A Life Cycle Assessment of UBC ICICS Building

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PROVISIO

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

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

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of

UBC ICICS Building

A Report Submitted in Partial fulfillment of the Requirements for CIVL498C

By

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Executive Summary

In demonstration of skills learned during the course of the term, students of CIVL 498C were asked to evaluate the environmental and health impacts resulting from the product and construction phases, i.e. to conduct a limited Life Cycle Assessment (LCA), of assigned building. In this case, the object of the assessment is the ICICS building at UBC. The predominant use of the building, which measures about 9711 square meters in floor area, is research in the domains of robotics, artificial intelligence (AI), and computer animation and other related research fields.

Athena's Impact Estimator (IE) and On-Screen Takeoff programs are the main tools used to complete the LCA study. Inputs in the IE model were re-organized according to a modified CISQ format. Also, models corresponding to level 3, in CISQ format, were created in the IE. Models were then evaluated for their individual and combined effects.

Results were then compared to a UBC wide benchmark which represented the average of all studies by the class. ICICS Global Warming impact for the two stages included in the study is about 50 percent more than the average UBC building. Level-3 Element A22 (Upper_Floor_Construction) contributes half the total impact of the building. Its impact is due mainly to the reinforced concrete floor slabs that cover a substantial surface area.

It is not clear what would the relative (normalized) environmental performance of ICICS if the LCA were extended to the Use stage. The heavy construction environmental toll could potentially contribute to the longevity of the building. Longer service life will not reduce Use impact but it could defer new construction projects for decades. The would-be-impact of deferred projects could be credited to the present building. However, under the present constraints of the study, ICICS building imposes much higher environmental impacts than the average UBC academic building.

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1.0 General Information on the Assessment

1.1 Purpose of the Assessment

An LCA is a study of the environmental impacts of an object throughout all its life stages (cradle to grave). Buildings, which could last for relatively long periods of time, could be more or less sustainable based on choices made during the design, construction and use stages. Hence, an LCA could be a tool that aid in evaluating an existing building, to make decisions regarding the specifics of a given design or to make a choice among design options.

This study is a comparative one in that it compares, for the product and construction stages, the environmental performance of the ICICS building against a UBC benchmark. The benchmark is an average of similarly conducted LCA studies carried out by other students on other academic buildings at UBC. In addition to their academic (teaching) value, the utility of these studies is to enlighten future decision making at the level of university planning. Administrators and others concerned could now evaluate the environmental and economic costs of proposed studied building as a guide.

The study could potentially be of value to a wider audience in the construction industry, provide that they have an access to the specifics of the buildings studied so correlations of costs and size and features used could be properly understood.

For completeness, it must be mentioned here that there are elements of the building that have been excluded from the study, such as flooring, the HVAC system and other finishing details, due mainly to limitations in IE capabilities or the lack of precise information regarding these products. Also based on a previous study[1], it turns out that the most significant environmental impacts are due to Concrete and rebar use in the building.

1.2 Identification of the building

Looking at it from any direction, ICICS (Institute for Computing, Information and Cognitive Systems) is not a minimalist building by any measure. Extensive use of concrete

[1] Cancade, Kipling, "Life Assessment of the ICICS Building", a report submitted in partial fulfillment of course work for CIVL 498C at UBC, 3/29/2010.

is plainly obvious. That means by extension the use of large quantities of rebar and other raw materials.

Located toward the southern end of the Main Mall on UBC campus, at 2366 Main Mall, ICICS comprises many research labs, seminar rooms, offices and comparatively few classrooms. The main impetus of the research conducted at ICICS is amply described by the building's name: Computing related research. Such activities include autonomous robotics, artificial intelligence (known by its acronym AI), computer animation and motion capture as well as related branches of research.

The building took three years to construct. Its floor surface area measures 9711 square meters (m^2), its cost totaled $17.5 million in 1993 dollars, the year construction on the building concluded. That is equivalent to $67.72 millions in today's dollars, assuming a modest 7.0 percent (7.0%) escalation rate.

It must be mentioned here that an annex to ICICS building that was added in 2005 is not included in the current LCA study or its cost.

1.3 Other Assessment Information

Table 1: Other assessment information

Client for assessment	Completed as coursework in Civil Engineering technical elective course at the university of British Columbia
Name and qualification of the assessor	Malek Charif (CEEN Program, UBC) and Kipling Cancade (UBC alumnus)
Impact assessment method	TRACI, an US EPA mid-point impact assessment tool which is incorporated in the Impact Estimator (version 4.2), was used to assess the building environmental impact
Point of assessment	Twenty 20 years has elapsed since the

	building's construction was completed in 1993. It had lasted 3 years.
Period of validity	Five (5) years
Date of assessment	Completed in December of 2013
Verifier	Student work, study not verified

2.0 General Information on the Object of Assessment

2.1 Functional Equivalent

Functional unit is defined as "a performance characteristic of the product system being studied that will be used as a reference unit to normalize the results of the study[2]." In other words, a functional unit makes it possible to quantify the environmental and health impacts of all product systems (products or processes) that fulfill similar functions on a per unit basis. Comparisons of functionally similar products become possible. The choice of functional unit must be consistent with the objective of the study.

For evaluating or comparing the environmental impacts of buildings designed for research and academic purposes, a unit of surface area, e.g. m^2, is an appropriate and logical choice for a functional unit. It is implied here that all floors are of appropriate heights for the activities to be conducted within the building.

Table 2: Functional equivalent definition

Aspect of Object of Assessment	Description
Building Type	An institutional/academic building subject to UBC Technical Guidelines http://technicalguidelines.ubc.ca/technical/divisional_specs.html
Technical and functional requirement	The building houses research facilities and labs, office spaces, seminar rooms and classrooms. It
Pattern of use	Monday through Friday, Saturday and Sunday. Less people per m^2 than

[2] ISO standards 14044

	other academic buildings which comprise more classrooms.
Required service life	All new UBC buildings are supposed to last a minimum of 100 years

2.2 Reference Study Period

As mentioned in the table above, the service (design) life of ICICS building is hundred years. That normally entails setting the service life in the Impact Assessment software to a hundred years. However, since the scope of the study was limited to evaluating and comparing the environmental impacts of the various buildings for the product and construction phases only, the reference study period in the Impact Estimator (IE) model was set to 1 year. That is the minimum period that could be specified in the model to account for all activities from materials extraction on to transportation and to construction without imputing to these stages other effects due to use of the building.

In other terms, referencing EN159787[3], only module A (Product and Construction stages) is covered in this study to the exclusion of module B (Use stage), C (End of Life stage) and D (Benefits and loads beyond the System boundaries).

2.3 Object of Assessment Scope

The ICICS building comprises 4 floors and two penthouses.Describe building from foundation to external work. Why addressing only the structure and envelope and using modified version of CISQ level 3.

Table 3: Building Definition

CIVL 498C Level 3 Elements	Description	Quantity (Amount)	Units
A11 Foundations	Wall and column and spread footings, pile caps, piles, caissons and other elements below slab on grade.		m^2
A21 Lowest Floor Construction	Slabs on grade, Slab thickening below interior bearing walls, Insulation, Shoring.		m^2
A22 Upper Floor Construction	Structural frame, Suspended floors, Stepped floors, Suspended ramps, Columns and beams, Stair construction etc. Excludes floor finishes and suspended ceiling finishes		m^2
A23 Roof Construction	Roof slabs and Roof supporting members,		m^2

[3] EN15978 Standards, http://www.coldstreamconsulting.com/services/life-cycle-analysis/whole-building-lca/en-15978-standard.

	Rafters and Trusses. Columns supporting roof slabs. Eaves soffit, Fascia, Skylight, Roof Finish, Flashing and Coping, Trafficable roof surface.		
A31 Walls Below Grade	Exterior walls below ground floor, Water Proofing and Insulation. Windows and Doors, Interior furring and Wallboard and other Material within the walls assembly		m^2
A32 Walls Above Grade	Exterior walls with facing materials, Exterior finishes, Miscellaneous metals and other elements within the wall assembly, Structural components of walls above grade, Curtain walls		m^2
B11 Partitions	Interior fixed partitions, Miscellaneous metals and other necessities within the wall assembly, Movable partitions, Doors and finishes, Interior glazing and frame, Furrings and Boxing		m^2

3.0 Statement of Boundaries and Scenarios Used in Assessment

3.1 System Boundary

The system boundary delimits between what is included in the LCA study and what is not. It is tightly connected with the objective of the study. All that could affect the results of the study should be contained within the system boundary or its contribution (flow) should be included.

The study being limited here to the product and construction stages, the boundary of the system is drawn to include all the processes involved in these stages and all the flows between them. Also included are the (raw materials and energy) flows that feed into the Product stage and the flows (products and waste) that feed into the Use stage. Following is a description of the two stages included in the study.

3.2 Product Stage

Athena LCI database correlates basic construction materials, such as rebar or aggregates, with environmental impacts generated by extraction, transport and manufacturing of raw materials into final product. Such impacts include energy use, emissions and solid wastes water and land use associated with transport, storage and processing of the raw materials. In Canada, where IE software was originated, the data base is fine-tuned to take account of regional differences[4]. Such differences become significant when considering the energy and transportation burdens assigned to the product system.

[4] "Atehna Impact Estimator for Buildings V4.2 Software and Database Overview". A course handout. April 2013.

Electricity generation and its impact vary widely from region to another. Distances too could range from a few kilometers to many thousands. Construction materials that are made offshore are treated in Athena IE as if they were produced in North America, an exception that is made explicit and which could be remedied in future versions of the software.

When regional specifics are not known or when processes are not uniform across the region, average burdens (energy use and other impacts) are assigned to products. Athens IE documents its sources of information and the year the data was generated to support calculations of average values used

3.3 Construction Stage

Construction stage starts at the gate of the Product stage and ends with the completion of the construction of the building. Impact estimator considers all activities (processes) and flows in between. More specifically, IE takes account of the energy used to transport materials and components from their production site to construction site going through an intermediate regional distribution center. It takes account of water, energy, emissions, wastes and land uses needed to construct elements, e.g. a cast-in-place wall, or associated with on-site construction activities[5].

IE does not account for activities specific to the construction site such as land disturbance or site rehabilitation etc. Also it is not clear how IE deals with stock energy or carbon sequestration in wood products

4.0 Environmental Data

4.1 Data Sources

The significance of the Life Cycle Impact Assessment, LCIA, depend in part on accuracy and applicability of information relating to the energy use and emissions associated with the extraction and/or manufacturing and transportation of elementary

[5] Unkown author. "Athena Impact Estimator for Buildings V4.2 Software and Database Overview." April 2013.

flows (raw materials and elementary products). The aggregate of all such data is the Life Cycle Inventory (LCI) database. Athena Impact estimator relies on Athena LCI and a US LCI databases.

Athena IE, and hence, its LCI database, is created by and managed by the Athena Sustainable Materials Institute, based in Ottawa, Canada. IE LCI database is created using independent research by Athena's group and in collaboration with suppliers of construction materials. The collected data take into account the geographic location where the product is manufactured and the processes used. Both of them are factors that determine the source and amount of energy used as well as the type and quantities of pollutants emitted.

The LCI database is TRACI which was developed by the Environmental Protection Agency (EPA) in the USA. TRACI has a modular design that allows its incorporation into LCA tools[6] such as the case in Athena's IE. The database depends on scientifically defendable models that relate emissions to mainly mid-point categories. The models were constructed to minimize sensitivity to local variations. When location specific data were unavoidable, US averages were used.

4.2 Data Adjustments and Substitutions

As structural elements and materials were inputted in the original IE model, certain assumptions or compromises were made. These compromises or deviations were marked by this study's author as potential areas of improvement. An example of that is the concrete ash content which was modeled as "average" when it could have been an exact value. In the end the model was left as is, for many reasons the first of which is that the actual percentage is not known to the author.

Secondly, there are a lot more significant omissions (detailed elsewhere in this report) that could affect the results of the LCA study a lot more than the adjustment of the percentage of the ash content in concrete. From a skill learning perspective, the exercise of

[6] Bare, Jane C. "Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI". http://www.epa.gov/nrmrl/std/traci/aiche2002paper.pdf.

making the substitution is a worthwhile learning opportunity. No changes were made, the modeling of the basic elements were left as is.

4.3 Data Quality

LCA studies are as good as the data used to complete the analysis and the model. The data in the IE model created to study the performance of the ICICS building came from a few sources. First, there is first the model and the elements entered by the modeller. Then there is the LCI (Life Cycle Inventory) data which is a part of the software. Inaccuracies in the model and the data could be due to many factors: temporal, geographical and non-standardization.

Many of the data is time and place sensitive, processes change from region to another and time to another. Technology and resource availability dictate processes which in turn affect the environmental impact associated with such process. Environmental impact due to the use of electricity is a lot different in BC than in Alberta or China. So processes and product the require electricity should be allocated a different environmental impact depending on their origin. The same could be said of time. Yesterday's technology isn't the same as today or tomorrow's. Modeling elements of a building that was built 20 years- and in other cases a lot further back- is not accurate either. Processes change in time for so many reasons: technology, sources, substitutions etc.

Even within the same geographic area and time frame, processes change from a manufacturer to another, from one supplier to another. While the LCI data base used here does account for regional variations, it uses averages for the region. That means variations from the actual data. So what to do?

Being aware of these sources of variations and their extent is important. Sensitivity analysis is regarded as an important tool is lending credibility to an LCA study[7]. It allows for determining the variations in the LCA results based on variations in the data and in the model.

5.0 List of Indicators Used for Assessment and Expression of the Results

Athena IE feeds the inventory analysis stage (the calculation of the environmental loads: resource use and pollution emissions)[8] into TRACI (Tool for the reduction and Assessment of Chemicals and other environmental Impacts), developed by the US EPA, to generate a complete environmental profile of the studied building, the ICICS in this case.

[7] "Uncertainty Management in LCA." A CIVL498C course handout, 2013.
[8] Buaman, Henrikke and Tillman Anne-Marie. "The Hitch Hiker's Guide to LCA". Studentlitteratur, 2004.

TRACI includes ten impact categories[9] in all, however in Athena IE only seven categories are considered. These categories along with their indicators and possible end-points impacts are summarized in the table below:

Table 4: Impact categories and Indicators

Impact Category	Category Indicator	Possible End-Point Impact
Fossil Fuel Depletion	MJ (mega Joule)	Natural resource depletion
Global Warming	Kg CO_2 Equivalent	Extreme climate, starvation
Acidification	Kg SO_2 Eq	Forestry
HH Particulate- 2.5	Kg $PM_{2.5}$ Eq	Impaired health
Eutrophication	Kg N Eq	Fishery
Ozone Depletion	Kg CFC-11 Eq	Skin Cancer
Smog Formation	Kg O_3 Eq	Respiratory diseases

For many of the category, e.g. the fossil fuel depletion, the cause-effect relationship to their end-point impact is obvious. For others it is less so like in the case eutraphication and fishery. In this instance, eutraphication leads to diminished oxygen in water which leads to the death of the fish.

Category indicators are used to represent the combined effects of multiple emissions that contribute to the same impact category on a per functional unit basis.

6.0 Model Development

CIQS[10] (Canadian Institute of Quantity Surveyors) format was used to assign constituent elements of the building to lower level aggregations. In the hierarchy of CIQS format, "Major Group Elements" is the topmost level followed by "Group Elements", "Elements" and then "Sub-Elements". See below for bills of materials (BOM) for each of the Elements of the ICICS building. Athena's Impact Estimator, version 4.2.0208, was used to analyze all of the models of the Elements and of the Building for their impacts. Discussion of the results is contained in Section 7.0.

[9] Bare, Jane C. and Gloria, Thomas P. "Life Cycle Impact Assessment for the Building Design and Construction Industry". www.bdcnetwork.com. November 2005.
[10] Sianchuk, Rob. "CISQ Elemental Format-modified". CIVL498C course handout, 2013.

The Elements are just groupings of more basic structural and envelope elements. Models of these elements were already identified and their quantities specified by an alumnus of the course (Kipling Cancade).

The modeling process consists of three steps. In step one, take-offs from structural and architectural drawings are obtained using OnScreen Takeoff version 3.6.2.25 software, a tool to speed up the takeoff process. In step two, the actual attributes of take-off elements, such as their physical measurements, composition or carrying capacity, are tabulated in an IE_Inputs document which has a well-defined format. Each take-off element is matched with an Athena LCI basic element (Wall, column, truss etc) and its parameters are specified. When there is not an exact match in IE LCI database, a near-match (in function and physical property) is chosen. Associated parameters are then modified to account for the near-match. For example, if the take-off is a wall of 38 cm thick and 10 sq. meter in area while the options in IE database is limited to walls of unit area and of thicknesses of 20, 30 and 45 cm, the user could chose to model the take-off wall as a 45 cm thick. In this case, the parameters to specify in IE to complete the definition of the wall, namely the width and length of the wall, are modified so that the volumes of the modeled and take-off walls are equal. There could be implied consequences to this "forcing" of match. For example, the rebar quantity may not scale properly to reflect the actual rebar quantity used. For that reason among others, all such modifications and remarks are noted and logged next to actual the take-offs in the IE_Inputs document as well as in the Assumptions document. For the IE_Inputs and Assumptions document see Annex D. Athena IE-program uses the IE_Inputs document to generate a bill of materials (BoM) that constitutes the bulk of materials used in the building. The logging of the inputs is the equivalent of Inventory Analysis in LCA parole.

In step three, the model is run to calculate the impacts of the individual Elements and of the building. The impact analysis is accomplished using the TRACI version 2.2, an US EPA tool that is integrated in IE. The output of the analysis, a report called Summary_Measures, is an assessment of the mid-point impacts for the Element or building modeled. The impacts are expressed in units of mid-point category indicators. Categories and corresponding indicators are shown in Table 4 above.

As part of the current study, a review of the past Assumptions document was conducted to identify improvement opportunities to the model of the building. The review revealed that although there are deficiencies in the model, the reasons stated for them are still valid today and cannot be overcome without a significant effort that is beyond the scope of this study. Nearly all the deficiencies stem from a lack in IE LCI database. Basic system's elements are either missing or their attributes are too restrictive. Possibility for improvements is tied to future expansions in the database of the Impact Estimator.

A building which satisfies the specifications set in the tender document is the equivalent of a "Reference flow" in LCA studies. *A reference flow* is a quantified amount of product(s), including product parts, necessary for a specific product system to deliver the performance described by the functional unit. Example: 15 daylight bulbs of 10000 lumen with a lifetime of 10000 hours. The reference flow is the starting point for building a model of the product system[11]. Product system is the subject of LCA study.

As mentioned above, in the present study, the building and its constituent (level 3) Elements were modeled. Bills of Materials of all Elements of the ICICS building are shown below.

BOM: Element_A11 (Foundations)		
Material	**Quantity**	**Unit**
Concrete 30 MPa (flyash av)	1163.6042	m3
Rebar, Rod, Light Sections	1.4788	Tonnes
BOM: Element _A21 (Lowest Floor Construction)		
Material	**Quantity**	**Unit**
6 mil Polyethylene	3967.7629	m2
Concrete 30 MPa (flyash av)	466.5007	m3
Rebar, Rod, Light Sections	1.5383	Tonnes
Welded Wire Mesh / Ladder Wire	3.3802	Tonnes

BOM: Element_A22 (Upper Floor Construction)		
Material	**Quantity**	**Unit**
#15 Organic Felt	30617.0715	m2
Ballast (aggregate stone)	367813.1794	kg
Concrete 30 MPa (flyash av)	5338.2448	m3
Extruded Polystyrene	17221.1357	m2 (25mm)
Galvanized Sheet	2.6667	Tonnes
Hollow Structural Steel	5.7262	Tonnes
Polyethylene Filter Fabric	0.4557	Tonnes

[11] "The Product, Functional Units and Reference Flow in LCA". Danish Ministry of the Environment. Environmental News No. 70, 2004.

Rebar, Rod, Light Sections	675.5415	Tonnes
Roofing Asphalt	45202.725	kg
Screws Nuts & Bolts	1.1992	Tonnes
Wide Flange Sections	18.229	Tonnes

BOM: Element_A23 (Roof Construction)		
Material	**Quantity**	**Unit**
24 Ga. Steel Roof (Commercial)	589.5599	m2
Galvanized Studs	7.3179	Tonnes
Modified Bitumen membrane	458.1952	kg
Screws Nuts & Bolts	0.1214	Tonnes
Solvent Based Alkyd Paint	34.9877	L

BOM: Element_A31 (Walls Below Grade)		
Material	**Quantity**	**Unit**
5/8" Regular Gypsum Board	134.277	m2
Concrete 30 MPa (flyash av)	38.4521	m3
Joint Compound	0.134	Tonnes
Nails	0.0013	Tonnes
Paper Tape	0.0015	Tonnes
Rebar, Rod, Light Sections	0.9069	Tonnes

BOM: Element_A32 (Walls Above Grade)		
Material	**Quantity**	**Unit**
#15 Organic Felt	1593.1714	m2
1/2" Moisture Resistant Gypsum Board	1423.9855	m2
1/2" Regular Gypsum Board	1742.9949	m2
5/8" Regular Gypsum Board	42.0255	m2
6 mil Polyethylene	2027.221	m2
Aluminum	90.0755	Tonnes
Cold Rolled Sheet	0.0134	Tonnes
Commercial(26 ga.) Steel Cladding	1423.9855	m2
Concrete 30 MPa (flyash av)	268.3834	m3
Concrete Blocks	4033.1863	Blocks
Concrete Brick	69.5476	m2
Double Glazed No Coating Air	2829.2827	m2
EPDM membrane (black, 60 mil)	3704.7784	kg
Expanded Polystyrene	214.83	m2 (25mm)
Extruded Polystyrene	190.6628	m2 (25mm)
FG Batt R11-15	6911.6967	m2 (25mm)
Galvanized Sheet	5.5564	Tonnes
Galvanized Studs	11.7437	Tonnes
Glazing Panel	23.8698	Tonnes
Joint Compound	3.2026	Tonnes
Mortar	14.3435	m3
Nails	3.3445	Tonnes
Paper Tape	0.0368	Tonnes
Rebar, Rod, Light Sections	7.882	Tonnes

Screws Nuts & Bolts	0.6643	Tonnes
Softwood Plywood	2256.0999	m2 (9mm)
Solvent Based Alkyd Paint	19.4555	L
Solvent Based Varnish	30.3692	L
Stucco over metal mesh	1423.3521	m2
Water Based Latex Paint	306.27	L

BOM: Element_B11 (Partitions)		
Material	**Quantity**	**Unit**
#15 Organic Felt	233.6958	m2
3 mil Polyethylene	676.1707	m2
5/8" Regular Gypsum Board	21281.3994	m2
6 mil Polyethylene	634.8679	m2
Aluminum	6.2599	Tonnes
Concrete 30 MPa (flyash av)	441.5544	m3
Concrete Blocks	15246.2174	Blocks
Double Glazed No Coating Air	285.5089	m2
EPDM membrane (black, 60 mil)	412.6872	kg
Extruded Polystyrene	1204.8944	m2 (25mm)
FG Batt R11-15	26056.1087	m2 (25mm)
Galvanized Sheet	24.0745	Tonnes
Galvanized Studs	25.7443	Tonnes
Joint Compound	21.2392	Tonnes
Mortar	291.5722	m3
Nails	2.536	Tonnes
Paper Tape	0.2438	Tonnes
Rebar, Rod, Light Sections	99.3277	Tonnes
Screws Nuts & Bolts	1.2066	Tonnes
Small Dimension Softwood Lumber, kiln-dried	47.4336	m3
Solvent Based Alkyd Paint	41.2692	L
Solvent Based Varnish	3.2599	L
Stucco over metal mesh	208.7857	m2
Water Based Latex Paint	449.7847	L

7.0 Communications of Assessment of Results

LCA results for the ICICS building and Elements for all mid-point categories considered in this study are shown below. The reader is reminded that these results reflect the impacts associated with the first two stages of LCA, namely the Product and the Construction stages. Also, it is important to note that in the graph below, the scale of the y-axis is logarithmic. A linear scale would have made impossible to see some of the impacts.

A lot of information is contained in this graph. Bars of the same color, which represent a given impact category, allow comparisons between the impacts of each of the Elements and that of the building. The first seven multi-colored bars summarize the overall impact of the building across all impact categories. Some of the obvious conclusions to make are the following:

- Element A22 (Upper Floor Construction), contributes the most in all impact categories. The floor slabs, reinforced concrete slabs measuring 9057 m^2, contribute almost 50 percent of the impact of A22 or 25 percent of the total impact of the building.
- The ozone layer depletion potential looks miniscule (in absolute value), so it could have been omitted from the graph altogether.

The disproportionate effect of Upper-Floor-Construction is consistent with the quantities of concrete and rebar used. It could have been exaggerated by miss-sorting. However that does not alter its impact to the total impact of the building. The impacts of the building are not affected by miss-sorting, but by inaccuracies in the entries or by omissions of critical elements. In this study, electrical elements, HVAC system, floor coverings and detailing were omitted for lack of accurate data or inability to model them in Impact Estimator due to limitation of the software. That does not however diminish of the importance of the results discussed here, as the inclusion of omitted parts could only exaggerate the impacts graphed below.

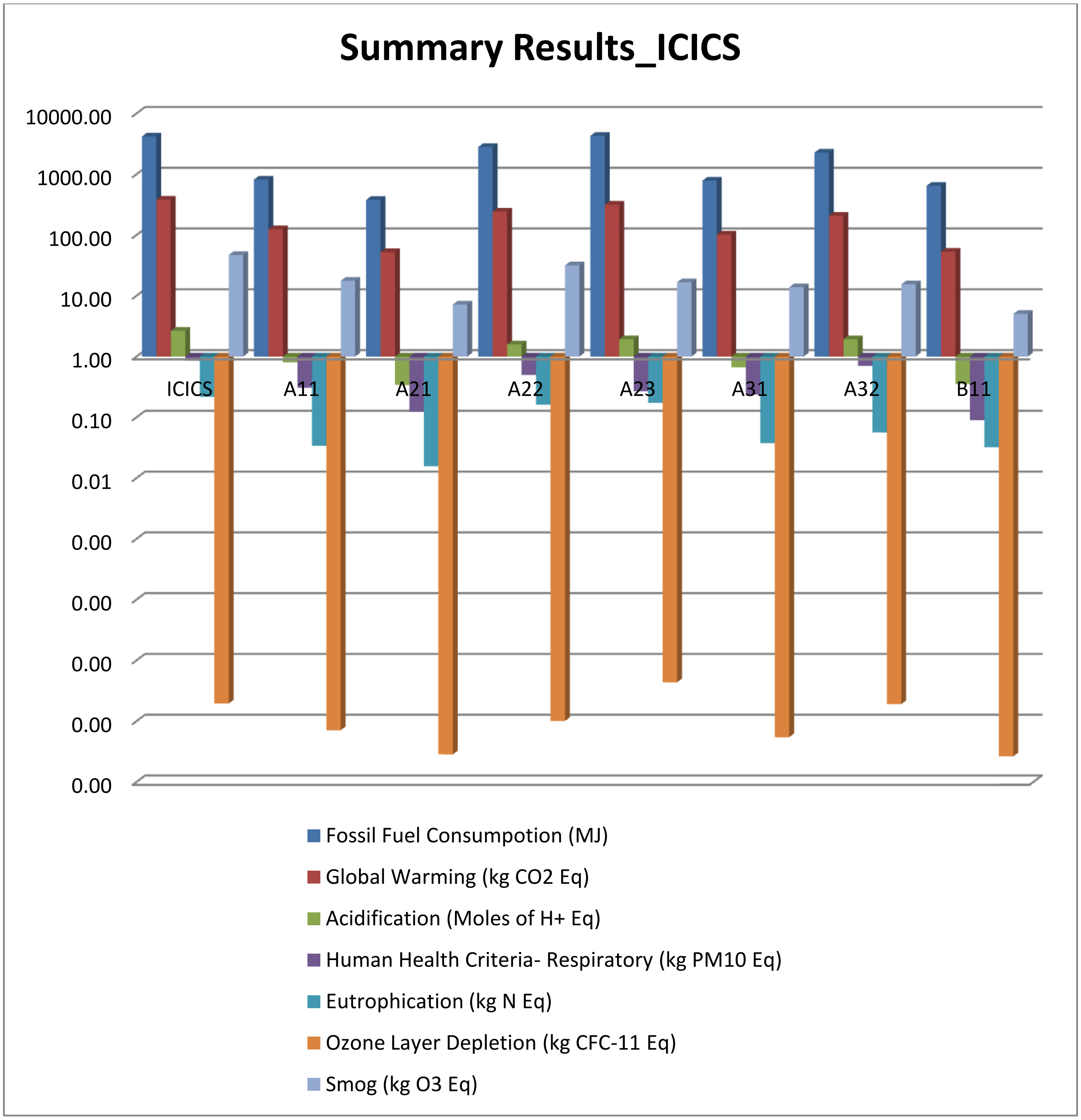

Figure 1: Summary results for the ICICS building

Following are Annexes that generally are not required as part of such building document (report) but could be useful in shedding further light on the results obtained and in providing more details about the work that goes into creating the IE model.

Annex A- Interpretation of Assessment Results

Benchmark Development

Results for an LCA study as expressed above are hard to appreciate. To appreciate the impact of a product system, the ICICS building in this case, its impact must be interpreted in relation to a “standard” that provide an equivalent function. The standard is the yard-stick by which the impacts of a building are measured. A benchmark building is such a standard. For comparisons, ICICS and the benchmark are compared on per-functional-unit basis, in this case a unit surface area. The benchmark building is not a physical one, but rather an average building of the same characteristics as the ICICS. Equivalence of functions and use of functional values are not sufficient conditions for a good benchmark.

Using academic buildings at UBC to construct an average building assure equivalence of purpose, of environment and of modeling tools and methodology. The benchmark is a building whose impacts are the averages of impacts of all the academic buildings included in CIVL498C course study.

UBC Academic Building Benchmark

The environmental impacts of ICICS are then measured relative to the benchmark. These are the normalized impacts of the building. The results are displayed in the graph below for three impact categories: Fossil fuel use, global warming and acidification potentials. The other categories were omitted for clarity, but follow the same trends. The global warming impact of ICICS is more than 50% higher than that for the benchmark. Element A22 (Upper Floor Construction) has a normalized impact that is over two and half times higher than for the benchmark, it is in fact what drives the total up. As mentioned above, the floor slabs are the main culprits and contribute about 25% of the building total.

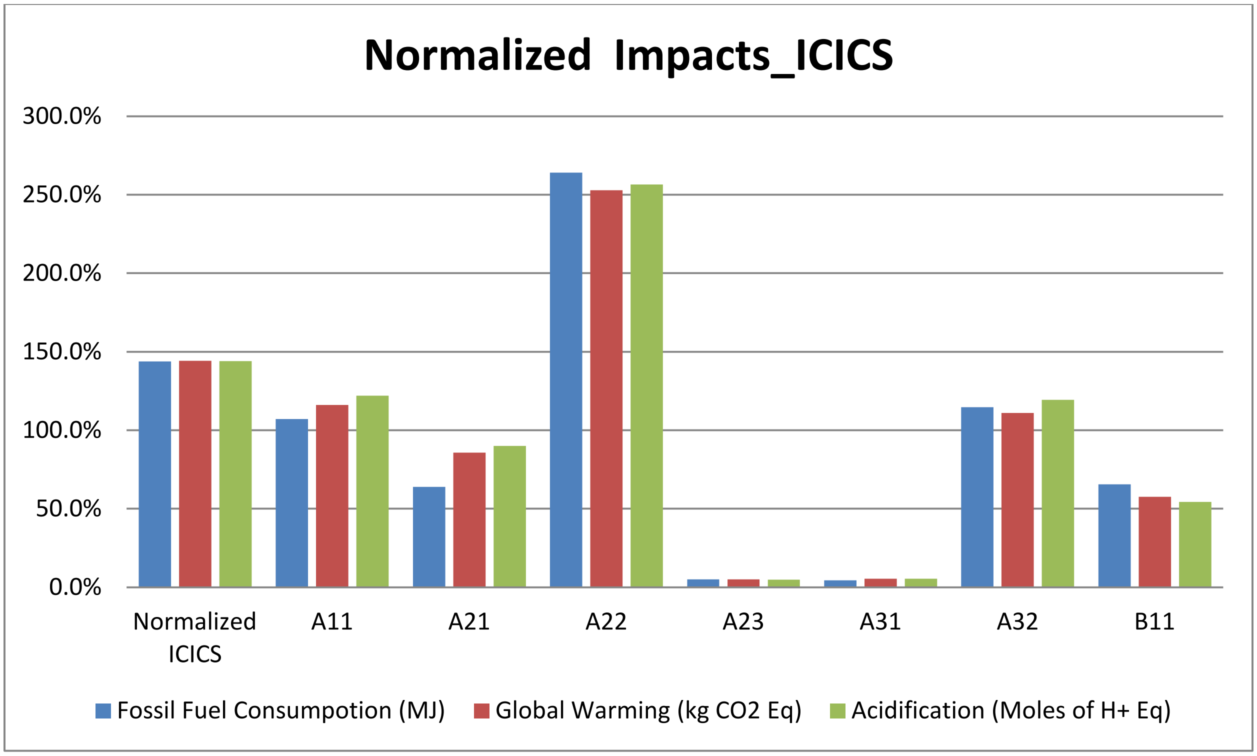

Figure 2: Normalized impacts of the ICICS building

The scatter graph below further illustrates the GWP impacts of the ICICS and other academic buildings relative to the benchmark. The study included over twenty buildings, however not all data was available at the time this report was prepared. Also, some data points were omitted because they were obviously erroneous.

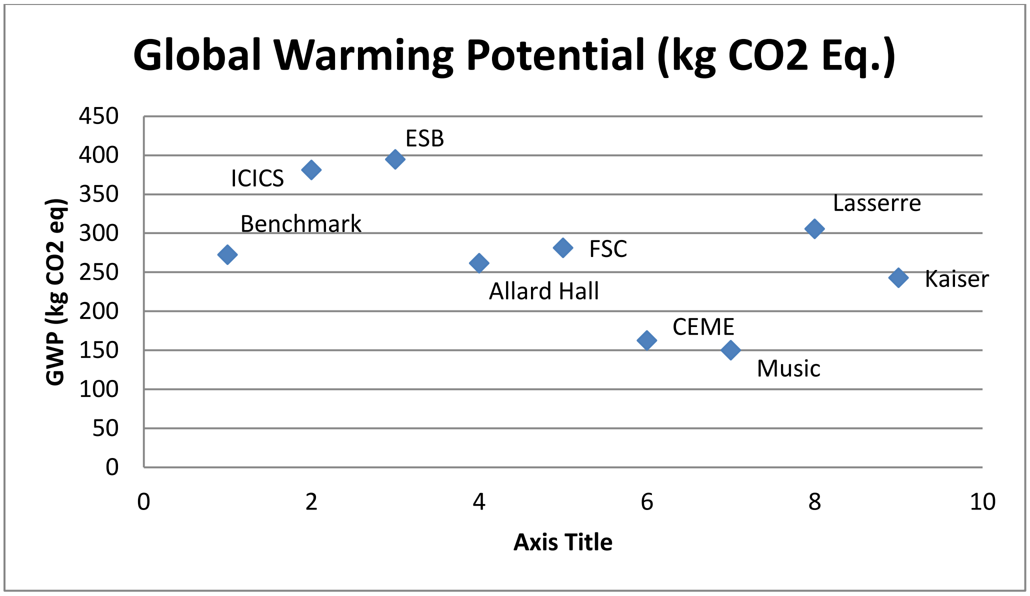

Figure 3: Global warming scatter graph UBC buildings

Another Scatter graph to illustrate the relative cost, in year 2013 dollars, of all UBC buildings included in the study as well as their average (the benchmark). Here too, the cost of the ICICS building is 60 % more than the benchmark. That however is debatable considering that the 7% escalation rate used to calculate the present value may not be realistic.

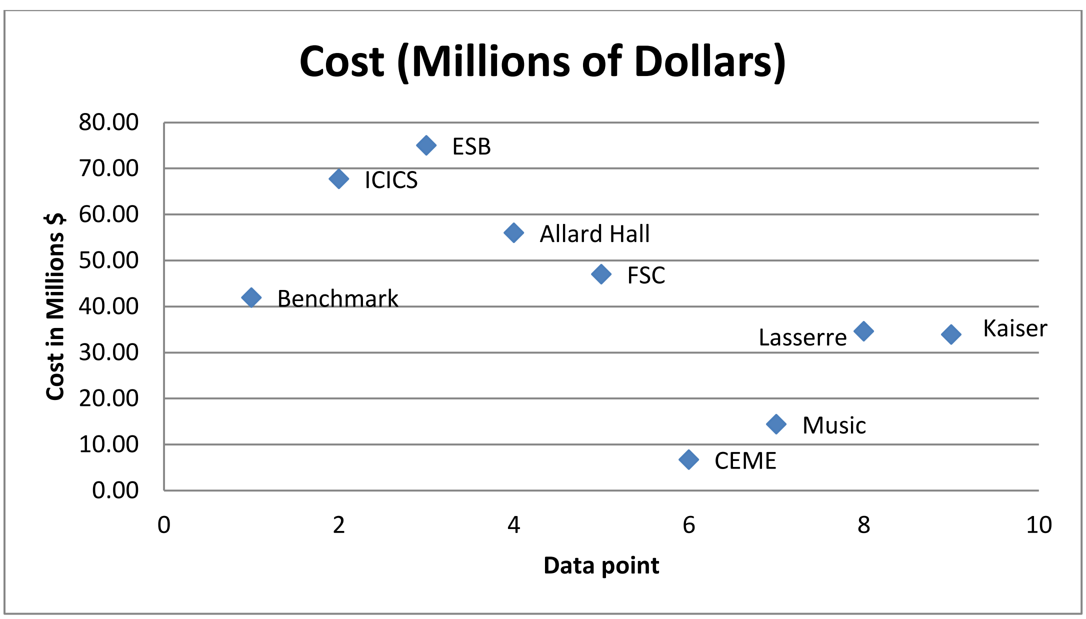

Figure 4: Cost scatter graph

Annex B- Recommendations for LCA Use

Life Cycle Analysis has been slowly coming into view. It is a tool born out of need. Its holistic approach to evaluating environmental and health impacts of existent and future product systems is not just desirable but necessary. Its value is making manifest future consequences hence enabling responsible decision making and action.

It was mentioned above that no firm conclusions could be based on this study in terms of total impacts on the environment, for inclusion of the Use and End of Life stages could turn the picture upside down. In this sense, this study is just a demonstration of what LCA analysis could do, but not a full-fledged study.

At the design stage, an LCA study of alternatives could be a tie breaker at worst or better yet a tool to optimize the design. Simulating the life cycle of a building under design, if done properly, is as clear a picture as possible of the cumulative environmental effects imposed by the proposed design. Of course, this is contingent on conditions such as accurate modeling of the building and use of exact or regionally-averaged product data. LCA studies are judged by the quality of data used in them, also by the choice of benchmark used for comparison. Sensitivity of results to uncertainties in the data will determine the validity and value of the LCA.

Another issue to consider when using LCA for decision making is the relative importance of environmental impacts. In this report, there is no questions like "what matters more: global warming or acidification or energy use?" That is, even for the same building, there is no comparison across impact categories. In fact impacts are expressed in different units (CO2 Eq. or MJ etc) altogether. The importance of categories is simply relative. In a class experiment, most of the students agreed that global warming warranted immediate attention despite of it being a global problem! But in general, prioritization of impact categories is a matter of personal (organizational) preference.

A weighting factor assigned by a group to an impact category designates it priority to them. Weighting factors are decided on by vote or some other method. By normalizing the impacts and giving them weighting factors, a single environmental score could be calculated for the design under consideration. Obviously, it is best to decide on weighting factors ahead of conducting the LCA.

At the level of UBC, a university that pledged to become carbon neutral and like to become a beacon for environmental research, LCA should be an integral part of the campus planning office. Studies like the ones conducted for this course make for a good reference to use to screen designs for environmental impacts and cost. The quality of the studies however is doubtful. A thorough check of every one of them is necessary by other students under direct supervision of the project manager: the instructor.

Annex C- Author Reflection

My first exposure to LCA was when I heard a talk by the (CIVL498C) course instructor –Rob Sianchuk- at another class on sustainability and environment. It was a revelation to me. The idea of a holistic approach to evaluating anything has a lot of intrinsic value. It makes you wish politicians and national decision makers thought in those terms. So, yes LCA sounded like the logical approach to analyzing the impact of systems, but it was also obvious that LCA has some ways to go before maturity. Applicable data is not always easy to come by and the tools are not exactly intuitive. But all that comes with time and research.

As a part of my CEEN program studies, I have to take another course that deals with LCA from an energy perspective. So I could not pass the opportunity to take CIVL498C as well. The two courses which are run totally differently could be a way to sub-specialize. I can't say it has worked…yet. But I could say, I do see the potentials for LCA to become an integral part of a design package. Just the same as stress analysis, fluid dynamics and heat transfer analysis software became integral modules of mechanical design tool packages.

The concept of LCA as being applicable to everything that has environmental impact is undisputable. But for LCA to progress fast, it has to specialize. Why? Because flexibility in a general purpose LCA software means a steeper learning curve. Experts in a given field want something "intuitive" for them. Athena's IE focus on the construction industry is the right approach to LCA. User friendliness and integration with a tool like OST would be great.

I've written before about including time as another parameter to consider when evaluating the environmental impacts of buildings. That is equivalent to defining a "reference flow" for the study. A building that, by virtue of its construction, could reasonably be assumed to last twice as long as the specs call for ought to be credited for "avoided" environmental impact.

And finally:

	Graduate Attribute M. Charif	Meng Program	Select the content code most appropriate for each attribute from the dropdown menue	Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.		The report required some knowledge of a specific engineering field, namely construction. It also required the application of specific emerging engineering tools (Athena Impact Estimator and OnScreen Takeoff software)
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.		In evaluating and verifying the validity of certain results there had to be some analysis, comparisons and calculations.
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.		There was a need for data analysis and identification of false 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.		Not so applicable in the context of this course
5	Use fo Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.		Team I worked in was multi-displinary. The course emphasized both individua;l and team activitties.
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.		The final report did in fact require developped communication schemes to expalin ideas, concepts, models and results.
8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.		Hosting practicing professionals in the classroom was a good way to convey these ideas.
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		The course itself has for focus the impact of engineering constructs on the environment and the health of people. There were occasions where professional and legal responsibilities discussed.

Annex D- Impact Estimator Inputs and Assumptions

The IE_Inputs and IE_ Assumptions documents are attached as separate folders for better quality. Both documents are included in the paper report.