	2.20E-07	8.45	450.3
Chemistry South Wing	65.8	0.455	0.145	2.11E-02	3.18E-07	11.09	522.7
Chemistry	178.9	1.211	0.486	5.73E-02	0.00E+00	29.84	1,873.0
ESB	63.0	0.447	0.138	2.19E-02	2.72E-07	11.54	550.1
Allard Hall	458.8	2.952	1.277	1.32E-01	1.66E-06	68.22	4,827.4
Forest Science Center	47.5	0.326	0.102	1.54E-02	2.16E-07	8.17	392.5
CEME	33.4	0.236	0.075	1.17E-02	1.37E-07	6.19	297.5
CHBE	73.9	0.507	0.164	2.38E-02	3.57E-07	12.53	576.4
Lasserre	45.3	0.326	0.102	1.58E-02	0.00E+00	8.32	423.4
Pharmacy	166.9	1.156	0.355	5.49E-02	7.74E-07	29.15	1,350.1
Kaiser	33.7	0.237	0.077	1.11E-02	1.55E-07	5.81	290.7
Douglas Kenny	52.4	0.355	0.123	1.63E-02	2.40E-07	8.59	440.7
AERL	42.1	0.303	0.094	1.48E-02	1.72E-07	7.79	389.3
Average	**79.5**	**0.539**	**0.193**	**2.50E-02**	**2.84E-07**	**13.11**	**737.0**

A22 Upper Floor Construction

	Global Warming Potential	Acidification Potential	HH Particulate	Eutrophication Potential	Ozone Depletion Potential	Smog Potential	To Pr Er
Building	kg CO2 eq	kg SO2 eq	kg PM2.5 eq	kg N eq	kg CFC-11 eq	kg O3 eq	MJ
Henn	129.2	0.8	0.4	0.0	0.0	19.1	1,
MCML	353.7	2.008	0.571	8.76E-02	1.76E-06	45.08	3
CIRS	54.1	0.384	0.264	2.65E-02	3.61E-06	6.39	
SCRF	120.4	0.782	0.324	3.51E-02	4.55E-07	18.28	1
HEBB	186.9	1.191	0.547	5.23E-02	6.44E-07	26.81	2
Chemistry North	281.1	1.810	0.793	8.06E-02	1.00E-06	41.62	3
Wesbrook	386.5	2.520	1.131	1.17E-01	1.20E-06	58.14	4
Henry Angus	193.1	1.072	0.516	3.95E-02	1.08E-06	19.62	2
Chemistry South Wing	350.7	2.209	1.044	9.60E-02	1.18E-06	49.34	3
Chemistry	53.4	0.337	0.268	1.85E-01	0.00E+00	6.85	1
ESB	129.2	0.829	0.357	4.07E-02	4.27E-07	19.14	1
Allard Hall	36.8	0.211	0.069	9.65E-03	7.65E-08	4.61	
Forest Science Center	174.3	1.126	0.459	5.15E-02	6.55E-07	26.28	1
CEME	129.6	0.766	0.315	3.28E-02	5.08E-07	16.84	1
CHBE	192.2	1.260	0.499	5.71E-02	7.64E-07	29.75	1
Lasserre	175.0	1.015	0.466	4.22E-02	0.00E+00	21.32	2
Kaiser	192.1	1.252	0.524	5.66E-02	7.05E-07	29.34	2
Douglas Kenny	258.0	1.542	0.744	6.52E-02	8.64E-07	33.09	3
AERL	153.3	0.996	0.406	4.49E-02	5.87E-07	23.43	1
Average	**186.8**	**1.165**	**0.508**	**6.11E-02**	**8.17E-07**	**26.06**	**2,**

A23 Roof

Building	Global Warming Potential kg CO2 eq	Acidification Potential kg SO2 eq	HH Particulate kg PM2.5 eq	Eutrophication Potential kg N eq	Ozone Depletion Potential kg CFC-11 eq
Henn	33.1	0.2	0.0	0.0	0.0
MCML	283.2	1.570	0.676	6.33E-02	1.67E-06
CIRS	106.2	0.754	0.517	5.19E-02	7.09E-06
SCRF	309.0	1.919	0.904	8.37E-01	7.78E-07
HEBB	123.3	0.709	0.457	4.85E-01	2.60E-07
Henry Angus	73.2	0.425	0.464	4.18E-01	3.24E-07
Geography	71.4	0.476	0.210	5.80E-01	6.47E-09
Chemistry South Wing	259.6	1.656	0.754	4.48E-01	7.93E-07
Chemistry	136.1	0.872	0.388	4.01E-02	0.00E+00
Allard Hall	30.2	0.195	0.060	1.00E-02	9.93E-08
Forest Science Center	222.3	1.544	1.497	8.47E-01	1.96E-06
Math Building	39.4	0.285	0.476	5.95E-01	4.86E-09
Civil and Mechanical Engineering Building	131.4	0.712	0.334	3.94E-01	2.18E-07
CHBE	290.3	1.795	0.606	1.92E-01	1.72E-06
Lasserre	207.2	1.258	0.923	5.69E-01	0.00E+00
Pharmacy	109.3	0.693	0.233	9.55E-02	5.74E-07
Kaiser	204.1	1.278	1.226	1.04E+00	1.00E-06
Douglas Kenny	156.6	0.985	1.023	4.67E-01	4.41E-07
AERL	432.3	2.442	0.742	6.43E-01	2.32E-06
AVERAGE	**169.4**	**1.042**	**0.606**	**4.10E-01**	**1.01E-06**

A31 Walls Below Grade

	Global Warming Potential	Acidification Potential	HH Particulate	Eutrophication Potential	Ozone Depletion Potential	Smog Potential	Total Primar Energy
Building	kg CO2 eq	kg SO2 eq	kg PM2.5 eq	kg N eq	kg CFC-11 eq	kg O3 eq	MJ
Henn	138.7	0.9	0.3	0.1	0.0	23.8	1,377
MCML	114.5	0.871	0.157	1.50E-01	2.27E-06	9.54	1,781
ICICS	34.7	0.234	0.080	1.11E-02	1.56E-07	5.57	295
CIRS	160.6	0.863	0.308	3.19E-02	1.30E-06	15.94	1,499
SCRF	104.0	0.693	0.245	3.34E-02	4.59E-07	16.62	908
HEBB	135.2	0.990	0.263	4.59E-02	4.49E-07	21.90	1,390
Chemistry North	74.1	0.464	0.167	2.26E-02	2.28E-07	11.16	826
Wesbrook	111.3	0.768	0.227	4.48E-02	7.98E-07	15.49	1,113
Henry Angus	58.6	0.343	0.142	1.44E-02	4.27E-07	7.23	600
Geography	67.5	0.457	0.157	2.14E-02	2.89E-07	11.22	601
Chemistry South Wing	88.2	0.590	0.206	3.05E-02	3.96E-07	13.26	870
Chemistry	539.2	3.247	3.313	1.72E+00	0.00E+00	67.68	6,270
ESB	138.7	0.942	0.320	4.55E-02	5.32E-07	23.80	1,377
Allard Hall	181.6	1.339	1.087	1.20E-01	6.32E-07	24.00	8,048
Forest Science Center	124.1	0.821	0.275	3.86E-02	5.29E-07	19.74	1,213
Math Building	64.0	0.433	0.149	2.29E-02	2.91E-07	10.38	607
CEME	62.0	0.427	0.153	2.08E-02	2.33E-07	10.89	599
CHBE	163.5	1.080	0.407	4.81E-02	7.24E-07	25.12	1,466
Lasserre	44.0	0.303	0.103	1.52E-02	0.00E+00	7.40	461
Kaiser	97.5	0.673	0.238	3.19E-02	4.20E-07	16.73	871
AERL	68.7	0.452	0.151	2.14E-02	2.83E-07	11.19	648
Average	122.4	0.81	0.40	1.21E-01	4.96E-07	17.56	1,563

A32 Walls Above Grade

Building	Global Warming Potential kg CO2 eq	Acidification Potential kg SO2 eq	HH Particulate kg PM2.5 eq	Eutrophication Potential kg N eq	Ozone Depletion Potential kg CFC-11 eq	Smog Potential kg O3 eq	Total Primar Energy MJ
Henn	43.0	0.3	0.3	0.0	0.0	4.91	1,83
MCML	75.4	0.408	0.269	2.94E-02	3.85E-07	6.23	1,90
ICICS	63.1	0.386	0.140	2.71E-02	2.67E-07	7.21	78
CIRS	13.8	0.096	0.021	9.03E-03	5.76E-08	1.37	23
SCRF	141.2	1.070	0.237	6.87E-02	9.16E-07	21.88	1,41
HEBB	96.5	0.654	0.224	4.99E-02	5.83E-07	14.89	87
Chemistry North	112.7	0.686	0.271	3.00E-02	3.73E-07	14.91	1,24
Wesbrook	50.3	0.349	0.133	3.42E-02	1.96E-07	8.74	49
Henry Angus	110.3	0.645	0.263	3.26E-02	8.28E-07	12.89	1,23
Geography	8.3	0.071	0.013	1.33E-02	1.10E-08	1.37	15
Chemistry South Wing	98.2	0.600	0.283	2.34E-02	3.59E-07	11.80	1,06
Chemistry	98.2	0.600	0.283	2.34E-02	3.59E-07	11.80	1,06
ESB	114.2	0.700	0.330	3.22E-02	0.00E+00	13.99	1,20
Allard Hall	43.0	0.299	0.264	4.32E-02	1.19E-07	4.91	1,83
Forest Science Center	28.1	0.177	0.039	1.57E-02	2.24E-07	2.54	40
Math Building	31.0	0.189	0.050	1.61E-02	1.53E-07	3.73	43
CEME	9.5	0.080	0.017	1.31E-02	1.93E-08	1.68	15
CHBE	58.8	0.362	0.159	1.70E-02	1.97E-07	7.38	69
Lasserre	1,120.5	6.800	2.978	2.90E-01	3.85E-06	134.08	12,73
Pharmacy	160.1	0.983	0.493	4.34E-02	0.00E+00	18.36	1,93
Kaiser	256.4	1.673	1.366	1.68E-01	8.22E-07	26.30	10,23
Douglas Kenny	43.3	0.258	0.112	1.26E-02	1.16E-07	4.68	54
AERL	34.5	0.214	0.055	2.29E-02	7.54E-08	3.57	50
AVERAGE	**122.2**	**0.765**	**0.359**	**4.59E-02**	**4.31E-07**	**14.75**	**1,86**

B11 Partitions

Building	Global Warming Potential kg CO_2 eq	Acidification Potential kg SO_2 eq	HH Particulate kg PM2.5 eq	Eutrophication Potential kg N eq	Ozone Depletion Potential kg CFC-11 eq	Smog Potential kg O_3 eq	Total Primar Energy MJ
Henn	43.0	0.3	0.3	0.0	0.0	4.9	1,835.
MCML	75.4	0.408	0.269	2.94E-02	3.85E-07	6.23	1,90
ICICS	63.1	0.386	0.140	2.71E-02	2.67E-07	7.21	78
CIRS	13.8	0.096	0.021	9.03E-03	5.76E-08	1.37	23
SCRF	141.2	1.070	0.237	6.87E-02	9.16E-07	21.88	1,41
HEBB	96.5	0.654	0.224	4.99E-02	5.83E-07	14.89	87
Chemistry North	112.7	0.686	0.271	3.00E-02	3.73E-07	14.91	1,24
Wesbrook	50.3	0.349	0.133	3.42E-02	1.96E-07	8.74	49
Henry Angus	110.3	0.645	0.263	3.26E-02	8.28E-07	12.89	1,23
Geography	8.3	0.071	0.013	1.33E-02	1.10E-08	1.37	15
Chemistry South Wing	98.2	0.600	0.283	2.34E-02	3.59E-07	11.80	1,06
Chemistry	98.2	0.600	0.283	2.34E-02	3.59E-07	11.80	1,06
ESB	114.2	0.700	0.330	3.22E-02	0.00E+00	13.99	1,20
Allard Hall	43.0	0.299	0.264	4.32E-02	1.19E-07	4.91	1,83
Forest Science Center	28.1	0.177	0.039	1.57E-02	2.24E-07	2.54	40
Math Building	31.0	0.189	0.050	1.61E-02	1.53E-07	3.73	43
CEME	9.5	0.080	0.017	1.31E-02	1.93E-08	1.68	15
CHBE	58.8	0.362	0.159	1.70E-02	1.97E-07	7.38	69
Lasserre	1,120.5	6.800	2.978	2.90E-01	3.85E-06	134.08	12,73
Pharmacy	160.1	0.983	0.493	4.34E-02	0.00E+00	18.36	1,93
Kaiser	256.4	1.673	1.366	1.68E-01	8.22E-07	26.30	10,23
Douglas Kenny	43.3	0.258	0.112	1.26E-02	1.16E-07	4.68	54
AERL	34.5	0.2	0.1	0.0	0.0	3.6	499.
AVERAGE	**122.2**	**0.765**	**0.359**	**0.046**	**0.000**	**14.7**	**1,868.**

APPENDIX B – Bills of Materials

A11 Foundations

Scarfe	**Quantity:**	**1332**
Material	Mass	
Concrete 30 MPa (flyash av)	163.408	Tonnes
Rebar, Rod, Light Sections	0.4576	Tonnes
TOTAL	163.866	Tonnes
Mass/m^2	0.123	Tonnes/m^2

Chem South	**Quantity:**	**1217**
Material	Mass	
Concrete 30 MPa (flyash av)	259.5258	Tonnes
Rebar, Rod, Light Sections	1.2021	Tonnes
TOTAL	260.7279	Tonnes
Mass/m^2	0.214	Tonnes/m^2

CEME	**Quantity:**	**6555.4**
Material	Mass	
Concrete 20 MPa (flyash av)	497.7096	Tonnes
Concrete 30 MPa (flyash av)	711.8061	Tonnes
Rebar, Rod, Light Sections	0.1916	Tonnes
TOTAL	1209.7073	Tonnes
Mass/m^2	0.185	Tonnes/m^2

Kaiser	**Quantity:**	**2704**
Material	Mass	
Concrete 30 MPa (flyash 35%)	345.3928	Tonnes
Rebar, Rod, Light Sections	1.9819	Tonnes
TOTAL	347.3747	Tonnes
Mass/m^2	0.128	Tonnes/m^2

ICICS	**Quantity:**	**2151**
Material	Mass	
Concrete 30 MPa (flyash av)	2704.9658	Tonnes
Rebar, Rod, Light Sections	1.4788	Tonnes
TOTAL	2706.4446	Tonnes
Mass/m^2	1.258	Tonnes/m^2

Geography	**Quantity:**	**272.39**
Material	Mass	
Concrete 30 MPa (flyash av)	435.444	Tonnes
Rebar, Rod, Light Sections	5.794	Tonnes
TOTAL	441.238	Tonnes
Mass/m^2	1.620	Tonnes/m^2

CIRS	**Quantity:**	**1309**
Material	Mass	
6 mil Polyethylene	0.3438	Tonnes
Concrete 30 MPa (flyash 25%)	712.0397	Tonnes
Concrete 30 MPa (flyash 35%)	208.4523	Tonnes
Rebar, Rod, Light Sections	0.9975	Tonnes
Welded Wire Mesh / Ladder Wire	2.6389	Tonnes
TOTAL	924.4722	Tonnes
Mass/m^2	0.706	Tonnes/m^2

Hebb	**Quantity:**	**1898**
Concrete 30 MPa (flyash av)	410.4649	Tonnes
Rebar, Rod, Light Sections	2.8405	Tonnes
TOTAL	413.3054	Tonnes
Mass/m^2	0.218	Tonnes/m^2

A21 Lower Floor Constructions

MacMillan	**Quantity:**	**3292**
Material	Mass	
6 mil Polyethylene	0.5238	Tonnes
Concrete 20 MPa (flyash av)	823.8937	Tonnes
Welded Wire Mesh / Ladder Wire	3.0534	Tonnes
TOTAL	827.4709	Tonnes
Matierl Mass/m^2	0.2514	Tonnes/m^2

CHEM N	**Quantity:**	**616**
Material	Mass	
Concrete 20 MPa (flyash av)	120.1587	Tonnes
Welded Wire Mesh / Ladder Wire	0.4453	Tonnes
TOTAL	120.6041	Tonnes
Matierl Mass/m^2	0.1958	Tonnes/m^2

Wesbrook	**Quantity:**	**2510**
Material	Mass	
5/8" Regular Gypsum Board	27.6656	Tonnes
6 mil Polyethylene	0.3889	Tonnes
Concrete 20 MPa (flyash av)	611.2067	Tonnes
Joint Compound	2.6833	Tonnes
Nails	0.0252	Tonnes
Paper Tape	0.0308	Tonnes
Welded Wire Mesh / Ladder Wire	2.2652	Tonnes
TOTAL	644.2657	Tonnes
Matierl Mass/m^2	0.2567	Tonnes/m^2

Henrey Angus	**Quantity:**	**1522**
Material	Mass	
Concrete 20 MPa (flyash av)	467.4434	Tonnes
Welded Wire Mesh / Ladder Wire	1.3749	Tonnes
TOTAL	468.8183	Tonnes
Matierl Mass/m^2	0.3080	Tonnes/m^2

ICICS	**Quantity:**	**2151**
Material	Mass	
6 mil Polyethylene	0.5952	Tonnes
Concrete 30 MPa (flyash av)	1083.1531	Tonnes
Rebar, Rod, Light Sections	1.5383	Tonnes
Welded Wire Mesh / Ladder Wire	3.3802	Tonnes
TOTAL	1088.6668	Tonnes
Matierl Mass/m^2	0.5061	Tonnes/m^2

Chemistry	**Quantity:**	**1,654**
Material	Mass	
3 mil Polyethylene	0.0845	Tonnes
Concrete 20 MPa (flyash av)	2169.2182	Tonnes
Rebar, Rod, Light Sections	55.3759	Tonnes
Welded Wire Mesh / Ladder Wire	0.9598	Tonnes
TOTAL	2225.6384	Tonnes
Matierl Mass/m^2	1.3456	Tonnes/m^2

Allard Hall	**Quantity:**	**2506.55**
Material	Mass	
Concrete 20 MPa (flyash av)	678.3897	Tonnes
Concrete 30 MPa (flyash av)	75.6322	Tonnes
Welded Wire Mesh / Ladder Wire	2.5455	Tonnes
TOTAL	756.5674	Tonnes
Matierl Mass/m^2	0.3018	Tonnes/m^2

CHBE	**Quantity:**	**3192**
Material	Mass	
Concrete 30 MPa (flyash av)	1557.7366	Tonnes
Welded Wire Mesh / Ladder Wire	2.8849	Tonnes
TOTAL	1560.6215	Tonnes
Matierl Mass/m^2	0.4889	Tonnes/m^2

Pharmacy	**Quantity:**	**1911**
Material	Mass	

Concrete 30 MPa (flyash av)	2020.0366	Tonnes
Welded Wire Mesh / Ladder Wire	3.7411	Tonnes
TOTAL	2023.7777	Tonnes
Matierl Mass/m^2	1.0590	Tonnes/m^2

A22 Upper Floor Construction

CIRS	**Quantity:**	**3635**
Material	Mass	
Concrete 30 MPa (flyash 25%)	424.4019	Tonnes
Concrete 30 MPa (flyash av)	70.4348	Tonnes
GluLam Sections	129.8881	Tonnes
Other	29.1974	Tonnes
TOTAL	653.9222	Tonnes
Matierl Mass/m^2	0.1799	Tonnes/m^2

Chem	**Quantity:**	**5796**
Material	Mass	
Concrete 20 MPa (flyash av)	2059.8227	Tonnes
Rebar, Rod, Light Sections	57.2855	Tonnes
TOTAL	2117.1082	Tonnes
Matierl Mass/m^2	0.3653	Tonnes/m^2

Allard Hall	**Quantity:**	**9710.5**
Material	Mass	
Concrete 30 MPa (flyash av)	5669.5791	Tonnes
Rebar, Rod, Light Sections	284.4932	Tonnes
TOTAL	5954.0723	Tonnes
Matierl Mass/m^2		Tonnes/m^2

Neville Scarfe	**Quantity:**	**3671**
Material	Mass	
Concrete 30 MPa (flyash av)	2273.0726	Tonnes
Rebar, Rod, Light Sections	95.3335	Tonnes
TOTAL	2368.4061	Tonnes
Matierl Mass/m^2	0.6452	Tonnes/m^2

MCML	**Quantity:**	**8962**
Material	Mass	
Concrete 30 MPa (flyash av)	6303.3925	Tonnes
Precast Concrete	9843.0664	Tonnes
Rebar, Rod, Light Sections	281.5846	Tonnes
Welded Wire Mesh / Ladder Wire	47.9697	Tonnes
TOTAL	16476.01	Tonnes
Matierl Mass/m^2	1.8384	Tonnes/m^2

Wesbrook	**Quantity:**	**3182**
Material	Mass	
Concrete 20 MPa (flyash av)	5031.7684	Tonnes
Concrete 30 MPa (flyash av)	1690.545	Tonnes
Rebar, Rod, Light Sections	362.757	Tonnes
Other	85.8898	Tonnes
TOTAL	7170.9602	Tonnes
Matierl Mass/m^2	2.253601571	Tonnes/m^2

Chemistry S	**Quantity:**	**2635**
Material	Mass	
Concrete 30 MPa (flyash av)	3948.0427	Tonnes
Mortar	122.28	Tonnes
Rebar, Rod, Light Sections	288.4612	Tonnes
8" Concrete Block	95.2448	Tonnes
TOTAL	4454	Tonnes
Matierl Mass/m^2	1.690333472	Tonnes/m^2

Chem N	**Quantity:**	**1199**
Material	Mass	
Concrete 30 MPa (flyash av)	1640.080	Tonnes
Rebar, Rod, Light Sections	87.817	Tonnes
TOTAL	1727.897	Tonnes
Matierl Mass/m^2	1.441	Tonnes/m^2

A23 Roof

Hennings	**Quantity:**	**1202**
Material	Mass	
Ballast (aggregate stone)	243.973	Tonnes
Concrete 20 MPa (flyash av)	52.987	Tonnes
Concrete 30 MPa (flyash av)	447.622	Tonnes
Precast Concrete	827.441	Tonnes
Laminated Veneer Lumber	72.958	Tonnes
Roofing Asphalt	74.252	Tonnes
Other	149.941	Tonnes
TOTAL	1869.173	Tonnes
Matierl Mass/m^2	1.555	Tonnes/m^2

CEME	**Quantity:**	**4286.1**
Material	Mass	
Ballast (aggregate stone)	227.668	Tonnes
Concrete 30 MPa (flyash av)	705.034	Tonnes
Roofing Asphalt	152.505	Tonnes
Open Web Joists	45.766	Tonnes
Precast Concrete	77.457	Tonnes
Rebar, Rod, Light Sections	58.005	Tonnes
Galvanized Decking	55.646	Tonnes
Other	77.542	Tonnes
TOTAL	1399.623	Tonnes
Matierl Mass/m^2	0.327	Tonnes/m^2

Allard Hall	**Quantity:**	**7439.4**
Material	Mass	
Concrete 30 MPa (flyash av)	1012.298	Tonnes
Galvanized Studs	77.019	Tonnes
Rebar, Rod, Light Sections	25.364	Tonnes
Other	4.561	Tonnes
TOTAL	1119.241	Tonnes/m^2
Matierl Mass/m^2	0.150	

CIRS	**Quantity:**	**1854**
Material	Mass	
Concrete 30 MPa (flyash 25%)	424.402	Tonnes
Concrete 30 MPa (flyash av)	70.435	Tonnes
GluLam Sections	129.888	Tonnes

Neville Scarfe	**Quantity:**	**1349**
Material	Mass	
Concrete 30 MPa (flyash av)	1427.364	Tonnes
Rebar, Rod, Light Sections	60.040	Tonnes
Roofing Asphalt	99.037	Tonnes
Type III Glass Felt	19.394	Tonnes
Ballast (aggregate stone)	147.849	Tonnes
#15 Organic Felt	13.472	Tonnes
1/2" Moisture Resistant Gypsum Board	26.748	Tonnes
Other	12.011	Tonnes
TOTAL	1805.916	Tonnes
Matierl Mass/m^2	1.339	Tonnes/m^2

AERL	**Quantity:**	**1388**
Material	Mass	
Concrete 30 MPa (flyash av)	837.174	Tonnes
Modified Bitumen membrane	156.431	Tonnes
Galvanized Studs	72.611	Tonnes
5/8" Moisture Resistant Gypsum Board	72.345	Tonnes
Polyiso Foam Board (unfaced)	20.985	Tonnes
Rebar, Rod, Light Sections	33.971	Tonnes
Other	15.838	Tonnes
TOTAL	1209.354	Tonnes
Matierl Mass/m^2	0.871	Tonnes/m^2

CHBE	**Quantity:**	**1164**
Material	Mass	
Concrete 20 MPa (flyash av)	353.741	Tonnes
Concrete 30 MPa (flyash av)	1015.585	Tonnes
Open Web Joists	25.174	Tonnes
Modified Bitumen membrane	26.838	Tonnes
Other	62.504	Tonnes
TOTAL	1483.842	Tonnes
Matierl Mass/m^2	1.275	Tonnes/m^2

CHEM S	**Quantity:**	**1202**
Material	Mass	
Concrete 30 MPa (flyash av)	1288.285	Tonnes
Ballast (aggregate stone)	65.837	Tonnes

Rebar, Rod, Light Sections	26.213	Tonnes
Other	2.984	Tonnes
TOTAL	653.922	Tonnes
Matierl Mass/m^2	0.353	Tonnes/m^2

Rebar, Rod, Light Sections	60.367	Tonnes
Roofing Asphalt	44.101	Tonnes
Other	21.980	Tonnes
TOTAL	1480.570	Tonnes
Matierl Mass/m^2	1.232	Tonnes/m^2

Henry Angus	**Quantity:**	**2351**
Material	Mass	
Ballast (aggregate stone)	305.928	Tonnes
Concrete 20 MPa (flyash av)	527.982	Tonnes
Precast Concrete	120.034	Tonnes
Concrete 30 MPa (flyash av)	64.935	Tonnes
Other	62.378	Tonnes
TOTAL	1081.257	Tonnes
Matierl Mass/m^2	0.460	Tonnes/m^2

A31 Walls Below Grade

ICICS	**Quantity:**	**424**
Concrete 30 MPa (flyash av)	89.194	Tonnes
Other	2.425	Tonnes
TOTAL	91.620	Tonnes
Matierl Mass/m^2	0.216	Tonnes/m^2

Henry Angus	**Quantity:**	**635**
Concrete 20 MPa (flyash 35%)	243.058	Tonnes
Concrete 20 MPa (flyash av)	87.610	Tonnes
Other	3.763	Tonnes
TOTAL	334.431	Tonnes
Matierl Mass/m^2	0.527	Tonnes/m^2

CEME	**Quantity:**	**447.1**
Concrete 20 MPa (flyash av)	207.254	Tonnes
Rebar, Rod, Light Sections	3.165	Tonnes
TOTAL	210.418	Tonnes
Matierl Mass/m^2	0.471	Tonnes/m^2

Lasserre	**Quantity:**	**798**
Concrete 20 MPa (flyash av)	240.952	Tonnes

MCML	**Quantity:**	**2515**
Concrete 20 MPa (flyash av)	647.318	Tonnes
Metric Modular (Modular) Brick	36.419	Tonnes
Double Glazed No Coating Air	50.811	Tonnes
Other	38.744	Tonnes
TOTAL	773.292	Tonnes
Matierl Mass/m^2	0.307	Tonnes/m^2

CHEM	**Quantity:**	**1,723**
Concrete 20 MPa (flyash av)	668.770	Tonnes
Concrete 30 MPa (flyash av)	227.436	Tonnes
Mortar	221.153	Tonnes
8" Concrete Block	171.562	Tonnes
Other	92.921	Tonnes
TOTAL	1381.842	Tonnes
Matierl Mass/m^2	0.802	Tonnes/m^2

Allard Hall	**Quantity:**	**7542.2**
Concrete 30 MPa (flyash av)	949.511	Tonnes
5/8" Regular Gypsum Board	67.008	Tonnes
Galvanized Studs	16.422	Tonnes

Other	10.319	Tonnes
TOTAL	251.271	Tonnes
Matierl Mass/m^2	0.315	Tonnes/m^2

AERL	Quantity:	664
Concrete 30 MPa (flyash av)	252.328	Tonnes
Other	4.654	
TOTAL	256.982	Tonnes
Matierl Mass/m^2	0.387	Tonnes/m^2

Math	Quantity:	588.45
Concrete 30 MPa (flyash av)	207.027	Tonnes
Stucco over metal mesh	6.166	Tonnes
Other	7.028	Tonnes
TOTAL	220.222	Tonnes
Matierl Mass/m^2	0.374	Tonnes/m^2

Other	21.111	Tonnes
TOTAL	1054.053	Tonnes
Matierl Mass/m^2	0.140	Tonnes/m^2

CHBE	Quantity:	832
Concrete 60 MPa (flyash av)	691.945	Tonnes
Mortar	24.834	Tonnes
8" Concrete Block	19.344	Tonnes
Other	16.604	Tonnes
TOTAL	752.727	Tonnes
Matierl Mass/m^2	0.905	Tonnes/m^2

A32 Walls Above Grade

CIRS	Quantity:	6901
Concrete 30 MPa (flyash av)	1275.895	Tonnes
Rebar, Rod, Light Sections	11.374	Tonnes
Other	9.306	
TOTAL	1296.576	Tonnes
Matierl Mass/m^2	0.188	Tonnes/m^2

CEME	Quantity:	6055.8
Concrete 20 MPa (flyash av)	1687.170	Tonnes
Rebar, Rod, Light Sections	43.867	Tonnes
1/2" Regular Gypsum Board	42.816	Tonnes
Other	34.983	Tonnes
TOTAL	1808.835	Tonnes
Matierl Mass/m^2	0.299	Tonnes/m^2

Doug Kenny	Quantity:	17913
Concrete 20 MPa (flyash av)	1341.052	Tonnes
Concrete 30 MPa (flyash av)	1583.481	Tonnes
Rebar, Rod, Light Sections	65.350	Tonnes
Other	87.713	Tonnes
TOTAL	3077.596	Tonnes

Wesbrook	Quantity:	3182
Metric Modular (Modular) Brick	1132.82	Tonnes
Mortar	817.27	Tonnes
Concrete 20 MPa (flyash av)	938.10	Tonnes
1/2" Regular Gypsum Board	178.32	Tonnes
Other	50.50	
TOTAL	3117.01	Tonnes
Matierl Mass/m^2	0.98	Tonnes/m^2

CHBE	Quantity:	3311
Concrete 30 MPa (flyash av)	3079.47	Tonnes
Concrete Brick	480.36	Tonnes
Mortar	207.33	Tonnes
8" Concrete Block	122.83	Tonnes
Other	237.94	Tonnes
TOTAL	4127.93	Tonnes
Matierl Mass/m^2	1.25	Tonnes/m^2

Pharm	Quantity:	2616
Glazing Panel	442.59	Tonnes
Aluminum	87.80	Tonnes

Matierl Mass/m^2	0.172	Tonnes/m^2

SCRF	Quantity:	2142
8" Concrete Block	4.043	Tonnes
Concrete 30 MPa (flyash av)	1068.580	Tonnes
Double Glazed Soft Coated Argon	10.955	Tonnes
Mortar	5.191	Tonnes
Rebar, Rod, Light Sections	11.453	Tonnes
Small Dimension Softwood Lumber, kiln-dried	2.493	Tonnes
Other	1.201	Tonnes
TOTAL	1103.917	Tonnes
Matierl Mass/m^2	0.515	Tonnes/m^2

Other	16.99	Tonnes
TOTAL	547.38	Tonnes
Matierl Mass/m^2	0.21	Tonnes/m^2

Kaiser	Quantity:	3609
Glazing Panel	198.69	Tonnes
Concrete 30 MPa (flyash 35%)	160.41	Tonnes
Aluminum	37.58	Tonnes
Other	18.52	Tonnes
TOTAL	415.20	Tonnes
Matierl Mass/m^2	0.12	Tonnes/m^2

AERL	Quantity:	3154
Metric Modular (Modular) Brick	996.26	Tonnes
Mortar	341.42	Tonnes
Glazing Panel	101.68	Tonnes
Concrete 30 MPa (flyash av)	223.96	Tonnes
5/8" Moisture Resistant Gypsum Board	108.44	Tonnes
5/8" Regular Gypsum Board	97.20	Tonnes
Other	163.45	Tonnes
TOTAL	2032.41	Tonnes
Matierl Mass/m^2	0.64	Tonnes/m^2

B11 Partitions

CIRS	Quantity:	2544
5/8" Regular Gypsum Board	42.444	Tonnes
Galvanized Studs	5.051	Tonnes
Joint Compound	4.117	Tonnes
Small Dimension Softwood Lumber, kiln-dried	4.124	Tonnes
Softwood Plywood	2.863	Tonnes
other materials	2.125	Tonnes
TOTAL	60.723	Tonnes
Matierl Mass/m^2	0.024	Tonnes/m^2

Neville Scarfe	Quantity:	2139
Mortar	663.020	Tonnes
Metric Modular (Modular) Brick	219.590	Tonnes
Concrete 30 MPa (flyash av)	65.849	Tonnes
8" Concrete Block	39.846	Tonnes
Other	29.091	Tonnes
TOTAL	1017.396	Tonnes
Matierl Mass/m^2	0.476	Tonnes/m^2

Column1	Column2	Column3

Geopraphy	**Quantity:**	**3935**
1/2" Regular Gypsum Board	65.238	Tonnes
Small Dimension Softwood Lumber, kiln-dried	38.479	Tonnes
Joint Compound	8.078	Tonnes
Softwood Plywood	7.346	Tonnes
Other	1.279	Tonnes
TOTAL	120.419	Tonnes
Matierl Mass/m^2	0.031	Tonnes/m^2

Math	**Quantity:**	**2580**
1/2" Regular Gypsum Board	36.748	Tonnes
Concrete 30 MPa (flyash av)	34.354	Tonnes
Small Dimension Softwood Lumber, kiln-dried	30.579	Tonnes
Joint Compound	4.550	Tonnes
Other	1.247	Tonnes
TOTAL	107.478	Tonnes
Matierl Mass/m^2	0.042	Tonnes/m^2

CEME	**Quantity:**	**9363**
Mortar	828.189	Tonnes
8" Concrete Block	642.873	Tonnes
Concrete 20 MPa (flyash av)	510.751	Tonnes
Rebar, Rod, Light Sections	131.399	Tonnes
1/2" Regular Gypsum Board	56.213	Tonnes
Other	78.810	Tonnes
TOTAL	2248.237	Tonnes
Matierl Mass/m^2	0.240	Tonnes/m^2

Pharmacy		4524
Mortar	558.181	Tonnes
8" Concrete Block	434.150	Tonnes
5/8" Fire-Rated Type X Gypsum Board	390.662	Tonnes
Glazing Panel	103.005	Tonnes
Galvanized Studs	87.072	Tonnes
Rebar, Rod, Light Sections	60.354	Tonnes
Other	186.753	Tonnes
TOTAL	1820.177	Tonnes
Matierl Mass/m^2	0.402	Tonnes/m^2

Kaiser	**Quantity:**	**14875**
Mortar	778.774	Tonnes
8" Concrete Block	605.452	Tonnes
Concrete 30 MPa (flyash av)	312.029	Tonnes
5/8" Regular Gypsum Board	210.366	Tonnes
Rebar, Rod, Light Sections	154.174	Tonnes
Galvanized Studs	28.367	Tonnes
Galvanized Sheet	19.496	Tonnes
Other	37.746	Tonnes
TOTAL	2146.405	Tonnes
Matierl Mass/m^2	0.144	Tonnes/m^2

ESB	**Quantity:**	**9863**
Concrete 30 MPa (flyash 35%)	277.116	Tonnes
5/8" Regular Gypsum Board	112.378	Tonnes
5/8" Fire-Rated Type X Gypsum Board	71.025	Tonnes
Ontario (Standard) Brick	53.322	Tonnes
Glazing Panel	44.881	Tonnes
Galvanized Studs	27.765	Tonnes
Small Dimension Softwood Lumber, kiln-dried	22.648	Tonnes
Galvanized Sheet	18.698	Tonnes

Joint Compound	18.179	Tonnes
Mortar	15.638	Tonnes
Other	40.926	Tonnes
TOTAL	702.576	Tonnes
Matierl Mass/m^2	0.071	Tonnes/m^2

Annex A: Author Reflections

Author Reflection – Vivian

This course is interesting and challenging to me. My previous exposure to LCA has been exclusively through previous courses, limited to LCA concepts and theoretical methodology. In this course, I have learned how to apply LCA in projects, from LCA goal and scope, to LCA inventory analysis and LCA impact assessment. It is a complete study experience to investigate LCA more deeply and understand the importance of LCA to sustainable development in any industry.

The project through this course is very practical. It provides me an opportunity to explore environmental performance at UBC from a scientific perspective. It firstly teaches me how to use LCA modeling software Athena Impact Estimator (IE) for calculating bill of materials, and associated environmental impacts. The results reveal the environmental footprints of existing building at UBC. Secondly, I create the benchmark for the buildings on campus, by individual element and whole building level. By doing this, I am able to compare my building (Kenny Douglas) with the campus benchmark, to examine its environmental performance. Integrated with the application of Athena Impact Estimator (IE), I make several changes to improve my buildings in order to meet LEEDv4 reference criteria. Finally, I am very glad to propose the institution of LCA at UBC, and share my opinions through my final report. Overall, I have obtained a better understanding of LCA in this course, and I would continuously study LCA out of the class for my future professions. (vivian)

1.Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IA = introduced & applied	knowledge base is covered through complete lecture slides.
2.Problem Analysis	An ability to use appropriate	IDA = introduced,	knowledge base is covered through

	knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	developed & applied	complete lecture slides.
3.Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.	IDA = introduced, developed & applied	project stage 1 and stage 2 at which inputing data, creating benchmarks and investigating the results.
4.Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	I = introduced	has been introduced in lectures.
5. Use for Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering	IDA = introduced, developed & applied	applying ATHENA (IE) modeling software for project stage 1. Introducing material take off software

	tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		
6.Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	IDA = introduced, developed & applied	individual assignments (project stage 1)and team project (project 2 and in class assignments) develop both individual problem solving ability and team work spirit. In class airplane activity was interesting.
7.Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	IDA = introduced, developed & applied	assignment 1, report and research/discussion developing reading and writing ability
8.Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of	ID = introduced & developed	Learned from guest speakers and course instructor

	protection of the public and the public interest.		
9.Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural 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	have been introduced through lectures, and practiced by completing the project.
10.Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	I = introduced	have been introduced in lectures
11.Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	I = introduced	introduced in lectures and gained more understanding throuhg research for final project.
12. Life-long	An ability to identify	A = applied	the knowledge gained

Learning	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.		from the course and the method to deomostrate environmental impacts of projects could be very useful.

Author Reflection - Lucia

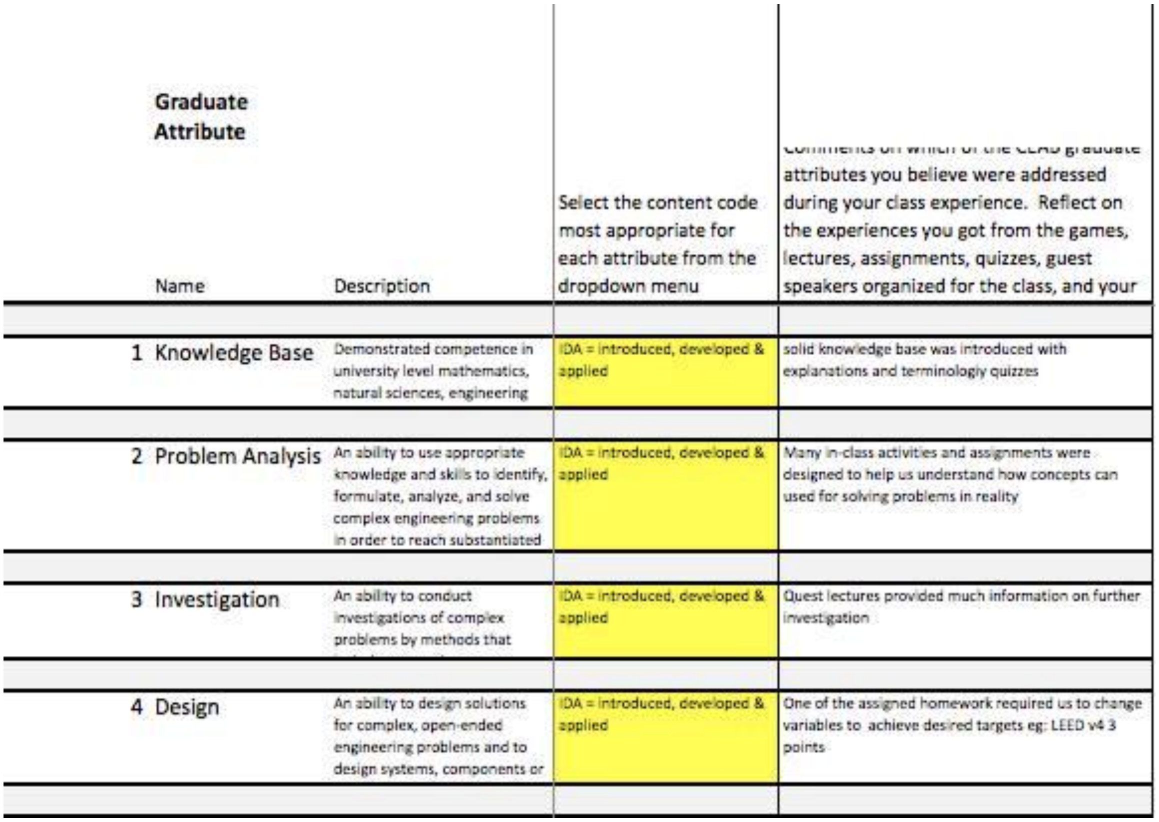
Before taking this course, I don’t know too much about LCA and its terminologies. But I have some knowledge on LEED and sustainability at UBC as we were asked to do research on CIRS, the most sustainable building in North America.

This course introduces the following topics:

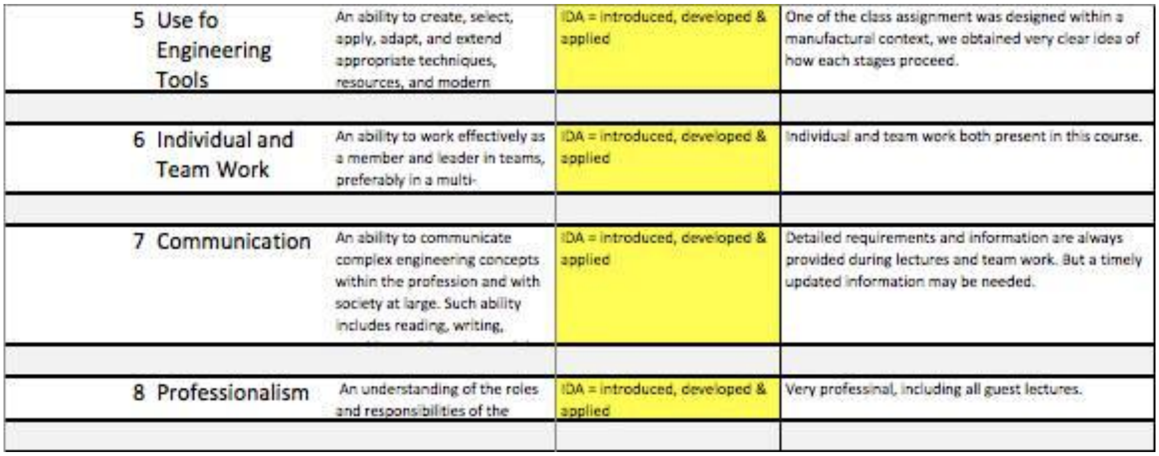
- History and current state of LCA
- Structure of LCA
- Development of a whole building LCA study
- Uncertainty in LCA

As engineers, we are always expected to design buildings and landscapes with low environmental impacts. However, we need a tool to evaluate the level of sustainability in terms of the outcomes through all stages. I am interested in how LCA assess inputs and produce quantified outcomes. And how these numbers can be compared with each other.

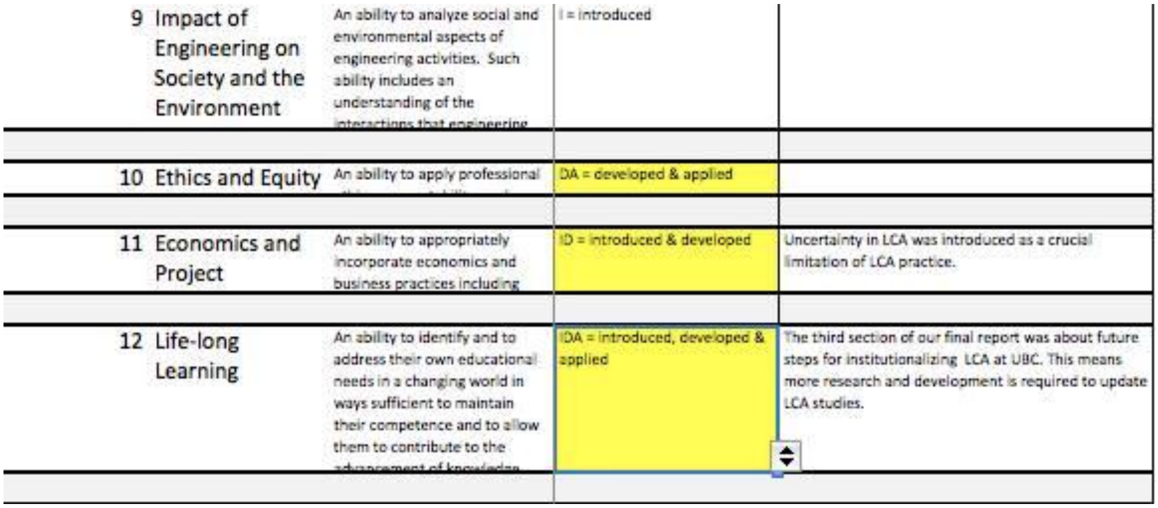
I am thinking a detailed exposure of how database work can be interesting. As at the second stage, we were using Athena Impact Estimator to work out the emission and potential values. The process may be complex. But I am curious how Impact Estimator assess each different building materials, and why not a special EPDs can be added directly into impact estimator? And also, when we were asked to change building materials, were we supposed to consider structural aspect at the same time, as changing material may result in structural failure.



	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe 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
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering	IDA = introduced, developed & applied	solid knowledge base was introduced with explanations and terminology quizzes
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated	IDA = introduced, developed & applied	Many in-class activities and assignments were designed to help us understand how concepts can used for solving problems in reality
3	Investigation	An ability to conduct investigations of complex problems by methods that	IDA = introduced, developed & applied	Quest lectures provided much information on further investigation
4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or	IDA = introduced, developed & applied	One of the assigned homework required us to change variables to achieve desired targets eg: LEED v4 3 points



5	Use fo Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern	IDA = introduced, developed & applied	One of the class assignment was designed within a manufactural context, we obtained very clear idea of how each stages proceed.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-	IDA = introduced, developed & applied	Individual and team work both present in this course.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing,	IDA = introduced, developed & applied	Detailed requirements and information are always provided during lectures and team work. But a timely updated information may be needed.
8	Professionalism	An understanding of the roles and responsibilities of the	IDA = introduced, developed & applied	Very professinal, including all guest lectures.



9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the	I = introduced	
10	Ethics and Equity	An ability to apply professional	DA = developed & applied	
11	Economics and Project	An ability to appropriately incorporate economics and business practices including	ID = introduced & developed	Uncertainty in LCA was introduced as a crucial limitation of LCA practice.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the	IDA = introduced, developed & applied	The third section of our final report was about future steps for institutionalizing LCA at UBC. This means more research and development is required to update LCA studies.

Author Reflection – Trent

Before CIVL 498c, my experience with sustainability was pretty limited, 3 classes that were focused on the environment or sustainability and a few modules in other random classes. My experience with LCA was basically none; there was a small module in CIVL200 – Engineering and Sustainable Development (with Dr. Susan Nesbitt). Dr. Nesbitt recommended CIVL498c in that class if we were interested in sustainability, so I decided to take it.

After taking the class, it is apparent many items/materials that are commonly thought of being “green” materials, may in fact be much more impactful than perceived. An example that comes to mind, is one that was in the “White Pages” collection of LCA articles that referred to an LCA that compared plastic and paper bags. After looking at impacts associated with manufacturing and disposal, paper bags were more impactful; this seems counter intuitive as paper bags come from a renewable, biodegradable resource.

Also, after completing all the stages, I was quite surprised at which buildings were yielding the best results. Consistently the best results came from buildings that were made from concrete, which I would have not considered to be a “green” material before this class. The materials going into the designs were minimal, and often designs with numerous materials had larger impacts.

Also, I don’t know how many buildings are constructed primarily of Wood at UBC, which may not be many as their used to be very strict regulations for wood designs, but there didn’t seem to be a noticeable presence of wood in any of the results. I would have been interested to see impacts from primarily wood designs.

	Graduate Attribute		
	Name	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, and guest speakers organized for the class, and your final project experience.
1	Knowledge Base	IDA = introduced, developed & applied	Because LCA isn't a well known practice, The class required "baby steps" at first, then developed, then applied during the three stages on the Project
2	Problem Analysis	DA = developed & applied	The third stage of the project required substantial analysis of the first two stages.
3	Investigation	A = applied	After analysing data in stage 3, students were encouraged to do more investigation to try further understand results

4	Design	N/A = not applicable	
5	Use fo Engineering Tools	A = applied	Many tools are required for LCAs. Students were taught how to use Athena Impact Estimator, a very useful tool for Impact Analysis.
6	Individual and Team Work	A = applied	Stage 1 & 2, and the first assignment were all completed by individuals. Stage 3, assignment 2, and many different activities were completed in groups
7	Communication	DA = developed & applied	Rob helped students understand how LCA work and how they are applied by using examples of very common, every day products to help us understand the basics first. Then applied it to more technical products like buildings - this helped with communication skills with nontechnical people. Also, Rob provided a number of previous years reports, and his personal reports that were very good examples of technical reports.

8	Professionalism	IDA = introduced, developed & applied	The premise of LCA is to identify environmental impacts; this is of interest to public as the state of our environment is of great concern these days.
9	Impact of Engineering on Society and the Environment	IDA = introduced, developed & applied	The premise of the class is analyzing and quantifying environmental impacts from buildings at UBC via LCA. This is the best tool for examining environmental impacts. Therefore, the class met this attribute.
10	Ethics and Equity	N/A = not applicable	
11	Economics and Project Management	D = developed	The class described how LCA can be used as a decision making tool via benchmarking, weighting, comparisons.
12	Life-long Learning	D = developed	Because LCA is just recently emerging as practice, students now how experience being in the early stages of new practice. This experience will be valuable for the rest of our lives.

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