Life Cycle Assessment Improvements of Frederic Lasserre Building at University of British Columbia

Andrew Russell

University of British Columbia

CIVL 498C

November 18, 2013

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.

If further information is required, please contact the course instructor Rob Sianchuk at rob.sianchuk@gmail.com

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EXECUTIVE SUMMARY

Previous cradle to gate life cycle assessment work on the Frederic Lasserre building of UBC was restructured and improved. This study took the previous Lasserre Impact Estimator model, reorganized the buildings construction to CIQS format, thoroughly inspected the previous model for material, property type, and geometric flaws, carried out improvement strategies regnerated the IE model with results, and finally developed a campus wide benchmark for comparative assertion.

From life cycle stage results it was clearly demonstrated that the product stage weighs heavily on impact for a cradle to gate analysis. From a CIQS elemental standpoint A22-Upper Floor Construction, A32-Walls above Grade and B11-Partitions are noted as hotspots in the Lasserre building contributing the majority of the seven impact categories assessed.

The Lasserre building in comparison to the developed benchmark performed below average as a whole and had particularly weak performance in elements B11-Interior Partitions and A32-Walls above Grade.

Global warming potential was determined to be the most salient impact from class aversion survey results. This led to a GWP versus construction cost (2013 $). In this comparison it was found that older UBC buildings tended to perform better than newer ones.

The results and recommendations from the study and all others in the collective project aid towards the operation of LCA methods in practice at UBC. Useful for the Universities sustainability ambitions and targets, the study has also provided students with the applicable hands on experience at tackling the expanse nature of a building LCA.

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1.0 General Information on the Assessment

Beginning with defining a clear purpose, intended use, motivation and audience for this assessment is valuable to prioritize the objectives and focus. These aforementioned parameters shape the preliminary framework to which the assessment is built around. A brief overview of the Lasserre building is also provided along with other assessment information such as assessment method, authors and date for any future reference or clarification.

1.1. Purpose of Assessment

As with any LCA study the primary purpose is rooted at quantifying the environmental impact of the object of assessment with respect to a referencing measure (functional unit). The intended use of this assessment is within a regional context. The study is one part of a whole LCA database being formulated for UBC buildings. As such, this study is used in establishing a benchmark for UBC buildings. This benchmark is very valuable for strategic planning and education within the campus' array of historic, new and future building construction. The study helps define and begins to answer important policy maker questions such as: 'What have we been doing?' and 'Where do we go?' Each building study can also be used at an individual level by providing insight into the most cost-effective measures to address environmental and economic potential (i.e. Energy & GWP savings).

Both internal and external pressures for UBC define reasons for carrying out this LCA study. Internally, UBC set forth a comprehensive Climate Action Plan in 2010 to maintain its image ''as an established leader in energy and climate management."[1] The plan has set forth aggressive GHG

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[1] UBC Sustainability. (2010). Climate Action Plan. Retrieved from http://sustain.ubc.ca/campus-initiatives/climate-energy/climate-action-plan

emission reduction targets that exceed provincial measures. In comparison to 2007 levels the plan mandates a CO2 equivalent reduction timeline as such:

Strategies to meet these targets have been divided into six categories with two of these categories falling into the building life cycle realm: 'Campus Development and Infrastructure', and 'Energy Supply and Management.[2] Two years on from the CAP inception has seen specific projects like Ecotrek and Building Tune-Up have positive impacts and now the focus shifts to searching for new and innovative projects to succeed these. These internal pressures of maintaining the UBC sustainability image, one that prides itself on meeting Kyoto targets in 2007, contributes greater reason for a study of this nature.

Externally there is pressure for comparative assertions with other competing sustainable Universities. A report from the Sustainable Endowment Institute ranked North American Universities across nine categories of sustainability, of which 'Climate Change and Energy' and 'Green Building' were both present factors. Figure 1 shows UBC is ranked closely amongst neighbouring schools such as UofC, UofT and UofW. A resourceful, informative LCA building database can aid UBC sustainable decision making to gain an edge in this friendly rivalry.

The final motivator for this study is cost. Financial payback of investment is attractive to the campus. Providing insight into how and what construction to choose for the most cost-effective, energy efficient building is a valuable asset.

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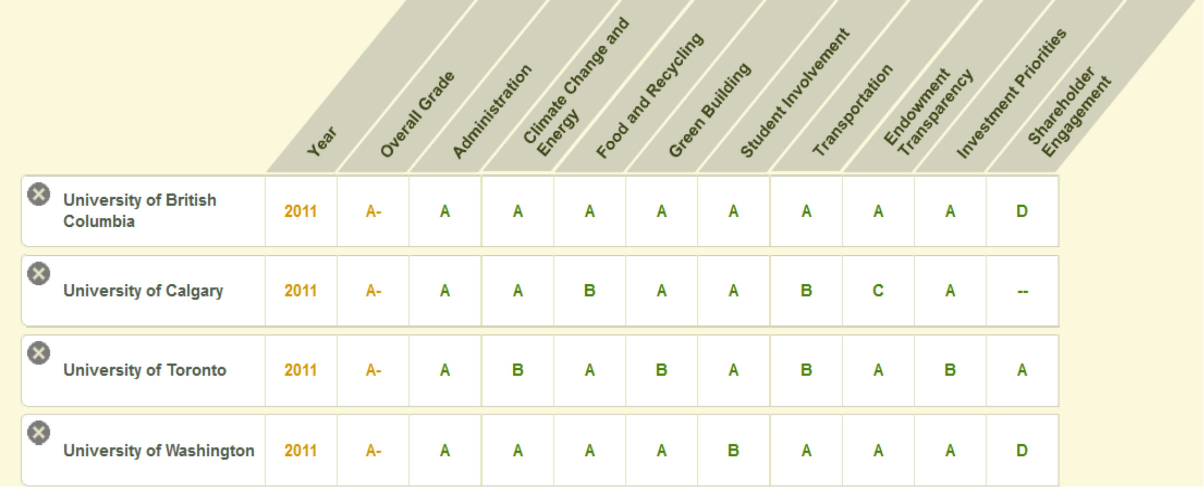
[2] UBC Sustainability. (2010). Climate Action Plan. Retrieved from http://sustain.ubc.ca/campus-initiatives/climate-energy/climate-action-plan



	Year	Overall Grade	Administration	Climate Change and Energy	Food and Recycling	Green Building	Student Involvement	Transportation	Endowment Transparency	Investment Priorities	Shareholder Engagement
University of British Columbia	2011	A-	A	A	A	A	A	A	A	A	D
University of Calgary	2011	A-	A	A	B	A	A	B	C	A	--
University of Toronto	2011	A-	A	B	A	B	A	B	A	B	A
University of Washington	2011	A-	A	A	A	A	B	A	A	A	D

Figure 1. Sustainable Endowments Institute University Report Card Comparison[3]

Comparative assertions exist within the purpose of this study both internally as benchmarking and externally as a way to display a strong sustainable persona to other schools and institutions. Stakeholders involved in campus policy-making, building development and infrastructure form the primary audience for this study. These parties include but are not reserved to UBC Sustainability, Building Operations and UBC Board of Governors. Secondary audiences include campus faculty and staff, involved architects, engineers, and contractors, federal and provincial government, sustainable NGO's, neighbouring Universities, and any LCA enthusiast.

1.2. Identification of Building

Opening its doors in 1962 the Frederic Lasserre building, commonly referred to as 'Lasserre', is located at 6333 Memorial Road. Situated on the corner of Memorial road and Main Mall, the building was designed by Thompson, Berwick & Pratt of Vancouver with flair for the international

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[3] Sustainable Endowments Institute. (2011). The College Sustainability Report Card. Retrieved from http://www.greenreportcard.org/compare

style of the fifties.[4] Standing 17.88m tall with a gross floor area of 5,276 m^2 the building is utilized by several parties including Community Planning, School of Architecture and General University Facilities.[5] As its main intended use was for Architecture the building is aptly named after Dr. Frederic Lasserre who was the programs first director.

The building is of concrete structure and slab and has three entrances located at the East, West and North facades. In terms of use of space the ground floor houses classroom and tiered lecture halls, the fourth floor contains administration offices while the second, third and basement levels offer studio and design work spaces.

Throughout the project timeline of 1960-62 the documented cost was $1 million, in present value equivalency this would amount to $34.7 million using a discount rate of 7.2%.[4] This discount rate was based off BC education norms. Sources of funding included A.W. Trueman contributing 50% while the other half was met by Canadian Council grants, UBC Development Fund, and the Koerner Foundation. Figures 2-6 illustrate a timeline of archived photographs from the UBC Library.

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[4] UBC Building Archives. (2013, July 30). Frederic Lasserre Building. Retrieved from http://www.library.ubc.ca/archives/bldgs/fredericlasserre.htm

[5] Thompson, Berwick, Pratt & Partners Fonds. (1960). Frederic Lasserre Architectural Building Drawings.

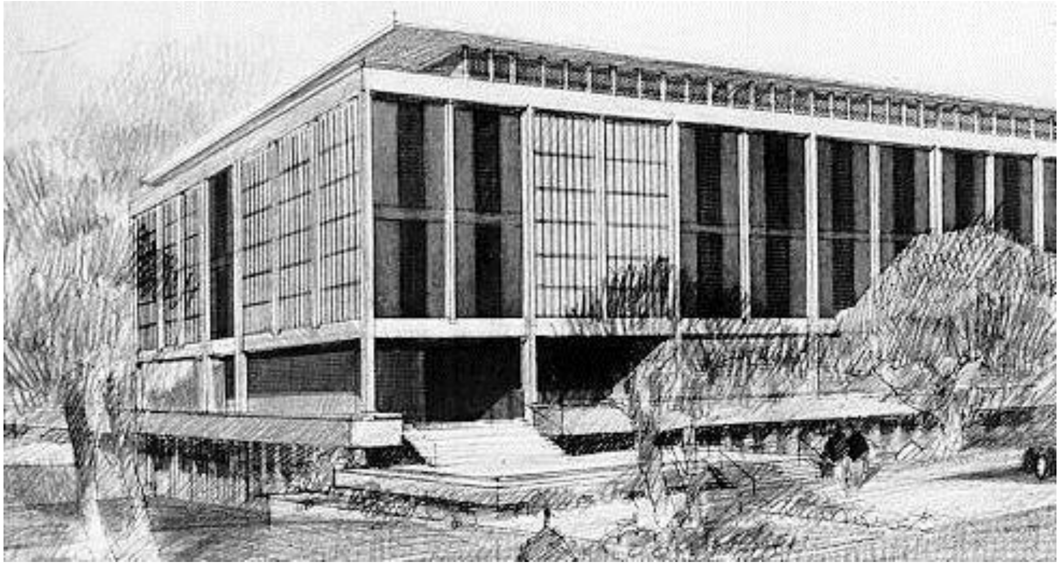

Figure 2. Design Sketch of Lasserre Building circa 1960 [6]

Figure 3. Lasserre Ground Work [7]

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[6] UBC Library Digital Photograph Collection. (1960). Sketch of Lasserre Building. Retrieved from http://digitalcollections.library.ubc.ca/cdm/singleitem/collection/arphotos/id/872/rec/4

[7] UBC Library Digital Photograph Collection. (1961). Construction of Lasserre Buildling. Retrieved from http://digitalcollections.library.ubc.ca/cdm/singleitem/collection/arphotos/id/13904/rec/70

Figure 4. Lasserre Foundation Construction[8]

Figure 5. Lasserre Frame and Floor Construction[9]

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[8] UBC Library Digital Photograph Collection. (1961). Construction of Lasserre Buildling. Retrieved from http://digitalcollections.library.ubc.ca/cdm/singleitem/collection/arphotos/id/13902/rec/68

Figure 6. Lasserre Finished Construction[10]

1.3. Other Assessment Information

Table 1 outlines further assessment information that may be useful for clarification of details in future work.

Table 1. LCA Assessment Information

Client for Assessment	Completed as coursework in Civil Engineering 498C, a technical elective course at the University of British Columbia.
Name and qualification of the assessor	Andrew Russell – Clean Energy Engineering (2013) Sahar Ranjbar – Civil Engineering (2010)
Impact Assessment method	Mid-point impact method using US EPA TRACI (2012, version 2.1).
Point of Assessment	As of 2013 the Frederic Lasserre building is 51 years into its lifetime
Period of Validity	5 years.
Date of Assessment	Completed in December 2013.
Verifier	Student work, study not verified.

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[9] UBC Library Digital Photograph Collection. (June 19, 1961). Construction of Lasserre Buildling. Retrieved from http://digitalcollections.library.ubc.ca/cdm/singleitem/collection/arphotos/id/32954/rec/44

[10] UBC Library Digital Photograph Collection. (Jan 6, 1962). Construction of Lasserre Buildling. Retrieved from http://digitalcollections.library.ubc.ca/cdm/singleitem/collection/arphotos/id/32959/rec/49

2.0 General Information on the Object of Assessment

Within this section the functional unit and equivalent are defined. A description of the reference study period with discussion on its deviation also follows. The final component to the section is defining the scope of the object of assessment by CIQS level 3 elemental construction format.

2.1. Functional Equivalent

Explicitly stating the functional unit is important to establish the scope of the study that will seek to consider its environmental impacts. The functional unit defines what precisely is being investigated and quantifies the performance delivered by the product system. It provides a unit of reference or scale to which all flows within the system boundary can be related. It also enables results to be comparatively asserted with competing products or services.

The declared functional unit, subject to analysis, in this LCA is defined as follows:

→ Cradle to gate construction of 1 m^2 of conditioned floor area.

Table 2. Functional Equivalent Definition

Aspect of Object of Assessment	Description
Building Type	Institutional/Education. Classroom, office, and studio design spaces.
Technical and functional requirements	From a regulatory perspective the construction is required to meet each of British Columbia's Building, Fire and Plumbing Codes. Additionally the construction must meet municipal building by-laws of the City of Vancouver. The client, UBC, requires all design, construction and renovation of University-owned institutional building's meet UBC Technical Guidelines. LEED Gold certification or equivalent is required for new construction or major renovations on institutional buildings, including 11 points from Energy & Atmosphere which states energy performance criteria be 32% and 28% below ASHRAE 90.1-2007 for new construction and major renovation respectively.[11]

	UBC in-house REAP Gold certification is required for new residential construction. [11] Finally, an absolute energy density target [kWh eq/m2/yr] shall be met during the design phase. [11]
Pattern of use	Design Occupancy=5276m^2/1.85m^2 per person = 2852 people.[12] Space Use Pattern: Ground Floor Classroom and Lecture Halls, Basement and Second Floor Design/Studios, Fourth floor Office space, Third Floor restricted access.
Required service life	With reference to LCA practioner Stefan Storey and LCA building literature a reasonable baseline scenario service life for Lasserre is 60 years[12, 13]. However, considering this is a 'Cradle to Gate' study a required service life of 1 year is used.

No documented occupancy was available for Lasserre from UBC Records or Campus and Community Planning. Therefore, an estimate was made from the City of Vancouver's Building Fire bylaw, sentence 2.7.1.3 on determining occupant loads. The bylaw recommends assigning 1.85 m^2 of floor space per occupant for classrooms, reading and writing rooms, and lounges.[12]

2.2 Reference Study Period

As this LCA study only accounts for impacts of 'Cradle to Gate' the reference study period deviates from the service life of the building to zero years. Zero years implies the reference study period closes once construction is complete. However, due to modeling constraints within the Impact Estimator (requires a non-zero value) a service life of 1 year is used and all impacts downstream of construction are negated. Modules B, C, and D of EN 15978 respectively include use, end of life and supplementary information stages. These stages are all downstream of the construction stage where the reference study period has been previously stated as closing. Module D is often situated outside the system boundary however modules B and C are often considered in LCA studies. It was decided that this study would not include modules B and C due to reasons such as:

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[11] UBC Sustainability. (2012). Green Buildings. Retrieved from http://sustain.ubc.ca/campus-initiatives/green-buildings

[12] City of Vancouver. (2004). Fire & Rescue Services – Calculation package occupant load calculations for assembly occupancies and licensed beverage establishments. Retrieved from http://vancouver.ca/files/cov/occupancy-load-calculation-package.pdf

→ Varying occupancy

→ Unpredictable occupant behaviour

→ Different building types (lab versus lecture hall) having adverse effects on use impacts

→ Varying services lives

→ Construction Materials focus

An interesting side note for future studies would be the occupant behavioural work being investigated by PhD candidate Stefan Storey. Stefan is looking at wireless phone data being a method of accounting for occupancy and occupant behaviour within UBC buildings[13]

By accounting for only the product and construction stages (Module A) the study is consistent across all campus building types and a reasonable benchmark can be developed.

2.3 Object of Assessment Scope

The Lasserre building is a concrete structure and slab building. Table 3, adapted from previous student work on the building depicts the general building construction organized by relevant CIQS level 3 elements for this report[14].

Table 3. General Building Construction Characterization by CIQS Level 3 Element

CIQS Level 3 Element	Characteristic
A11 Foundations	Concrete cast in place strip and pad footings with 6mm polyethylene vapour barrier
A21 Lowest Floor Construction	Concrete Slab on Grade 6'' on well consolidated gravel fill. Checkerboard Pattern
A22 Upper Floor Construction	Concrete precast double T floor, Concrete column and beam
A23 Roof Construction	Flat asphalt built up roof, slab varies 4'' and 8'' thick
A31 Walls Below Grade	10'' concrete block
A32 Walls Above Grade	10'' concrete block with 4'' glazed brick on exterior surface
B11 Partitions	10'' concrete block with ½'' GWB either side

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[13] Storey, Stefan. Personal communication, November 6, 2013.

[14] Ranjbar, S. (2010) Life Cycle Assessment of Frederic Lasserre Building at University of British Columbia. CIVL 498C, University of British Columbia, Vancouver, BC.

The CIQS elemental construction format was adopted for this study to be congruent with Canadian quantity surveyors and building metrics. A modified version of Level 3 CIQS was adopted to help simplify the analysis. In general all finishes were left out of the analysis. For example, within B11-Partitions all interior floor, ceiling and wall finishes (B21-23) were considered outside scope. Likewise fittings and equipment B31 and B32 were also excluded. It was felt that the majority of the building impact would be addressed by focusing on the seven elements described in Table 4 with reference to the Lasserre building.

Table 4. Building CIQS Level 3 Definitions

CIVL 498C Level 3 CIQS ELEMENT	Description	Unit of Measure	Quantity	Units
A11 Foundations	All wall and column strip footings. Average (9%) Fly ash, reinforced.	Area of SOG	1055	m^2
A21 Lowest Floor Construction	6'' Slab on grade at basement. Thickened to 9'' below interior bearing walls	Area of SOG	1055	m^2
A22 Upper Floor Construction	All columns and beams above SOG but not supporting roof. Suspended floors excluding roof. Stair structure.	Area of all upper floors	4221	m^2
A23 Roof Construction	Columns and Beams supporting roof. Suspended roof, including membrane system, insulation, moisture and vapour barriers	Area of Roof surface	1055	m^2
A31 Walls Below Grade	Exterior wall construction below grade and above SOG. Interior GWB and exterior insulation and vapour barrier.	Surface area of exterior walls below grade	798	m^2
A32 Walls Above Grade	Exterior wall construction above grade. GWB and exterior assembly materials. Exterior glazing and doors.	Surface area of exterior walls above grade	2020	m^2
B11 Partitions	Fixed partitions. Interior doors and glazing	Surface area of interior walls	3013	m^2

3.0 Statement of Boundaries and Scenarios Used in the Assessment

This section sets the system boundary for the study and describes the process information for the two stages within the established boundary, product and construction process.

3.1. System Boundary

In this study Figure 7 illustrate that modules A1-A5 are included within the system boundary. Each module includes supporting upstream and downstream processes. A general description processes involved in each module is provided in Table 5.

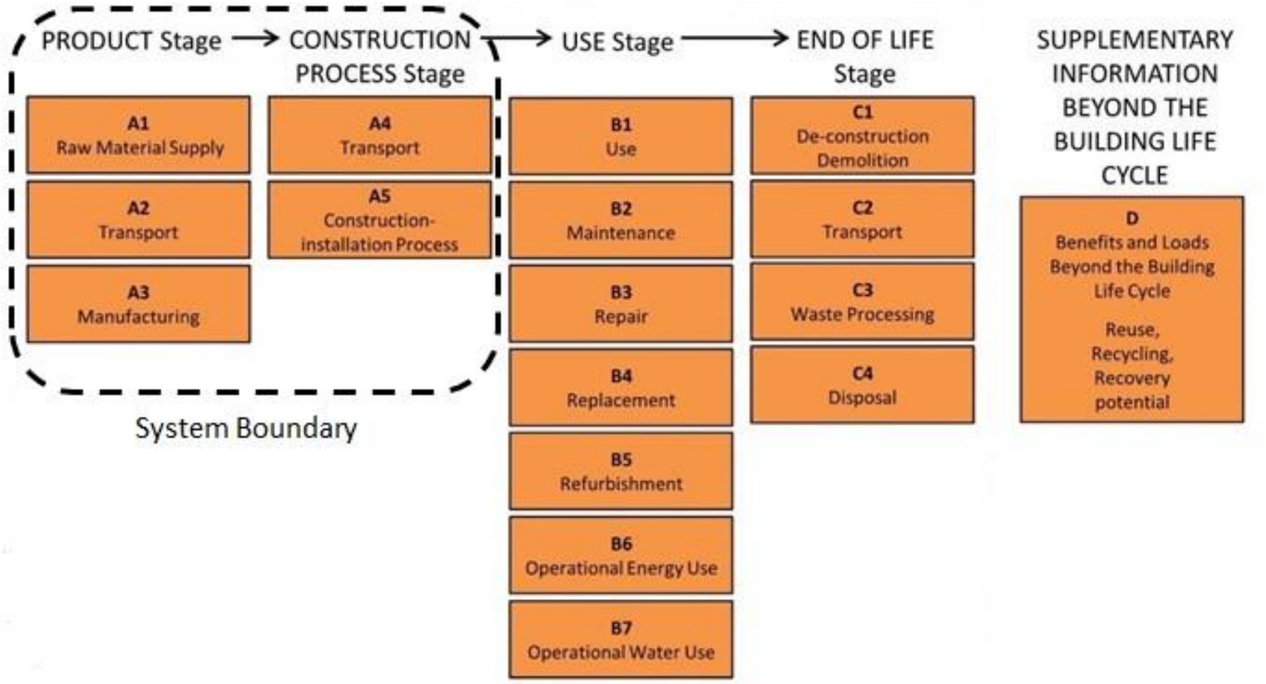

Figure 7. Defined System Boundary[15]

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[15] Coldstream Consulting. (2011). EN 15978 Standard. Retrieved from http://www.coldstreamconsulting.com/services/life-cycle-analysis/whole-building-lca/en-15978-standard

Table 5. Modules A1-A5 Description

Module	Upstream Processes	Downstream Processes
A1- Raw Material Supply	Transport to site, fuels to extract.	Waste material disposal, slag, water treatment, storage.
A2 – Transport (Material)	Transport fuel extraction, processing, transmission.	Maintenance and replacement parts for transport trucks, trains etc.
A3 - Manufacturing	Plant energy extraction, processing, transmission.	Energy to dispose, treat or store waste, water treatment. Packaging materials embodied energy
A4 – Transport (Construction)	Transport fuel extraction, processing, transmission	Maintenance and replacement parts for transport trucks, trains etc.
A5 – Construction Installation Process	Installation and construction fuel extraction, processing, transmission.	Energy to remove all site equipment and waste materials.

3.2. Product Stage

IE accounts for all energy, direct and indirect, used to transform or transport raw materials into products, and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources (natural gas).[15] In addition the IE captures the indirect energy use associated with processing, transporting, converting and delivering fuel and energy plus the operating energy.[16] Table 6 summarizes the process information considered in the production modules.

Table 6. Product Stage Process Information Summary

Product Stage Flows	How does IE Handle It?
Extraction of raw materials	All Energy, fuel and additional materials (water) for extraction.
Manufacturing of products	Process energy impact and its upstream demands, waste management impact. Recycled content. Does not include fixed capital equipment impact.

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[16] Athena Impact Estimator for Buildings. (2013). Help topics – Total Primary Energy Consumption.

Generation of energy input	Region specific grid of energy use mix. Hydro, thermal coal, gas fired plant, biomass, wind, etc. Inherent energy in raw or feedstock materials commonly used as energy sources also accounted for.
Production of ancillary materials	Included. Similar to raw material.
Packaging	Included. Raw materials and energy requirement for packaging.
Transport up to production gate & to construction site	Region specific transportation grid assigned. I.e. Varying % of light/heavy truck, train, barge etc. Does not include employee transport.
Collection and transport of waste to disposal	From WF a mass is assigned per material to be collected and transported.
Waste management during product and construction stages	Product and construction waste factor (WF) for each material calculated as a % of the amount. Net amount is added to BOM. Net Amount = Amount + (Amount x WF)[17]

3.3. Construction Stage

Table 7 summarizes the process information considered in the construction modules.

Table 7 Construction Stage Process Information Summary

Construction Stage Flows	**How does IE Handle It?**
Transport from manufacturing gate to construction site	Region specific transportation grid assigned. Does not include transportation of employees to site
Storage of products	Energy required maintaining product integrity. Does not include land use.
Installation of the product into the building	Construction Effects: Assumes that a crane is used to move all material through distance of half the building height.
Waste management processes on site and disposal	Construction waste factor gives mass of waste. Process impacts resultant of mass to manage and dispose. Decomposition of materials in landfill is not accounted for.[18]

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[17] Athena Impact Estimator for Buildings. (2013). Help topics – Extra Materials.

[18] Athena Sustainable Materials Institute. (2013). IE for Buildings. Retrieved from http://www.athenasmi.org/our-software-data/impact-estimator/

4.0 Environmental Data

Data is always sourced and collected with uncertainty. Awareness of the quality and what types of uncertainties exist is useful when drawing appropriate recommendations. Sources of data for this study are sited, adjustments to data within the previous student's findings are described and the quality of data is assessed.

4.1. Data Sources

The Athena Institute LCI database was formed to help move the construction sector and product suppliers towards LCA. Its' vision is clear: create a verifiably sustainable built environment. [19] It compiles averaged industry data, actual and modeled, for production of building materials, energy use, transportation and on-site construction. The databases are regionally sensitive, considering technology, transportation, recycled content, seismic effects and electricity grid variances by region. Industry questionnaires are a common method in sourcing data from industry by Athena. The aim is to account for 99% of the mass of a product, 99% of the energy used in its production and any environmentally sensitive flows.[20] Data inaccuracies can arise in Athena from the techno-sphere. Questionnaire subjects often do not have access to data relevant to input/output flows from their production processing. In this case secondary sources are used from LCA-practioner tools such as national databases or data sets like Natural Resources Canada.

Athena is managed by a team of LCA experts while financial support is met from members and sponsors of the institute which include construction sector practitioners, product manufactures and

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[19] Athena Sustainable Materials Institute. (2013). About ASMI – Vision. Retrieved from http://www.athenasmi.org/about-asmi/vision/

[20] Trusty, W. (2010). An Overview of Life Cycle Assessments: Part One of Three. Building Safety Journal. Volume VII, No. 8.

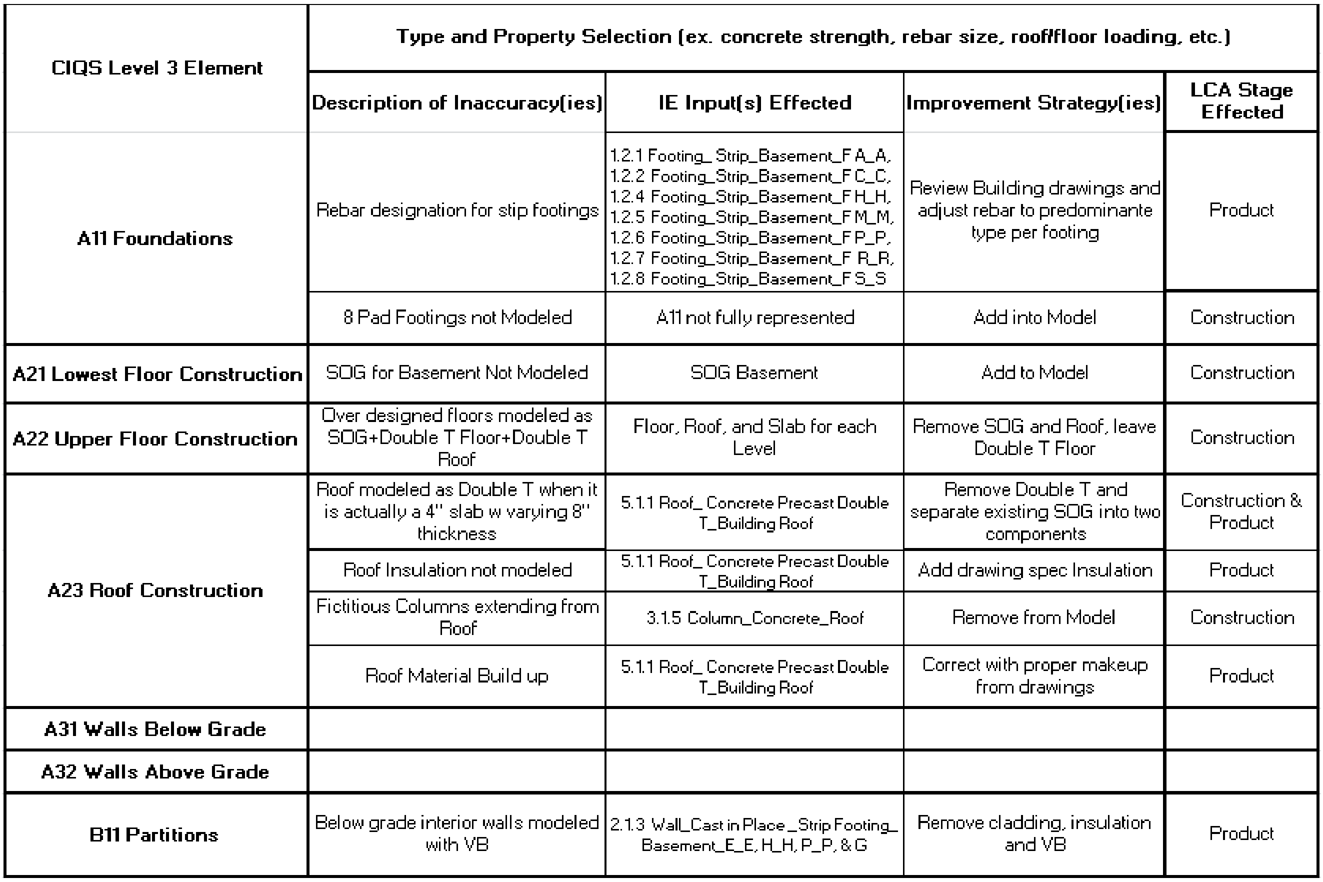
policy makers. A list of sponsors can be found on the institute's website as well which includes Natural Resources Canada and Green Building Initiative.

The US LCI database is a publicly available database created by the National Renewable Energy Laboratory in 2001 for LCA practitioners. The goals of the database project are centered towards data quality and transparency while expanding LCA acceptance. The database is sourced and managed by the NREL's high-performance buildings research group collaborating with government stakeholders, and industry partners. The Athena Institute is listed as a principal supporter along with the U.S. Department of Energy and the U.S. Navy amongst many others.

4.2. Data Adjustments and Substitutions

Some of the material type and property selection inaccuracies found in the previous Lasserre building IE model are listed by relevant CIQS element in table 8.

Table 8. Material type and Property Improvements



CIQS Level 3 Element	Type and Property Selection (ex. concrete strength, rebar size, roof/floor loading, etc.)			
	Description of Inaccuracy(ies)	IE Input(s) Effected	Improvement Strategy(ies)	LCA Stage Effected
A11 Foundations	Rebar designation for stip footings	1.2.1 Footing_ Strip_Basement_F A_A, 1.2.2 Footing_Strip_Basement_F C_C, 1.2.4 Footing_Strip_Basement_F H_H, 1.2.5 Footing_Strip_Basement_F M_M, 1.2.6 Footing_Strip_Basement_F P_P, 1.2.7 Footing_Strip_Basement_F R_R, 1.2.8 Footing_Strip_Basement_F S_S	Review Building drawings and adjust rebar to predominante type per footing	Product
	8 Pad Footings not Modeled	A11 not fully represented	Add into Model	Construction
A21 Lowest Floor Construction	SOG for Basement Not Modeled	SOG Basement	Add to Model	Construction
A22 Upper Floor Construction	Over designed floors modeled as SOG+Double T Floor+Double T Roof	Floor, Roof, and Slab for each Level	Remove SOG and Roof, leave Double T Floor	Construction
A23 Roof Construction	Roof modeled as Double T when it is actually a 4" slab w varying 8" thickness	5.1.1 Roof_ Concrete Precast Double T_Building Roof	Remove Double T and separate existing SOG into two components	Construction & Product
	Roof Insulation not modeled	5.1.1 Roof_ Concrete Precast Double T_Building Roof	Add drawing spec Insulation	Product
	Fictitious Columns extending from Roof	3.1.5 Column_Concrete_Roof	Remove from Model	Construction
	Roof Material Build up	5.1.1 Roof_ Concrete Precast Double T_Building Roof	Correct with proper makeup from drawings	Product
A31 Walls Below Grade				
A32 Walls Above Grade				
B11 Partitions	Below grade interior walls modeled with VB	2.1.3 Wall_Cast in Place _Strip Footing_ Basement_E_E, H_H, P_P, & G	Remove cladding, insulation and VB	Product

The previous students work in general seems to be excessive and lacking in design. Beginning with A11-Foundations, the previous model did not account for 8 pad footings placed under primary columns. These eight footings were noticed in the On-Screen take off file yet were missing from the IE model. A second inaccuracy in foundations was noted in rebar designation to strip footings. Comparing building drawings to IE inputs did not correspond well on several occasions. The predominant type of rebar (#4, 5 or 6) specified in the drawings was taken and model inputs were adjusted accordingly. For A22-Lowest Floor Construction a major inaccuracy to the construction and product stages was that no slab on grade was modeled. This was corrected with appropriate materials from the building drawings. In A22-Upper Floor Construction, each floor of the building had been modeled as a 4'' concrete slab, double T roof and double T floor. In the new model the slab and roof components to each floor have been removed leaving just the double T flooring. This representation for each floor is seen as a more realistic model based off the Lasserre building drawings. The drawings do not specify or lend well to determining the actual concrete form used. From conversation with UBC Architecture and Building Science professor Greg Johnson it is suggested that the flooring is concrete hollow-core as shown in figure 8. As the same live load is assigned to the input double T flooring it is assumed that the amount of concrete issued for the double T flooring is representative of the believed hollow-core panel.

Figure 8. Hollow-Core Concrete Flooring[21]

A23-Roof Construction was found to be the greatest source of inaccuracy. Originally the roof was modeled as concrete double T when drawings specify it as a slab with varying 4’’ and 8’’ sections. Another construction stage inaccuracy was the inclusion of roof columns. In reality the fourth floor columns and beams support the roof slab so the reason for additional roof columns was unknown. These columns were removed from the model. Two product inaccuracies also existed in the A23.

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[21] Greg Johnson. (Novemeber 12, 2013) Verbal Discussion with reference to building drawings.

No roofing insulation was modeled previously. Rigid 38mm foam insulation (EPS) was added to the entire roof to accommodate building drawings. The second product flaw was the build-up of the roof. Originally the materials included were fibreglass, glass felt + gypsum (101.6mm total). With closer reference to the building drawings the roof assembly was changed to a modified bitumen-EPS-gypsum build up with aggregate stone ballast. Finally, within B11-Partitions, many below grade interior walls had been modeled with excessive envelope material. Any insulation, vapour barrier, and cladding present were removed creating the new IE building model. It is felt that these adjustments and substitutions will help give a more realistic model into the LCA of Lasserre.

4.3. Data Quality

Uncertainty within a LCA model may arise from the following five sources of uncertainty: data, model, temporal, spatial, and variability between sources. Table 9 describes each type and provides an example within the LCI databases called upon in this study.

Table 9. Uncertainties within LCA

Type of Uncertainty	Sources of Uncertainty	Example within LCI Databases
Data	Collection, allocation procedures (mass or economic), inaccurate or missing data, lifetimes of substances, travel potential in impacts (eutrophication , acidification	Travel potential exists as TRACI acidification category developed on U.S. empirical models with specific location.[22] Vancouver weather and geography different, resulting in uncertainty with travel potential
Model	Linear vs. non-linear model (increasing, constant or decreasing returns?) Characterization factors inaccurate or not known	As Athena and US LCI databases are young (10-15 years), the models are still improving as years of data strengthen them
Temporal	Differences in seasonal factory emissions, e.g. Sawmill lumber	Lasserre built with vintage 1960's materials, transport, energy, processing,

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[22] United States Environmental Protection Agency. (2013). Tool for the Reduction and Assessment of Chemical and Environmental Impacts (TRACI). Retrieved from http://www.epa.gov/nrmrl/std/traci/traci.html

	diameter changing from winter to summer. Data vintage. Climate effect on impact severity (temperature).	and construction techniques but Athena and US LCI use current.
Spatial	Regional differences (factories, energy mix, preferred transport), regional environment sensitivity, distribution of emissions (plane vs. factory)	Athena uses North American industry averages for construction materials. Some Lasserre materials may be international (China, Japan, Europe). TRACI assumes North American context for characterization factors while some impacts may be felt elsewhere in production chain like bauxite extraction in Australia.
Variability between Sources	Differences between factory practices and standards. Human exposure patterns (sawmill workers vs. residents nearby, elderly vs. youth)	Athena assumes similar Human exposure to process when worker would have much higher exposure to paint than occupant once dry.

Many of the data inaccuracies in Athena arise from the techno-sphere. Questionnaire subjects often do not have access to data relevant to input/output flows from their production processing. In this case secondary sources are used from LCA-practioner tools such as national databases or data sets like Natural Resources Canada.

5.0 List of Indicators Used for Assessment and Expression of Results

As this study utilizes the Athena Impact Estimator for its life cycle inventory assessment (LCIA), the methodology is consistent with US EPA TRACI which uses midpoint assessment. Figure 8, sourced from IMPACT World+, is a useful representation of LCAI practice. Some midpoint categories are listed in the figure. IMPACT World+ accounts for spatial uncertainty with global representation in its framework. This state of the art software offers midpoint impacts to be broken down to subcategories for greater detail: for example, ecotoxicity can be sub divided into freshwater, marine and terrestrial ecotoxicity[23]. End points are not assessed in this study, but as shown in figure 8 they are the summation of all midpoint damages.

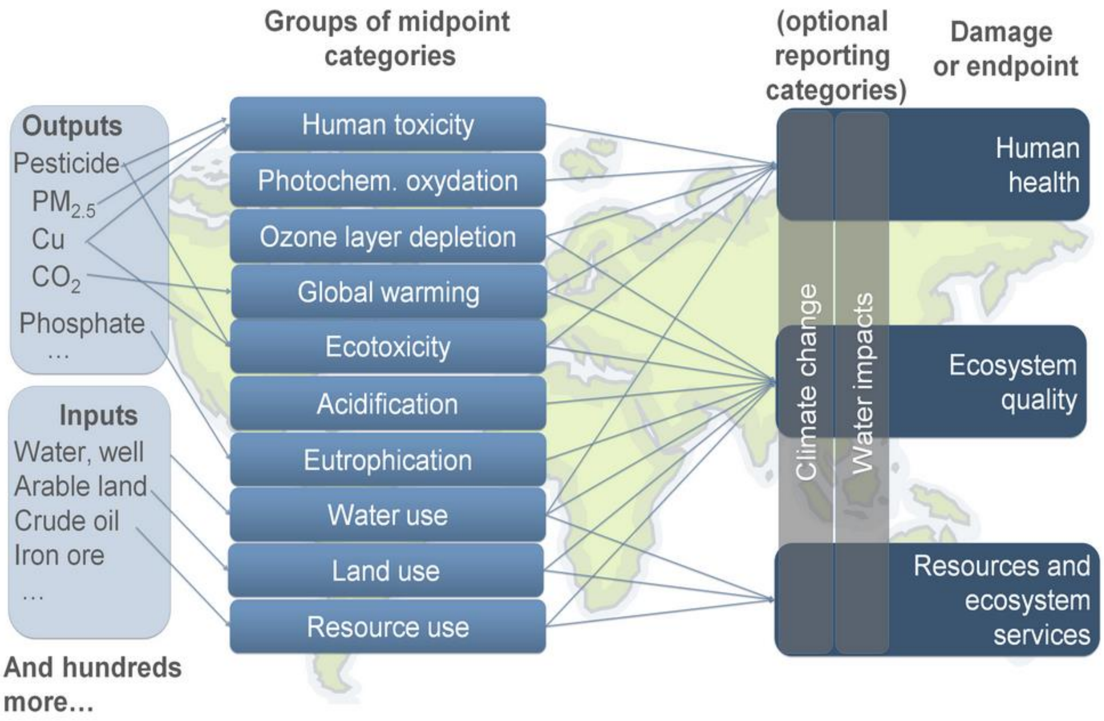

Figure 9. IMPACT World+ LCIA Methodology[24]

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[23] IMPACT World+. (2013). Presentation Tab. Retrieved from http://www.impactworldplus.org/en/presentation.php

[24] IMPACT World+. (2013) Methodology Tab. Retrieved from http://www.impactworldplus.org/en/methodology.php

The midpoint impact categories used in this study are summarized with their resultant endpoint impacts in table 10.

Table 10. Impact Categories

Midpoint Category	Category Indicator	Endpoint Impacts
Fossil Fuel Consumption	MJ	Human Health, Ecosystem quality, Resources and ecosystem services
Global Warming	kg CO_2 eq	Human Health (malaria), Ecosystem quality (Forests, agriculture, coastline)
Acidification	moles of H+ eq	Ecosystem quality
Human Health Criteria (Respiratory)	kg PM10 eq	Human Health (Respiratory illness)
Eutrophication	kg N eq	Ecosystem quality (Agriculture, fishing, drinking, reduced biodiversity)
Ozone Layer Depletion	kg CFC-11 eq	Human Health (skin cancer, immune sys suppression), Ecosystem quality (Agriculture, marine life)
Smog Formation	kg O_3 eq	Human Health (Asthma, restricted activity, mortality)

Each impact category has a distinct cause-effect chain that is generalized from the following model:

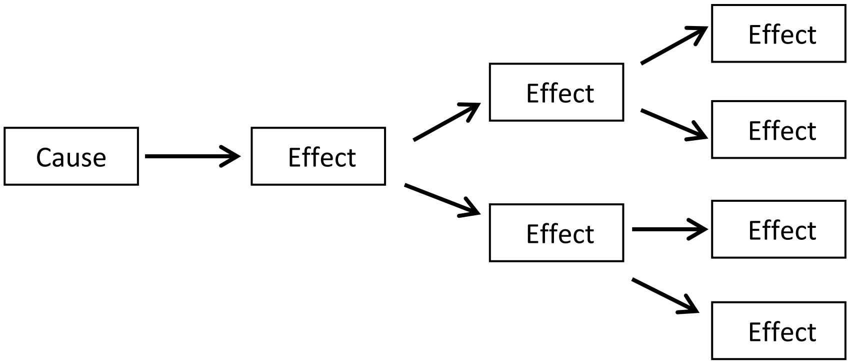
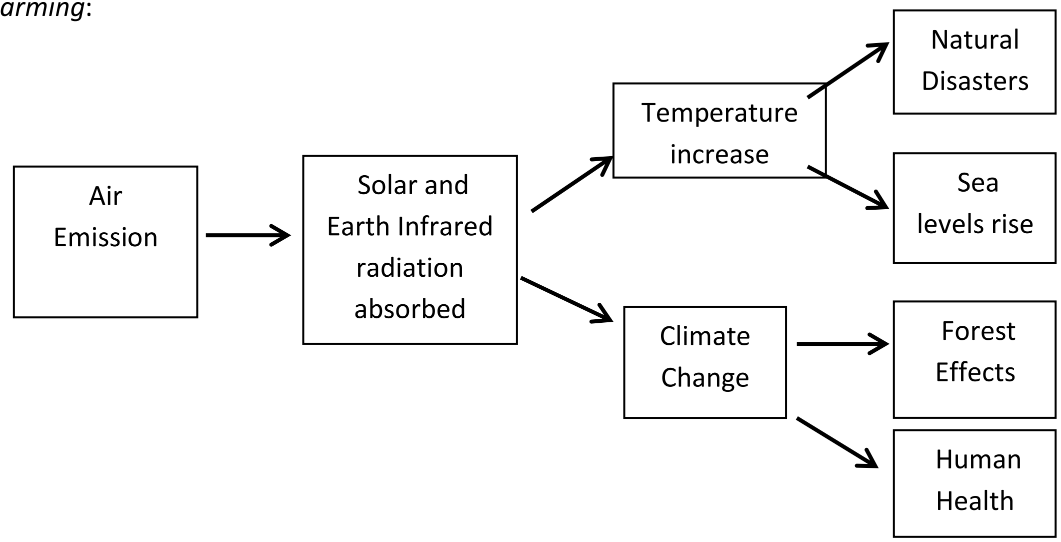


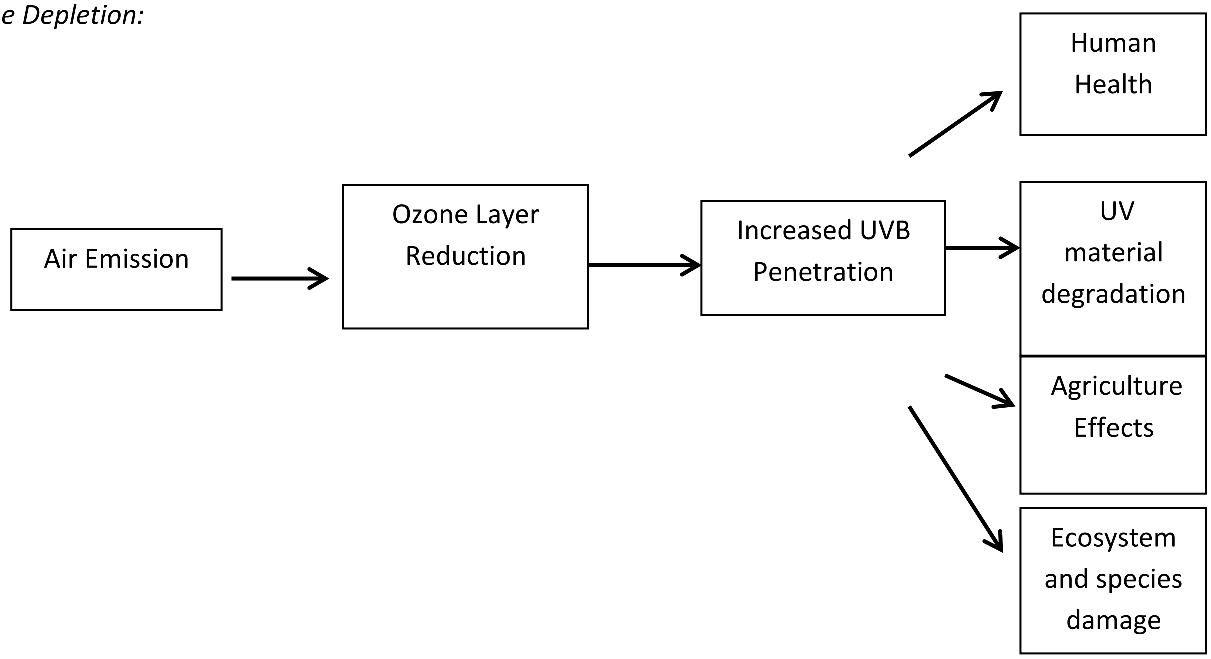
Figure 10. Cause-Effect Model for Impact Categories

The following cause-effect chain diagrams were adapted from Rob Sianchuk CIVL 498C Week 6_Impact assessment lecture slides.[25]

Global Warming:



Ozone Depletion:



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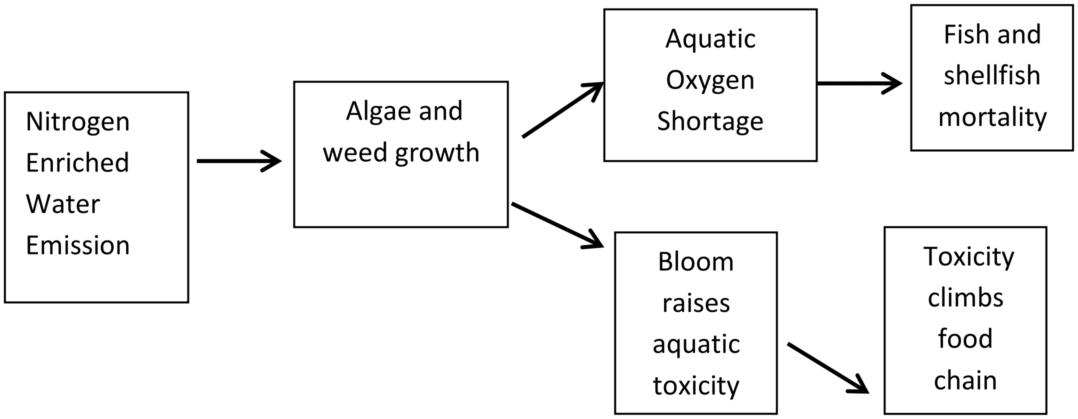
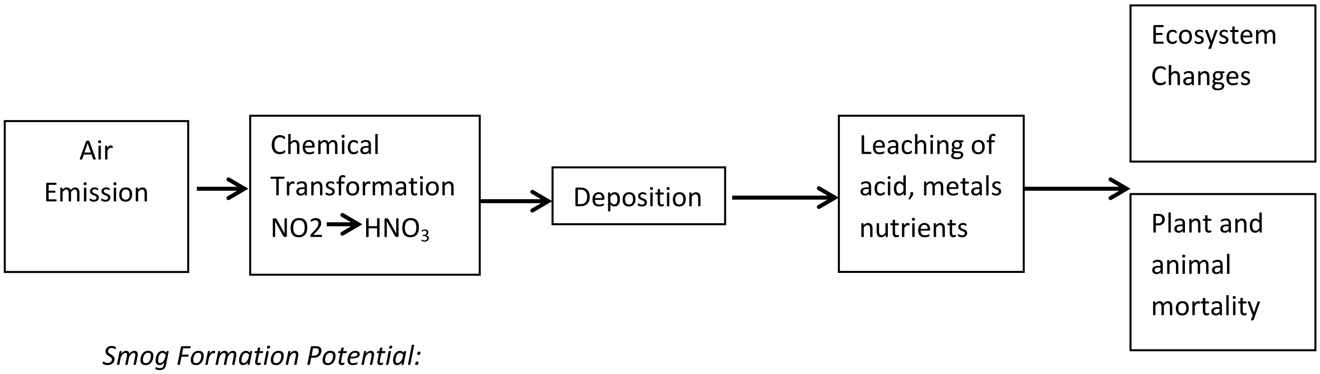
[25] Sianchuk, Robert. (October, 2013). Week6_Impact Assessment [PowerPoint slides]. Retrieved from http://civl498c.wikispaces.com/Class+Presentations+and+Handouts

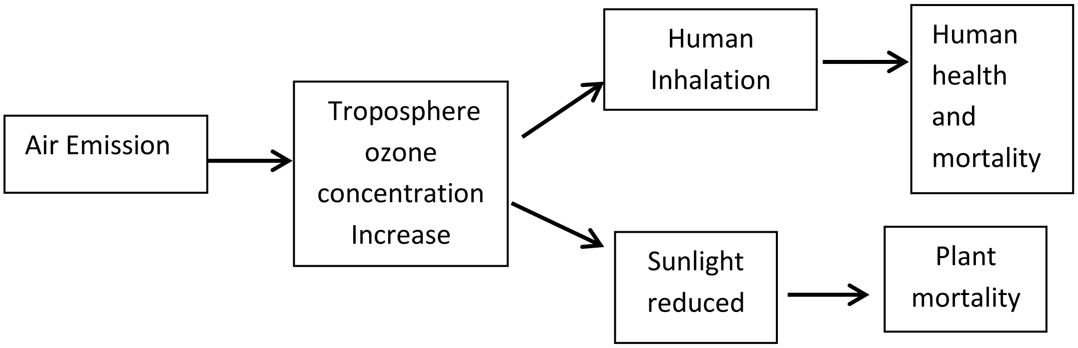
Eutrophication:



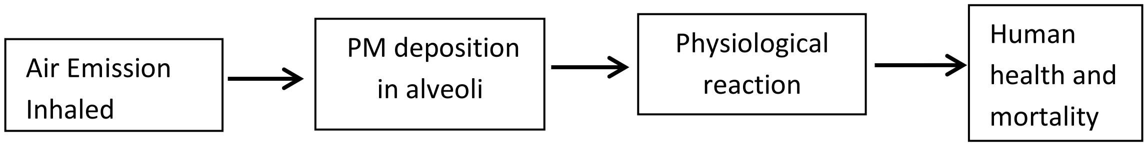
Acidification:



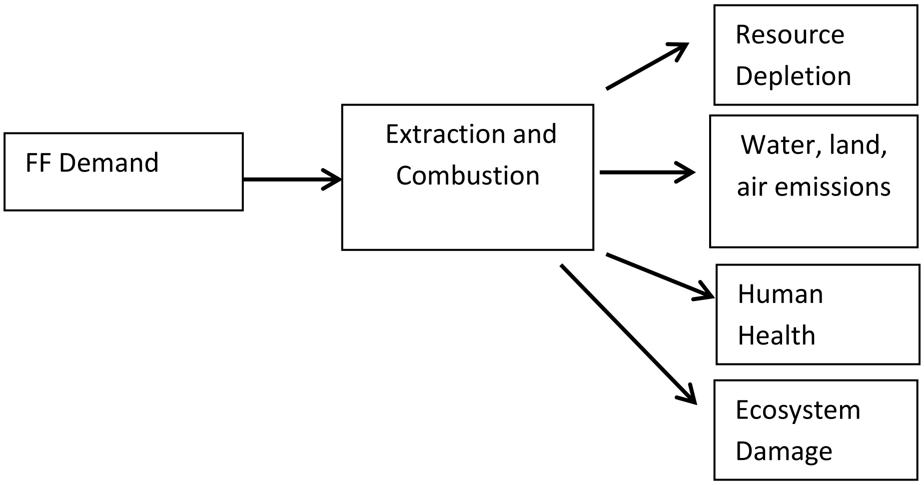
Smog Formation Potential:



Human Health Criteria (Respiratory):



Fossil Fuel Consumption:

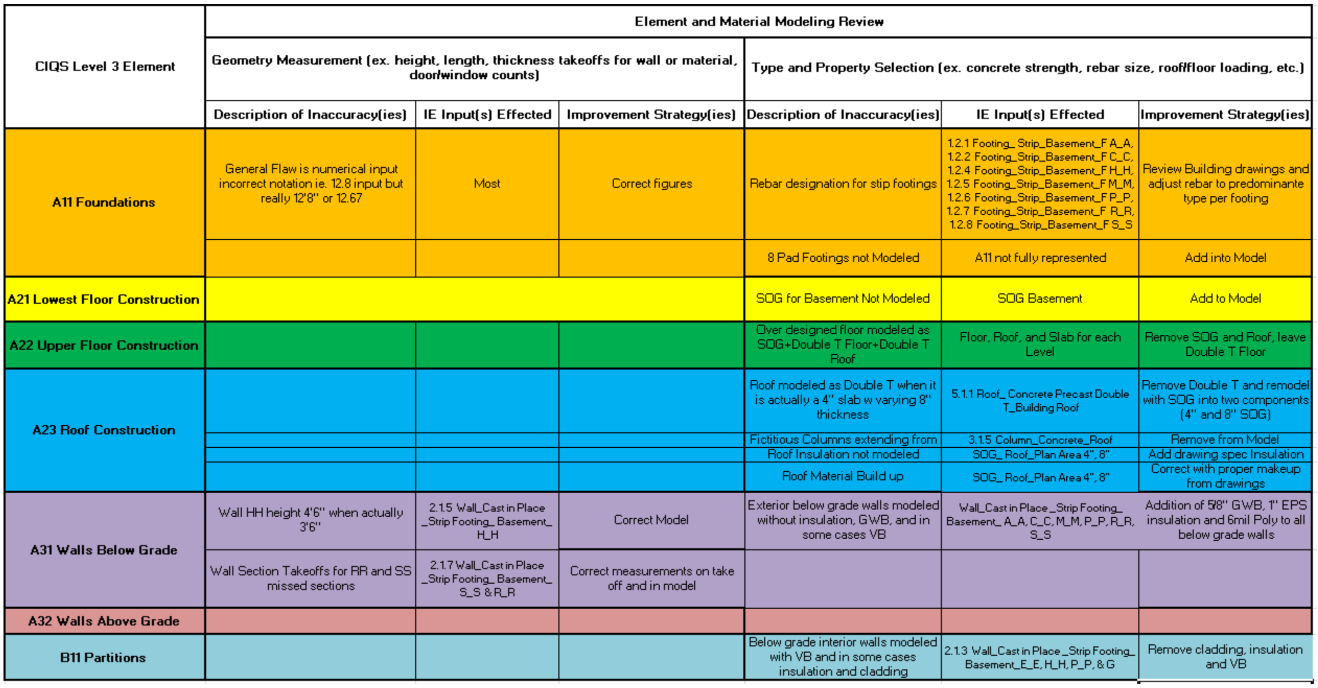


6.0 Model Development

Each CIQS Level 3 element within this study was modeled in the same manner. Following a consistent format was important to ensure all grounds were covered within each element while revamping the IE model. As a first course of action the Lasserre building drawings were reviewed and a site visit was taken to gain an understanding of the general construction. As the drawings have been digitized from their original 1960 format many details in the drawings were not visible, making it difficult to determine exact construction. Following this step, a review of the previous student's, Sahar Ranjbar, LCA report was undertaken. Understanding the previous methodology and assumptions made in the design helped direct focus to areas (hotspots) that were most sensitive to uncertainty and areas where improvement seemed most plausible.

After this preliminary analysis was complete, a more hands on, direct, approach took stage. The previous students IE inputs and assumptions excel worksheet was used in conjunction with CIQS level 3 elemental construction format to categorize the inputs under the seven levels listed in Annex D – Impact Estimator Inputs and Assumptions. Reorganizing the inputs to CIQS format gave recognizable structure and breakdown to the building orientated audience. It also helped in the analysis of the model as greater construction detail was determined. After reorganizing, the previous model was combed over with comparison to building drawings and On Screen Takeoff, version 3.9.0.6. Here the model was critiqued and assessed for uncertainty and error. Within stage 3 of this report a table of all geometric, type and property selection inaccuracies were described, inputs affected were noted, and improvement strategies were developed. This work is displayed in table 11. As the Lasserre building drawings are unclear and vague, specific materials could not easily be taken off. Many assumptions in the materials were carried over from the previous students work. This inadequacy made pursuing material changes in the Impact Estimator, from an Environmental Product Declaration (EPD), less productive. Newer buildings such as CIRS which uses a large amount of modern materials such as mineral wool insulation and glue lam beams would be more receptive to this type of analysis.

Table 11. Model Improvements



CIQS Level 3 Element	Element and Material Modeling Review					
	Geometry Measurement (ex. height, length, thickness takeoffs for wall or material, door/window counts)			Type and Property Selection (ex. concrete strength, rebar size, roof/floor loading, etc.)		
	Description of Inaccuracy(ies)	IE Input(s) Effected	Improvement Strategy(ies)	Description of Inaccuracy(ies)	IE Input(s) Effected	Improvement Strategy(ies)
A11 Foundations	General Flaw is numerical input incorrect notation ie. 12.8 input but really 12'8" or 12.67	Most	Correct figures	Rebar designation for stip footings	1.2.1 Footing_ Strip_Basement_F A_A, 1.2.2 Footing_Strip_Basement_F C_C, 1.2.4 Footing_Strip_Basement_F H_H, 1.2.5 Footing_Strip_Basement_F M_M, 1.2.6 Footing_Strip_Basement_F P_P, 1.2.7 Footing_Strip_Basement_F R_R, 1.2.8 Footing_Strip_Basement_F S_S	Review Building drawings and adjust rebar to predominante type per footing
				8 Pad Footings not Modeled	A11 not fully represented	Add into Model
A21 Lowest Floor Construction				SOG for Basement Not Modeled	SOG Basement	Add to Model
A22 Upper Floor Construction				Over designed floor modeled as SOG+Double T Floor+Double T Roof	Floor, Roof, and Slab for each Level	Remove SOG and Roof, leave Double T Floor
A23 Roof Construction				Roof modeled as Double T when it is actually a 4" slab w varying 8" thickness	5.1.1 Roof_ Concrete Precast Double T_Building Roof	Remove Double T and remodel with SOG into two components (4" and 8" SOG)
				Fictitious Columns extending from	3.1.5 Column_Concrete_Roof	Remove from Model
				Roof Insulation not modeled	SOG_ Roof_Plan Area 4", 8"	Add drawing spec Insulation
				Roof Material Build up	SOG_ Roof_Plan Area 4", 8"	Correct with proper makeup from drawings
A31 Walls Below Grade	Wall HH height 4'6" when actually 3'6"	2.1.5 Wall_Cast in Place _Strip Footing_ Basement_ H_H	Correct Model	Exterior below grade walls modeled without insulation, GWB, and in some cases VB	Wall_Cast in Place _Strip Footing_ Basement_ A_A, C_C, M_M, P_P, R_R, S_S	Addition of 5/8" GWB, 1" EPS insulation and 6mil Poly to all below grade walls
	Wall Section Takeoffs for RR and SS missed sections	2.1.7 Wall_Cast in Place _Strip Footing_ Basement_ S_S & R_R	Correct measurements on take off and in model			
A32 Walls Above Grade						
B11 Partitions				Below grade interior walls modeled with VB and in some cases insulation and cladding	2.1.3 Wall_Cast in Place _Strip Footing_ Basement_E_E, H_H, P_P, & G	Remove cladding, insulation and VB

These inaccuracies were then addressed through altering the effected inputs to create a new list of IE inputs as documented in Annex D. With these improvements complete, the IE model was rerun to project an updated BOM and impact assessment results for the building and for each CIQS Level 3 element.

Reference flows are outputs from a process, such as construction, that are required to fulfill the function expressed by the functional unit. In the case of this study the building and its CIQS elements are the reference flows or required outputs to address and quantify the environmental impacts per m^2 of conditioned building area. An intermediate flow within the study is the BOM. The current BOM for the Lasserre building and each of the Level 3 elements are now provided.

Table 12. Lasserre Whole Building BOM

Material	Quantity	Unit
#15 Organic Felt	1962.6	m2
1/2" Gypsum Fibre Gypsum Board	7801.7	m2
1/2" Moisture Resistant Gypsum Board	946.8	m2
3 mil Polyethylene	699.5	m2
5/8" Regular Gypsum Board	544.7	m2
6 mil Polyethylene	3884.0	m2
Aluminum	8.5	Tonnes
Ballast (aggregate stone)	54227.6	kg
Cold Rolled Sheet	0.4	Tonnes
Concrete 20 MPa (flyash av)	929.8	m3
Concrete 30 MPa (flyash av)	1035.2	m3
Concrete Blocks	52240.2	Blocks
Concrete Brick	1798.7	m2
Double Glazed No Coating Air	245.8	m2
EPDM membrane (black, 60 mil)	339.5	kg
Expanded Polystyrene	2827.9	m2 (25mm)
FG Batt R11-15	2175.5	m2 (25mm)
Galvanized Sheet	0.3	Tonnes
Glazing Panel	0.2	Tonnes
Joint Compound	8.3	Tonnes
Metric Modular (Modular) Brick	101.5	m2
Modified Bitumen membrane	7606.8	kg
Mortar	1034.6	m3
Nails	1.1	Tonnes
Paper Tape	0.1	Tonnes
Precast Concrete	448.8	m3
Rebar, Rod, Light Sections	532.3	Tonnes
Roofing Asphalt	6370.0	kg
Small Dimension Softwood Lumber, kiln-dried	6.8	m3
Water Based Latex Paint	60.9	L
Welded Wire Mesh / Ladder Wire	9.0647	Tonnes

Table 13. A11 Foundations BOM

Material	Quantity	Unit
Concrete 20 MPa (flyash av)	128.6	m3
Rebar, Rod, Light Sections	1.6	Tonnes

Table 14. A21 Lowest Floor Construction BOM

Material	Quantity	Unit
6 mil Polyethylene	1679.3	m2
Concrete 20 MPa (flyash av)	166.2	m3

Welded Wire Mesh / Ladder Wire	1.4	Tonnes

Table 15. A22 Upper Floor Construction BOM

Material	Quantity	Unit
1/2" Gypsum Fibre Gypsum Board	1160.9	m2
Concrete 20 MPa (flyash av)	26.7	m3
Concrete 30 MPa (flyash av)	821.0	m3
Joint Compound	1.2	Tonnes
Nails	0.0	Tonnes
Paper Tape	0.0	Tonnes
Precast Concrete	448.8	m3
Rebar, Rod, Light Sections	241.5	Tonnes
Welded Wire Mesh / Ladder Wire	5.4	Tonnes

Table 16. A23 Roof Construction BOM

Material	Quantity	Unit
#15 Organic Felt	1962.6	m2
1/2" Moisture Resistant Gypsum Board	946.8	m2
Ballast (aggregate stone)	54227.6	kg
Concrete 20 MPa (flyash av)	112.9	m3
Concrete 30 MPa (flyash av)	214.2	m3
Expanded Polystyrene	2314.6	m2 (25mm)
Galvanized Sheet	0.3	Tonnes
Modified Bitumen membrane	7606.8	kg
Nails	0.4	Tonnes
Rebar, Rod, Light Sections	67.8	Tonnes
Roofing Asphalt	6370.0	kg
Welded Wire Mesh / Ladder Wire	0.8	Tonnes

Table 17. A31 Wall below Grade BOM

Material	Quantity	Unit
5/8" Regular Gypsum Board	544.7	m2
6 mil Polyethylene	525.3	m2
Concrete 20 MPa (flyash av)	104.0	m3
Expanded Polystyrene	513.2	m2 (25mm)
Joint Compound	0.5	Tonnes
Nails	0.0	Tonnes
Paper Tape	0.0	Tonnes

Rebar, Rod, Light Sections	3.7	Tonnes

Table 18. A32 Walls above Grade BOM

Material	Quantity	Unit
1/2" Gypsum Fibre Gypsum Board	725.4	m2
3 mil Polyethylene	699.5	m2
Aluminum	8.5	Tonnes
Cold Rolled Sheet	0.3	Tonnes
Concrete 20 MPa (flyash av)	62.3	m3
Concrete Blocks	18022.3	Blocks
Concrete Brick	1798.7	m2
Double Glazed No Coating Air	245.7	m2
EPDM membrane (black, 60 mil)	339.5	kg
FG Batt R11-15	2175.5	m2 (25mm)
Glazing Panel	0.2	Tonnes
Joint Compound	0.7	Tonnes
Mortar	378.3	m3
Nails	0.4	Tonnes
Paper Tape	0.0	Tonnes
Rebar, Rod, Light Sections	54.4	Tonnes

Table 19. B11 Partitions and Doors BOM

Material	Quantity	Unit
1/2" Gypsum Fibre Gypsum Board	5915.4	m2
Cold Rolled Sheet	0.0	Tonnes
Concrete 20 MPa (flyash av)	34.2	m3
Concrete Blocks	34217.9	Blocks
Double Glazed No Coating Air	0.1	m2
Joint Compound	5.9	Tonnes
Metric Modular (Modular) Brick	101.5	m2
Mortar	656.3	m3
Nails	0.2	Tonnes
Paper Tape	0.1	Tonnes
Rebar, Rod, Light Sections	161.8	Tonnes
Small Dimension Softwood Lumber, kiln-dried	6.8	m3
Water Based Latex Paint	60.9	L

7.0 Life Cycle Assessment Results

The life cycle inventory assessment results generated in the Impact Estimator were output as summary of measure tables. It is interesting to compare the results by Level 3 element and by life cycle stage. In doing so, product system hotspots or areas of concentrated impact are revealed. Figures 10 and 11 display the results, first by element per unit of measurement (UOM) and then by life cycle stage per m^2 of total conditioned floor area. The comparison of elements by UOM may not be a fair representation. For instance the UOM for A21 Lowest Floor Construction is the area of the slab on grade which directly represents the components to this element. However, element A22-Upper Floor Construction has a UOM (area of all floors above lowest) that does not represent all the components to the element. For example, columns and beams are somewhat independent of the UOM yet contribute directly to the impacts. The results though are still informative and provide a level of indication as to where hotspots are within the building structure. A22, A32 and B11 are consistently the most impactful elements to study. All three of these elements have a common component of walls in their characterization. Walls in Lasserre are not only concrete, but also require insulation, vapour barrier and sheathing in most cases. These added contributions per m^2 make for an impactful component.

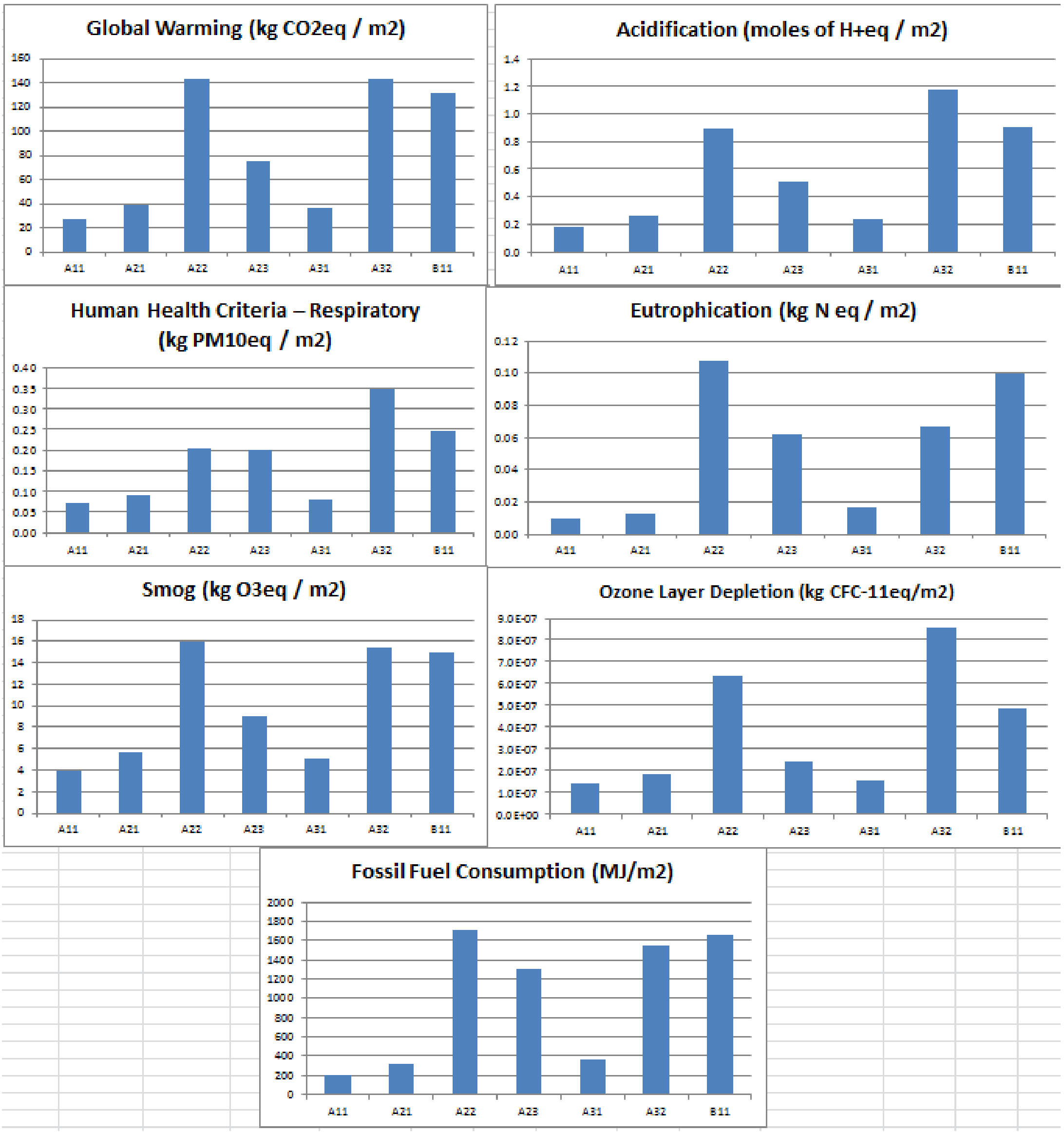


Figure 11. Lasserre LCIA Results by Level 3 CIQS Element

Viewing the LCIA results by life cycle stages (Product and Construction) it is very clear that the product stage makes up the majority of the impact in all categories. Within the product stage it is the manufacturing step that is most impactful. Transportation in both stages plays a minor role in total impact. This may be a bit misrepresentative if in reality products are being transported much greater distances than that assigned by the Impact Estimator. Regardless, manufacturing is the key area to improving the LCA of construction materials. For this reason LCA certification in construction materials is being sought after by many organizations. The US Green Building Council recently announced embedding LEED v.4 with two LCA based credits in Materials and Resources (MRc1 & MRc2).[26] This initiative is perhaps the beginning of LCA becoming an integral fixture for manufactures to gain transparent sustainability credit.

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[26] Athena Sustainable Materials Institute (2013). Green design codes and standards now have LCA paths – finally, a performance basis is coming to sustainable design. Retrieved from http://www.athenasmi.org/resources/about-lca/lca-in-construction-practice/

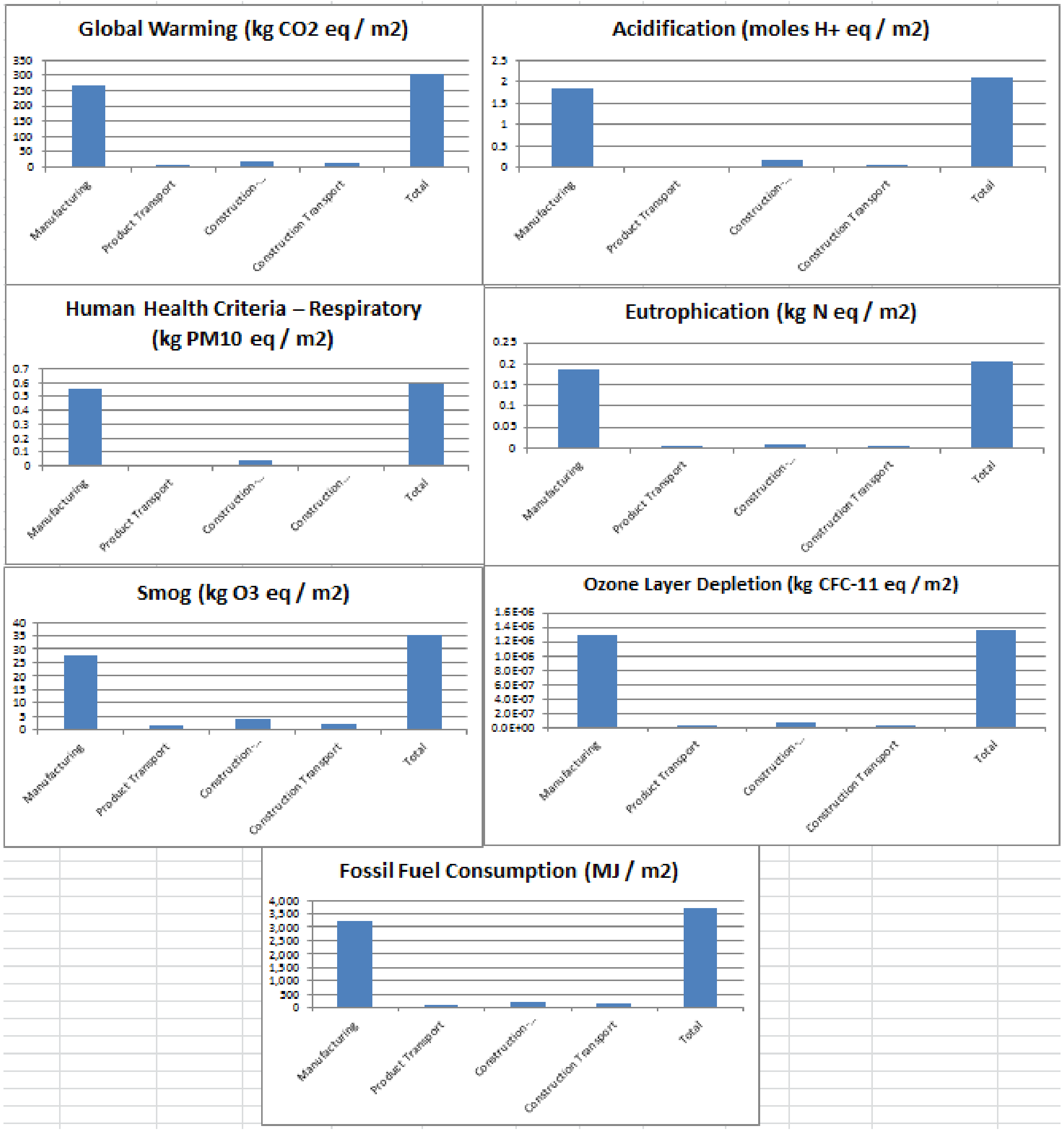


Figure 12. Lasserre Whole Building LCIA Results by Life Cycle Stage

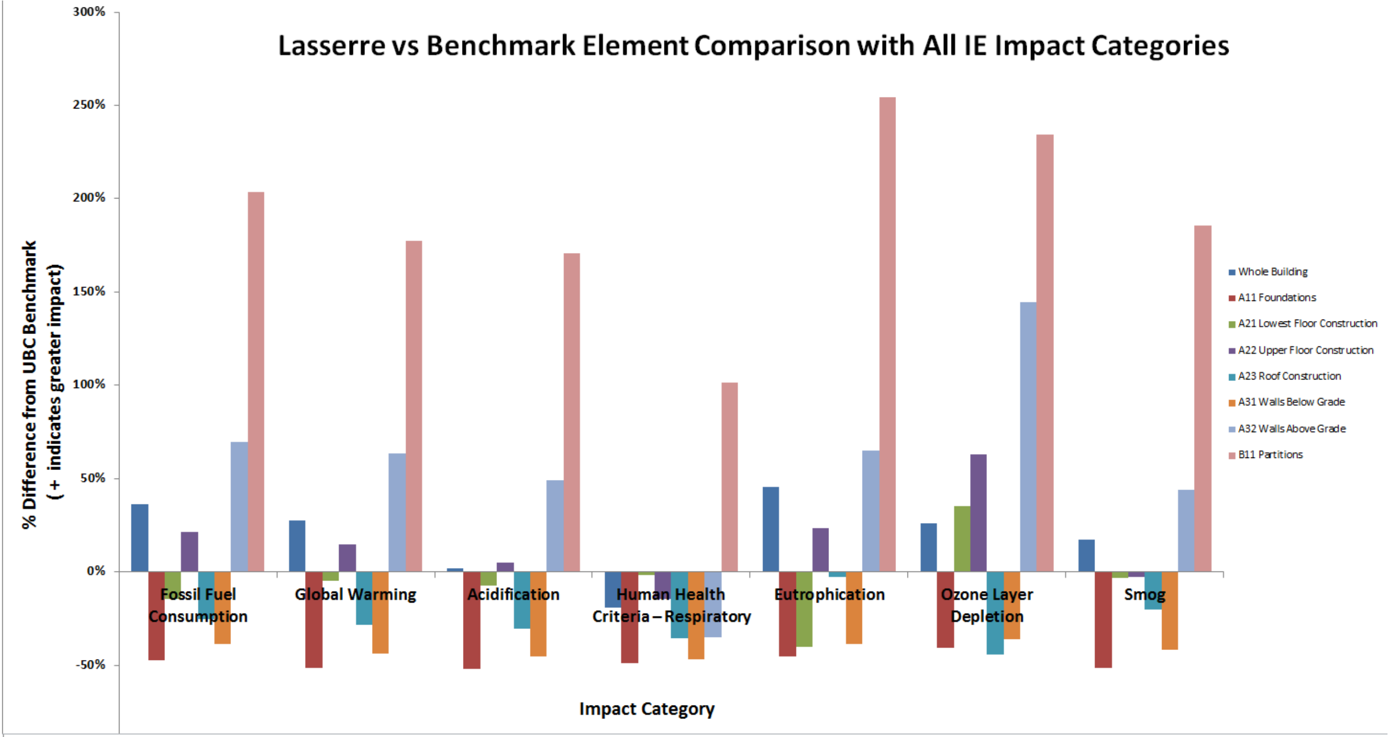
Further interpretation of results is provided in the included annexes. Annex A – 'Interpretation of Assessment Results' outlines the concept and value of benchmark development in LCA; it then introduces the UBC academic building benchmark and its results from the collaboration of CIVL 498C project findings. Annex B – 'Recommendation for LCA Use' explores qualitative approaches for recommendations to operationalize LCA in building design. Annex C – 'Author Reflection' comments on the experiences had in this study and the CIVL 498C course. Finally, Annex D – 'Impact Estimator Inputs and Assumptions' documents all inputs and assumptions made while compiling the Lasserre IE building model. This annex will be especially useful in any future work on Lasserre, just as the previous inputs and assumption document was for this study.

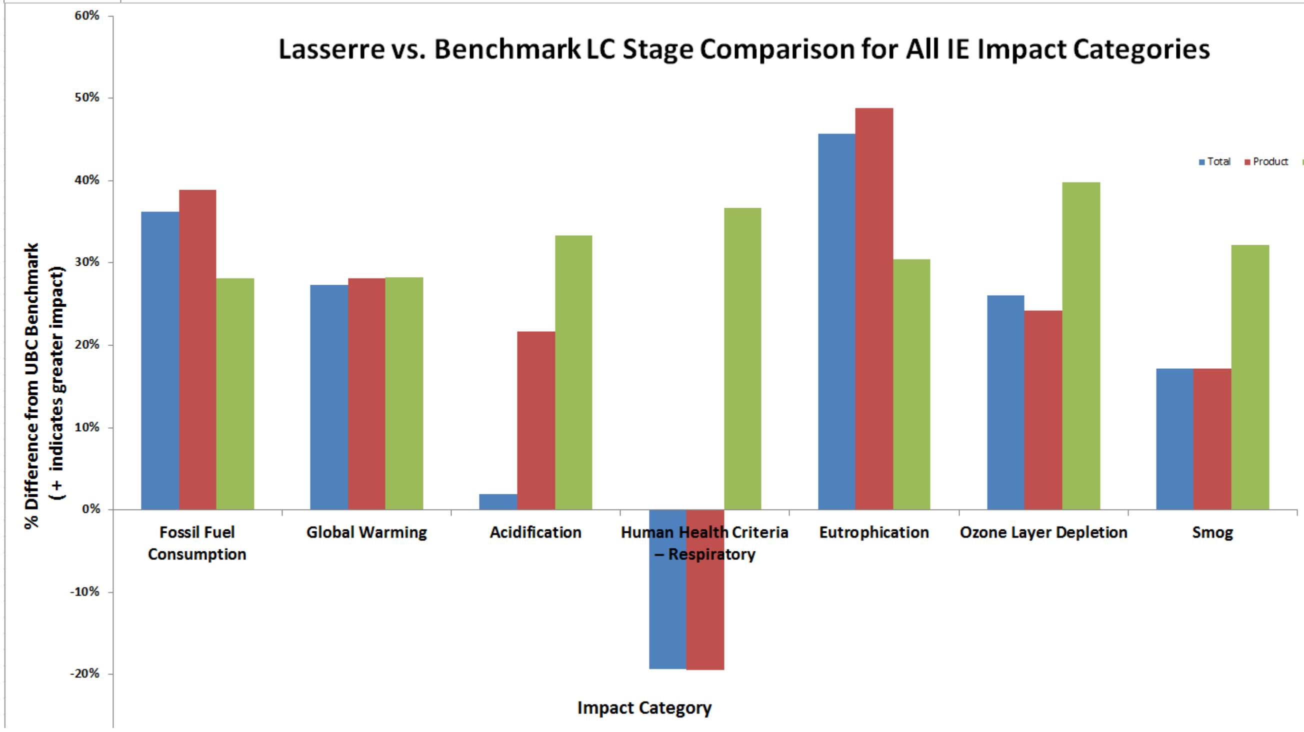
Annex A – Interpretation of Assessment Results

Within the industrial sectors and indeed, individual products, there is always a need to optimize efficiency. However, it is impossible to make changes and demonstrate that the changes have been effective if there is no standard against which to measure the altered system. This is the basis of benchmarking. By making any proposed changes and re-calculating with comparison to the benchmark it is possible to understand whether or not the changes have produced the desired effect. In this manner a route of optimization unfolds where ideas and philosophies are trialed with their resultant effects noted. The end result is a product, process or industry that improves, optimizes and becomes more efficient with materials, water, and energy. Even if environmental considerations are not the driving force, economic factors such as savings potential can evoke interest.

The use of common goal & scope in model development is essential to developing a robust and fair benchmark. Having the same intentions, purpose and system boundaries ensure that the studies are similar and a fair comparison can be made within the benchmark. Benchmarking is a valuable tool for making sense of LCA-based information as it equates the functional unit and provides a measure of performance amongst the collective group or individual iterations.

A final results benchmark was taken on November 14th at 8pm from the Google drive. A few buildings had to be excluded, Pharmacy and AERL, from developing the benchmark due to lack of or erroneous results at the time. The following two figures visually summarize how Lasserre compares to the benchmark. The building as a whole performs inferior to the benchmark and in almost all impact categories from 5-50% greater impact, with the one exception being Human Health. On an elemental basis Lasserre performs poorly compared to the benchmark in elements A22, A32 and B11, especially B11. This is likely due to the partitions being constructed as concrete block. This large variance from the benchmark in B11 also likely contributes significantly to whole building performance mentioned previously. For all other elements Lasserre performs reasonable well, the brightest spot being foundations at ≈ 50% improvement.





The GWP versus construction cost scatter plot had to omit some buildings because they did not have a cost listed at time of publication. A number of buildings, Math, CEME, Chemistry South, were listed in original dollars. They were converted to 2013 $ for this plot using the same discount rate used for Lasserre at 7.2%.

Lasserre performs relatively average to the others in this plot. A general consensus drawn is that older buildings tend to perform well, bottom left corner of plot. This is likely due construction costs being relatively cheaper back then and the use of more natural materials such as wood and stone. One important aspect to consider here is that all construction was assigned present date intensity factors. This limitation makes the plot a somewhat unfair representation.

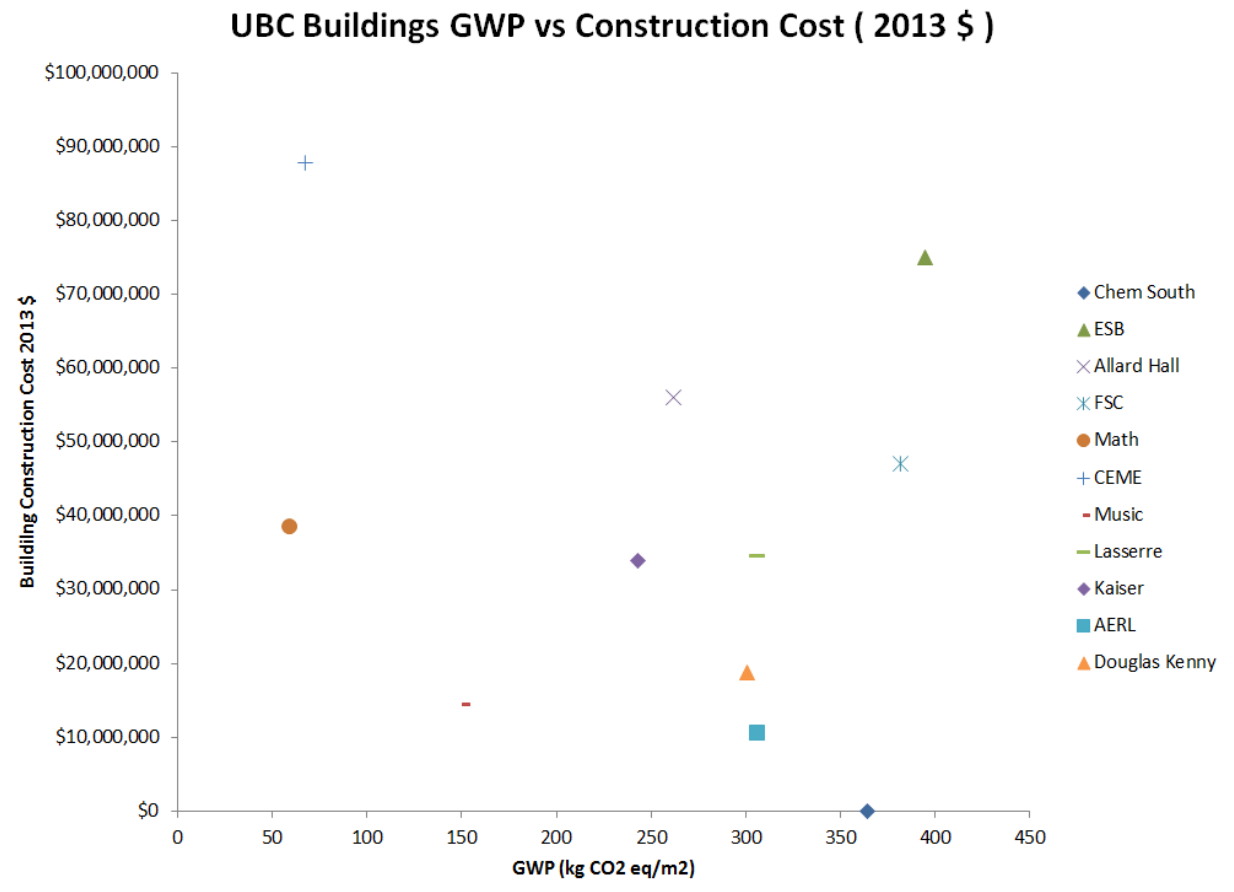


Figure 13. Global Warming Potential versus Construction Cost of UBC Buildings

Annex B – Recommendations for LCA Use

As the scope of this study is narrowed to a 'cradle to gate' approach, EN 15798 modules B and C, use and end of life, are not considered. Representation of modules B and C in a 'cradle to grave' analysis is recommended. Over the lifetime of the building use impact increases, becoming the most impactful stage as the building ages. The use impact continues to develop within the buildings lifetime, the only stage to do so. Investigating rate of change in use impact over time would be interesting for UBC buildings. The growth is often observed as exponential as repair, replacement and maintenance modules accumulate more so towards the latter half of the lifetime. A building LCA case study analysis by Ramesh et al. revealed the use stage accounted for, on average, 80-90% of the total life cycle energy. The end of life stage in traditional LCA analysis has not been given great consideration. Its impact on the total life cycle is less than the other modules but offers opportunity to minimize product stage impact in future buildings through salvaging and recycling materials. As the product stage impact is easily the greatest in 'cradle to gate' analysis the end of life stage gains more emphasis in establishing this mutual relationship for future construction.

Decision making at the early stages of design is important for establishing a sustainable building. Once the building in constructed it is increasingly difficult (logarithmic relationship) to reap benefits from retrofitting design flaws. By establishing sustainable decision making at the design stage all the materials, construction techniques and energy efficiency measures are embedded to reduce impacts along the entire life cycle.

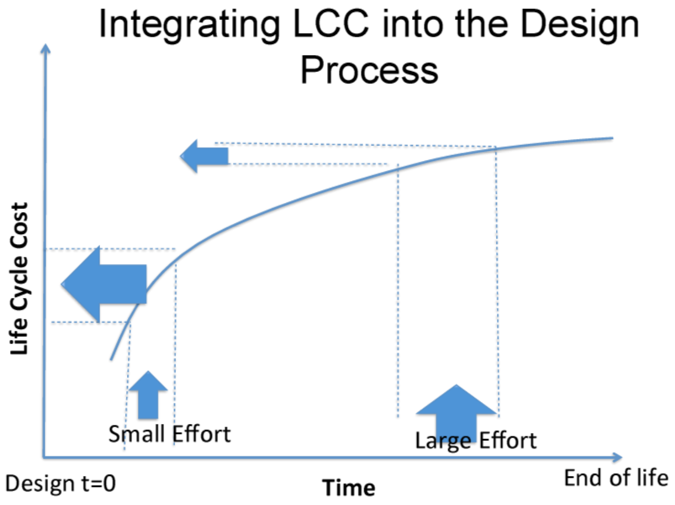


Figure 14. LCC over Lifetime of Building[27]

For these aforementioned early design strategies to succeed it is paramount to establish an integrated design approach. That is a design where all contributing parties act cohesively and collectively.

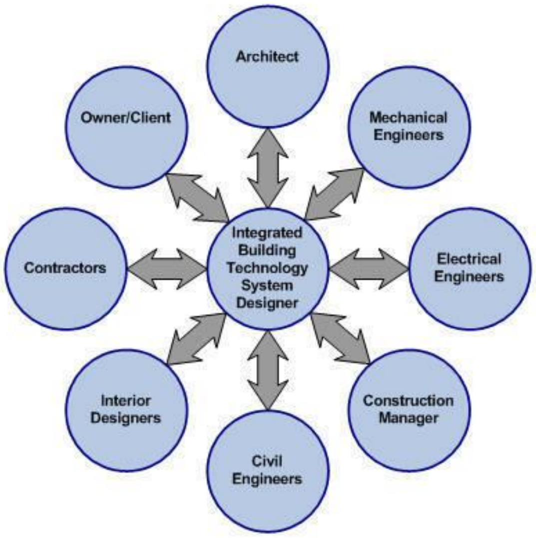


Figure 15. Integrated Design[28]

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[27] Storey, Stefan. (November 4th, 2013) Fundamentals of Life Cycle Costing (LCC) and Application. CIVL 498C Lecture Slides.

[28] Automated Buildings. (January 2007). Coordinating the Design of Integrated Building Technology Systems. Retrieved from http://www.automatedbuildings.com/news/jan07/articles/sinopoli/061228120158sinopoli.htm

As the building industry moves towards greater sustainable design and as LEED certification gathers backing LCA will be increasingly important in building design. Heather Goodland of Brantwood Consulting gave a lecture which commented on how the shift towards more energy efficient building policies within Vancouver will decrease the operating carbon yet a slight increase in embodied carbon results from technology advancements and greater demand of materials (thicker insulation, triple glazing, etc.). This shift in energy will be best accounted for through the city adopting a LCA approach to building design, otherwise embodied effects could get out of hand. The accompanying figure to her presentation depicts this shift in line with the City of Vancouver 'greenest city' 2020 and 2050 targets.

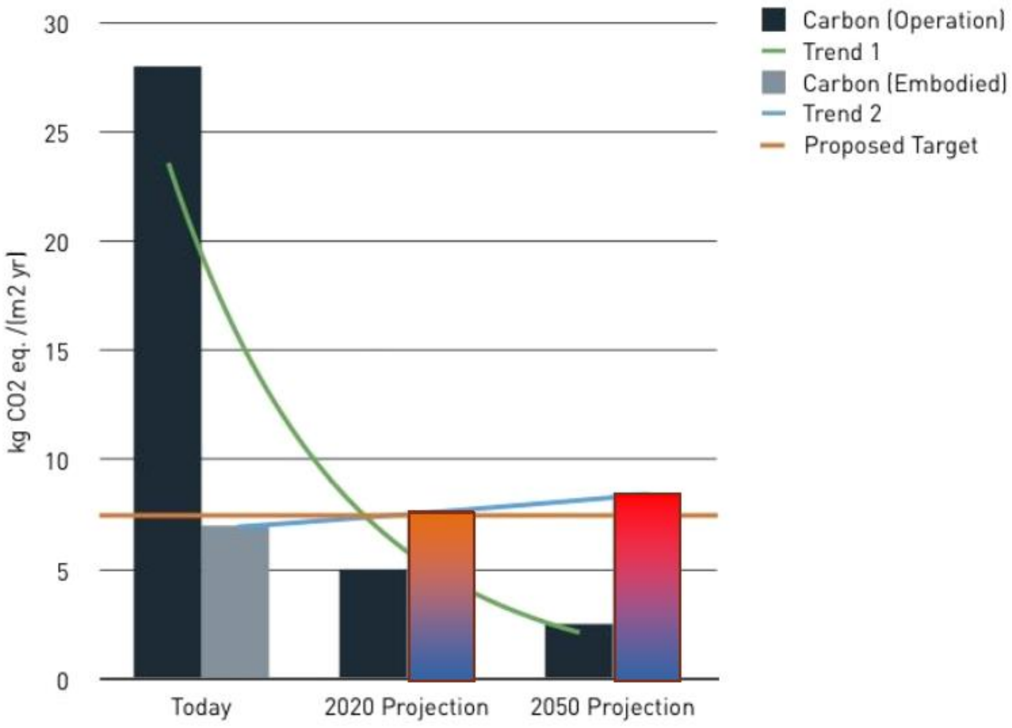

Figure 16. Operation and embodied energy policy framework for multi-family residential buildings in Vancouver, Canada[29]

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[29] Brantwood Consulting. (October, 2013). UBC LCA Class Lecture – Green Building Trends and Projects. Retrieved from http://civl498c.wikispaces.com/Class+Presentations+and+Handouts

The availability of quality data for buildings is limited. Many material databases such as Athena are restricted. Their embedment in LCA tools is the extent to the user, a black box so to speak. As a result, LCA certified materials such as environmental product declarations (EPD) are very limited and many existing products claim to be sustainable on little to no grounds. Developing a transparent, informative and vast building product database is needed to make LCA more accessible to the masses. As LCA is still a relatively new tool in sustainable design there are not a lot of peer reviewed studies to draw robust benchmarks from. This is the purpose and intent of this study; provide UBC with a benchmark building to plan future sustainable design from.

Impact categories assessed in LCIA are often prioritized by regional values. What is important in Los Angeles (Smog Potential) may not be as important in Vancouver (GWP). How do you get people to agree on what should take priority in the LCA study. There may also be trade-offs between two priority competing categories that breeds indecision. Sometimes political and economical values force priority on an impact category that may not be the most impactful. Take for example the mandate that all institutions must be carbon-neutral in British Columbia. There may be an instance where human health is impacted greater than GWP yet GWP wins out in favour of policy and less carbon off-sets to purchase. How do you decide? The general method is to form a consensus through a survey of professionals and LCA experts. This discrepancy in how to best prioritize impacts brings a level of unprofessionalism into LCA and may hinder its industry wide acceptance.

CIVL 498C has begun a framework in developing LCA operation for buildings at UBC. Establishing ‘cradle to gate’ studies on all major campus buildings has then led further to benchmark development. The next step in this framework would logically be to continue the progression by including EN 15978 modules B and C, use and end of life. To investigate these modules some specific data would be required. Establishing a baseline energy consumption and peak demand profile for each building would be a first step. Data mining for UBC buildings has been present for a number of years so the data is available. Pulse Energy has energy monitoring systems providing real time and archived data to this regard for UBC. Gathering data on building occupancy and occupant behaviour would also be beneficial for the use stage as it is a main driver. As mentioned in section 2.2, occupant studies have already begun within UBC buildings.

The end of life stage is easily modeled by the Impact Estimator however the degree of uncertainty within it could be minimized with UBC specific data. Investigating demolition practices such as materials salvaged, % recycled content and transportation distances to processing facilities are needed to develop module C. Involvement of the life cycle costing (LCC) aspect would also contribute to the development of LCA at UBC. Costing would provide another perspective to the analysis by allowing cost benefit relationships to emerge, presenting methods at achieving high environmental performance at minimal cost. Bringing economic and sociology students on board to pursue LCC and social life cycle assessment in conjunction with the existing work by CIVL 498C is recommended as a way to grow the UBC network.

Policy framework incorporating LCA into UBC technical specifications and sustainability initiatives such as the climate action plan is needed to bring LCA into common practice. A requirement that new building design have an LCA study performed with it along with environmental criteria is one example. Including a continuous optimization plan to monitor the actual construction and use to the design would be another valuable initiative. This would create a closed loop system with feedback to the model and others going forward to increase prediction performance.

Annex C – Author Reflection

After completing this study a point of reflection can be taken to discuss and address the experience, interests, concerns and gained attributes. Prior to enrolling in this course I had been exposed to the concept of LCA and its framework in a graduate level course within the Clean Energy Engineering Master's program. This exposure in CEEN 523- Energy and the Environment was similar in material but different in application. CEEN 523 had a term project as well but it was on any professor approved topic. I worked with two other students on developing a carbon footprint study comparing the proposed UBC microbrewery and Molson Canadian on the functional unit of one standard beer keg.

I noticed a lot of similarities in the two courses material and method of presenting which I found effective in both cases. Beginning by establishing why LCA is important and where it can be used grabbed my attention as to how useful and powerful a tool LCA can be. The core of this course looked at each step within an LCA. Beginning with the topics of goal and scope, and then proceeding in order to inventory analysis, impact assessment, uncertainty analysis, and economic evaluation was an effective means at delivering the material. The team work assignments I found to be quite effective at instilling the concepts both in a practical and written manner. The specific case of carrying out a short LCA of paper planes and spheres was a project that I found quite informative with a lot of take-away points. In particular to the term project, I found the incorporation of the software, Impact Estimator and On Screen Take-off, two valuable acquired skills. I feel confident in using this software and the value it holds in performing a professional LCA study. In many courses, you are introduced to software but never have a chance to apply it; this was not the case in this course.

Comments regarding CEAB graduate attributes are listed below. The study was good at requiring many of these attributes to not only be introduced but also developed and applied throughout.

	Graduate Attribute			
	Name	Description	Select the content code most appropriate for each attribute from the dropdown menu	Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	N/A = not applicable	
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	A = applied	The LCA study was quite a vast amount of information that needed to be processed. Although difficult by parts, the collective process was challenging
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	The methodology of LCA was introduced in lectures. It was then developed and applied to the specific case of building the UBC-LCA building database.

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.	N/A = not applicable	For the most part the study used established solutions in emerging LCA software tools to solve the engineering problems.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.	D = developed	Knowledge of On Screen Takeoff was gained and applied to aid in validating model inputs and finding inaccuracies that could be improved. Impact Estimator was applied to revamp the building model in CIQS sorted format. Both software tools were valuable learning tools
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	A = applied	Individual work was predominantly on project. Group work was done in class that supported learning principles. Often in the group work the team had a significant amount of work to deliver on time. This required effective use of time and a cohesive method to be successful. I felt this team work was useful in applying leadership and membership skills

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.	DA = developed & applied	Following definite project instructions required clear and effective communication. Taking previous documentation of the project to develop a renewed report was applied. APA formatting was applied throughout the written report.
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.	IA = introduced & applied	Making sure that all assumptions and assertions in the report were professional and responsible was applied to ensure the report was not misleading.
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	This LCA course and study involved a triple bottom line analysis. As LCA pertains to a holistic approach the aspects of the environment, health, economic were addressed. Although cultural and social aspects were not applied they were introduced in lectures as social life cycle costing. Uncertainty analysis although not directly applied to the report was introduced in lectures and developed in the report with discussion.

10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	A = applied	Professional engineering ethics and accountability were applied to the report. Results are to be published.
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 as Life cycle costing but not developed or applied in report.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	DA = developed & applied	I took this course to expand my knowledge base in an emerging engineering discipline. I hope to find work where I involve LCA in daily activities and this course has helped gain confidence in comprehending the LCA language and application.

Annex D – Impact Estimator Inputs and Assumptions

IE Inputs Document - Lasserre

Lasserre Building - GFA 5276m^2

CIQS Type III Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Known/Measured Information	IE Inputs (Imperial)
A11 Foundations	**1055**	**m^2**					
			Footings	Footing_ Strip_Basement_FA_A			
					Length (ft)	59	59
					Width (ft)	1.60	1.60
					Thickness (in)	10	10
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#4	#4
				Footing_Strip_Basement_FC_C			
					Length (ft)	345	345
					Width (ft)	2.20	2.20
					Thickness (in)	12	12
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#5	#5
				Footing_Strip_Basement_FE_E			
					Length (ft)	88	88
					Width (ft)	2	2
					Thickness (in)	12	12
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#4	#4
				Footing_Strip_Basement_FH_H			
					Length (ft)	27	27
					Width (ft)	2.6	2.6
					Thickness (in)	19	19
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#4	#4
				Footing_Strip_Basement_F			

	M_M			
		Length (ft)	64	64
		Width (ft)	2.2	2.78
		Thickness (in)	19	19
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#6	#6
	Footing_Strip_Basement_F P_P			
		Length (ft)	123	123
		Width (ft)	2.00	2.00
		Thickness (in)	12	12
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#4	#4
	Footing_Strip_Basement_F R_R			
		Length (ft)	66	66
		Width (ft)	2	2
		Thickness (in)	12	12
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#4	#4
	Footing_Strip_Basement_F S_S			
		Length (ft)	47	47
		Width (ft)	1.60	1.60
		Thickness (in)	8	8
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#4	#4
	Footing_Pad_Basement_F_ A_1	Length (ft)	16	16
		Width (ft)	6.75	12.8
		Thickness (in)	36	19
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#6	#6
	Footing_Pad_Basement_F_ A_2	Length (ft)	16	16
		Width (ft)	6.75	12.8
		Thickness (in)	36	19
		Concrete (psi)	?	3000
		Concrete flyash %	?	average
		Rebar	#6	#6

Footing_Pad_Basement_F_A_3	Length (ft)	16	16
	Width (ft)	6.75	12.8
	Thickness (in)	36	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_A_4	Length (ft)	16	16
	Width (ft)	6.75	12.8
	Thickness (in)	36	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_A_5	Length (ft)	16	16
	Width (ft)	6.75	12.8
	Thickness (in)	36	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_A1_1	Length (ft)	16	16
	Width (ft)	6.75	12.8
	Thickness (in)	36	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_A1_2	Length (ft)	16	16
	Width (ft)	6.75	12.8
	Thickness (in)	36	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_B	Length (ft)	15	15
	Width (ft)	5.5	9.57
	Thickness (in)	33	19
	Concrete (psi)	?	3000
	Concrete flyash %	?	average
	Rebar	#6	#6
Footing_Pad_Basement_F_	Length (ft)	2.75	2.75

				C			
					Width (ft)	2.75	2.75
					Thickness (in)	12	12
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#4	#4
				Footing_Pad_Basement_F_D_1	Length (ft)	2.5	2.5
					Width (ft)	2.5	2.5
					Thickness (in)	12	12
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#5	#5
				Footing_Pad_Basement_F_D_2	Length (ft)	2.5	2.5
					Width (ft)	2.5	2.5
					Thickness (in)	12	12
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#5	#5
A21 Lowest Floor Construction	**1055**	**m^2**					
			Slab on Grade	SOG_ Basement_Plan Area	Length (ft)	160	160.00
					Width (ft)	71	106.50
					Thickness (in)	6	4
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
A22 Upper Floor Construction	**4220**	**m^2**					
			Floor				
				Floor_Concrete Precast Double T_Main floor	Number of Bays	16	16
					Bay Size	20	20
					Span Size	35.5	35.5
					With or W/out Concrete Topping	W	W
					Live Load	?	75
				Floor_Concrete Precast Double T_Second floor			
					Number of Bays	16	16
					Bay Size	20	20
					Span Size	35.5	35.5
					With or W/out Concrete Topping	W	W
					Live Load	?	75

	Floor_Concrete Precast Double T _Third floor			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	W	W
		Live Load	?	75
	Floor_Concrete_PrecastDouble T_Fourth Floor			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	W	W
		Live Load	?	75
Roof	Main Floor_Roof_ Concrete Precast Double T			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	?	W/O
		Live Load	?	75
		Envelope Category	?	Gypsum Board
		Envelope Material	?	1/2" Gypsum fiberglass Board
		Thickness	?	0
	Roof_Second Floor_Roof_ Concrete Precast Double T			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	?	W/O
		Live Load	?	75
		Envelope Category	?	Gypsum Board
		Envelope Material	?	1/2" Gypsum fiberglass Board
		Thickness	?	0
	Roof_ Third Floor _Roof_ Concrete Precast Double T			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	?	W/O

		Live Load	?	75
		Envelope Category	?	Gypsum Board
		Envelope Material	?	1/2" Gypsum fiberglass Board
		Thickness	?	0
	Roof_Fourth floor_Roof_ Concrete Precast Double T			
		Number of Bays	16	16
		Bay Size	20	20
		Span Size	35.5	35.5
		With or W/out Concrete Topping	?	W/O
		Live Load	?	75
		Envelope Category	?	Gypsum Board
		Envelope Material	?	1/2" Gypsum fiberglass Board
		Thickness	?	0
Column /Beam	Column_Concrete_Basemnet_9			
		Number of Beam	35	35
		Number of Columns	64	64
		Floor to Floor Height	7	7
		Bay Size	10	10
		Span Size	20	20
		Live Load	?	75
	Column_Concrete_Main Floor_6			
		Number of Beam	10	10
		Number of Columns	60	60
		Floor to Floor Height	13	13
		Bay Size	20	20
		Span Size	35.5	35.5
		Live Load	?	75
	Column_Concrete_Second Floor			
		Number of Beam	10	10
		Number of Columns	60	60
		Floor to Floor Height	12	12
		Bay Size	20	20
		Span Size	35.5	35.5
		Live Load	?	75
	Column_Concrete_Third Floor			
		Number of Beam	10	10

					Number of Columns	60	60
					Floor to Floor Height	12.2	12.2
					Bay Size	20	20
					Span Size	35.5	35.5
					Live Load	?	75
			Stairs	Footing_Stairs_ Main Floor			
					Length (ft)	187	187
					Width (ft)	5.60	5.60
					Thickness (in)	10.5	10.5
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar	#4	#4
A23 Roof Construction	**1055**	**m^2**					
			Column /Beam				
				Column_Concrete_Fourth Floor			
					Number of Beam	10	10
					Number of Columns	60	60
					Floor to Floor Height	8.6	8.6
					Bay Size	20	20
					Span Size	35.5	35.5
					Live Load	?	75
				Column_Concrete_Fourth Floor small bay size			
					Number of Beam	92	92
					Number of Columns	70	70
					Floor to Floor Height	8.6	8.6
					Bay Size	10	10
					Span Size	9.1	9.1
					Live Load	?	75
			Roof				
				SOG_ Roof_Plan Area 4"			
					Length (ft)	157.00	157.00
					Width (ft)	?	44.30
					Thickness (in)	4	4
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
				SOG_ Roof_Plan Area 8"			
					Length (ft)	120	120
					Width (ft)	19.25	19.25
					Thickness (in)	8	8

					Concrete (psi)	?	3000
					Concrete flyash %	?	average
A31 Wall Below Grade	**798**	**m^2**					
			Basement Walls	Wall_Cast in Place _Strip Footing_ Basement_ A_A			
					Length (ft)	62	62.00
					Height (ft)	13.6	13.6
					Thickness (in)	8	8
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar		
				Envelope	Category		Sheathing
					Material		Gypsum
					Thickness		5/8"
				Envelope	Category		Insulation
					Material		Polystyrene Extruded
					Thickness		1"
				Envelope	Category	?	Vapour Barrier
					Material	?	Poly
					Thickness	?	6
				Wall_Cast in Place _Strip Footing_ Basement_ C_C			
					Length (ft)	362	452.5
					Height (ft)	13.6	13.6
					Thickness (in)	10	8
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar		#5
				Envelope	Category		Sheathing
					Material		Gypsum
					Thickness		5/8"
				Envelope	Category		Insulation
					Material		Polystyrene Extruded
					Thickness		1"
				Envelope	Category	?	Vapour Barrier
					Material	?	Poly
					Thickness	?	6
				Wall_Cast in Place _Strip Footing_ Basement_ M_M			
					Length (ft)	44	55.00
					Height (ft)	17	17
					Thickness (in)	10	8
					Concrete (psi)	?	3000
					Concrete flyash	?	average

			%		
			Rebar		
		Envelope	Category		Sheathing
			Material		Gypsum
			Thickness		5/8''
		Envelope	Category		Insulation
			Material		Polystyrene Extruded
			Thickness		1''
		Envelope	Category	?	Vapour Barrier
			Material	?	Poly
			Thickness	?	6
		Wall_Cast in Place _Strip Footing_ Basement_ P_P			
			Length (ft)	94	117.5
			Height (ft)	15	15
			Thickness (in)	10	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar		
		Envelope	Category		Sheathing
			Material		Gypsum
			Thickness		5/8''
		Envelope	Category		Insulation
			Material		Polystyrene Extruded
			Thickness		1''
		Envelope	Category	?	Vapour Barrier
			Material	?	Poly
			Thickness	?	6
		Wall_Cast in Place _Strip Footing_ Basement_ R_R			
			Length (ft)	64	64.00
			Height (ft)	7	7
			Thickness (in)	8	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar		
		Envelope	Category		Sheathing
			Material		Gypsum
			Thickness		5/8''
		Envelope	Category	?	Vapour Barrier
			Material	?	Poly
			Thickness	?	6
		Envelope	Category		Insulation

					Material		Polystyrene Extruded
					Thickness		1.5"
				Wall_Cast in Place _Strip Footing_ Basement_ S_S			
					Length (ft)	45	73
					Height (ft)	7	7
					Thickness (in)	8	8
					Concrete (psi)	?	3000
					Concrete flyash %	?	average
					Rebar		
				Envelope	Category		Insulation
					Material		Polystyrene Extruded
					Thickness		1.5"
				Envelope	Category	?	Vapour Barrier
					Material	?	Poly
					Thickness	?	6
				Envelope	Category		Sheathing
					Material		Gypsum
					Thickness		5/8"
A32 Walls Above Grade	**2020**	**m^2**					
				Wall_Concrete Block_Main Floor_Exterior			
					Length (ft)	546	546
					Height (ft)	13	13
					Rebar	0	0
				Envelope	Envelope Category	Insulation	Gypsum Board
					Material	1/2 "Gypsum Fiberglass board	1/2" Gypsum fiberglass Board
					Thickness	0	0
					Envelope Category	Cladding	Cladding
					Material	Brick_Concrete	Brick_Concrete
					Thickness	0	0
					Envelope Category	Insulation	Insulation
					Material	Fiberglass Batt	Fiberglass Batt
					Thickness	2"	2"
				Door	Number of Doors	0	0
				Window	Number of Windows	40	40
				Wall_Concrete Block_Second Floor_Exterior			
					Length (ft)	463	463
					Height (ft)	12	12

	Rebar	0	0
Envelope	Envelope Category	Insulation	Gypsum Board
	Material	1/2 "Gypsum Fiberglass board	1/2" Gypsum fiberglass Board
	Thickness	0	0
	Envelope Category	Insulation	Insulation
	Material	Fiberglass Batt	Fiberglass Batt
	Thickness	2"	2"
	Envelope Category	Cladding	Cladding
	Material	Brick_Concrete	Brick_Concrete
	Thickness	0	0
Door	Number of Doors	0	0
Window	Number of Windows	40	40
Wall_Concrete Block_Third Floor_Exterior			
	Length (ft)	463	463
	Height (ft)	12.2	12.2
	Rebar	0	0
Envelope	Envelope Category	Insulation	Gypsum Board
	Material	1/2 "Gypsum Fiberglass board	1/2" Gypsum fiberglass Board
	Thickness	0	0
	Envelope Category	Insulation	Insulation
	Material	Fiberglass Batt	Fiberglass Batt
	Thickness	2"	2"
	Envelope Category	Cladding	Cladding
	Material	Brick_Concrete	Brick_Concrete
	Thickness	0	0
Door	Number of Doors	0	0
Window	Number of Windows	46	46
Wall _Concrete Block_Fourth Floor_Exterior			
	Length (ft)	400	400
	Height (ft)	8.6	8.6
	Rebar	0	0
Envelope	Envelope Category	Gypsum Board	Gypsum Board
	Material	1/2 "Gypsum Fiberglass board	1/2" Gypsum fiberglass Board
	Thickness	0	0

					Envelope Category	Insulation	Insulation
					Material	Fiberglass Batt	Fiberglass Batt
					Thickness	2"	2"
					Envelope Category	Cladding	Cladding
					Material	Brick_Concrete	Brick_Concrete
					Thickness	0	0
				Door	Number of Doors	0	0
				Window	Number of Windows	85	85
B1 Partitions and Doors	**3013**	**m^2**					
				2.2.2 Wall_Concrete Block_Main Floor_Interior			
					Length (ft)	467	467
					Height (ft)	13	13
					Rebar	0	0
				Door	Number of Doors	12	12
				Window	Number of Windows	0	0
				2.2.2 Wall_Concrete Block_Second Floor_Interior			
					Length (ft)	665	665
					Height (ft)	12	12
					Rebar	0	0
				Door	Number of Doors	22	22
				Window	Number of Windows	0	0
				2.2.2 Wall_Concrete Block_Third Floor_Interior			
					Length (ft)	665	665
					Height (ft)	12.2	12.2
					Rebar	0	0
				Door	Number of Doors	22	22
				Window	Number of Windows	0	0
				Wall_Concrete Block_ Fourth Floor_Interior			
					Length (ft)	977	977
					Height (ft)	8.6	8.6
					Rebar	0	0
				Door	Number of Doors	31	31
				Window	Number of Windows	0	0
				2.1.3 Wall_Cast in Place _Strip Footing_			

		Basement_E_E			
			Length (ft)	80	80
			Height (ft)	13	13
			Thickness (in)	8	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar	#5	
		Envelope	Category		Cladding
			Material		Brick - Modular (metric)
			Thickness		-
		2.1.4 Wall_Cast in Place _Strip Footing_ Basement_ G			
			Length (ft)	27	33.75
			Height (ft)	6.90	6.90
			Thickness (in)	10	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar	#5	#5
		2.1.5 Wall_Cast in Place _Strip Footing_ Basement_ H_H			
			Length (ft)	23	23
			Height (ft)	3.5	3.5
			Thickness (in)	8	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar		
		2.1.7 Wall_Cast in Place _Strip Footing_ Basement_ P_P			
			Length (ft)	27	33.75
			Height (ft)	15	15
			Thickness (in)	10	8
			Concrete (psi)	?	3000
			Concrete flyash %	?	average
			Rebar		

IE Assumptions Document - Lasserre

Level 3 CIQS Element	Assembly Type	Assembly Name	Specific Assumptions
A11 Foundations			
	1.1 Concrete Footing		
		Footing _Strip_Basement_FH_H	In The Impact Estimator there is a limitation range of [7.5", 19.7"] for acceptable thickness. In order to find the width corresponding to the corrected thickness the Volume of original footing is calculated and equated to the volume of the corrected footing, to calculate the width related to the corrected volume: 1*2.6*23(ft)=(19(in))⁄12*23(ft)*Corrected Width Corrected Width=1.6 (ft)
		Footing_Strip_Basement_FM_M	In The Impact Estimator there is a limitation range of [7.5", 19.7"] for acceptable thickness. In order to find the width corresponding to the corrected thickness the Volume of original footing is calculated and equated to the volume of the corrected footing, to calculate the width related to the corrected volume: 2*2.2*44(ft)=(19(in))⁄12*44(ft)*Corrected Width Corrected Width=2.78 (ft)

		Footing_Strip_Basement_F K_K	Since the dimensions and material for Footing_Strip_Basement_ F K_K is the same as Footing_Strip_Basement_ F P_P .I have accounted K_K the same as P_P.
		Footing_Stairs_Concrete_TotalLength/Thickness	The thickness of the stairs was estimateded to be 10.5" based on the cross-section structural drawings
		Footing_Pad_Basement_F_A_1-5 & Footing_Pad_Basement_A1_1-2	Impact Estimator thickness limitation [7.5" to 19.7"] resulted in assuming 19" thickness ,as per strip footings, and adjusting width from 6.75' to 12.8' in order to maintain equal volume.
		Footing_Pad_Basement_F_B	Impact Estimator thickness limitation [7.5" to 19.7"] resulted in assuming 19" thickness ,as per strip footings, and adjusting width from 5.5' to 9.57' in order to maintain equal volume.
A21 Lowest Floor Construction			
	SOG	SOG Basement Plan Area	
			The thickness of the slab is 6". Input adjusted to 4" for IE limitations resulted in the width being adjusted from 71' to 106.5'.
A22 Upper Floor Construction			
	Floors / Roofs		

<table>
<tr>
<td rowspan="2"></td>
<td colspan="3">Each level was modeled as 2x Concrete Double T (1 floor , 1 roof) to best represent the actual concrete hollow-core panels that are not a modeling option in IE. The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete fly ash content and live load. The assumptions that had to be made in this assembly group were:

1. Live Load

Live load for the main, second, third and fourth floors were assumed to be 75 psi. This assumption was based on the below reasoning

In the drawing the live loads are specified as;

Classroom: 60 psi
Corridor: 100 psi
Offices: 50 psi

Since there is no option in the Impact Estimator to separate these live loads, The average of the specified live loads was taken which is62.5 psi and 75 psi which is the closet option to it has chosen from the Impact Estimator 45, 75 and 100 psi options.

2. Concrete Strength

Concrete strength was assumed to be 3,000 psi. In the drawings there is no specified concrete strength; however they mention that light weight concrete has been used. Light weight concrete generally has strength around 3000 psi which is the reason behind my assumption regarding concrete`s strength.

3. Fly Ash Percentage

Fly Ash percentage was assumed to be average, as discussed in the lectures.</td>
</tr>
<tr>
<td></td>
<td>Floor_Concrete Precast Double T_Main Floor</td>
<td>For simplicity the elevation of main floor is assumed to be constant in all classrooms.</td>
</tr>
</table>

	Columns and Beams	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; • Number of beams, • Number of columns, • Floor to floor height, • Bay size, • Supported span • Live load Since the live loading was not located within the Lasserre building information, a live load of 75psf on all four floors and the basement level were assumed.
A23 Roof Construction		
	General	
	• Live Load Live load for the roof of the building was assumed to be 45 psi since it is the closet to the specified live load in the drawings which is 40 psi. • Concrete Strength Concrete strength was assumed to be 3,000 psi. In the drawings there is no specified concrete strength; however they mention that light weight concrete has been used. Light weight concrete generally has strength around 3000 psi which is the reason behind my assumption regarding concrete`s strength. • Fly Ash Percentage Fly Ash percentage was assumed to be average, as discussed in the lectures.	
	Columns and Beams	

		Column _Concrete_Fourth Floor Small Bay Size	For the fourth floor since there are two different span and bay sized. Two conditions for the beam and column section have been created in order to address this size difference. The first set which is the same as other floors and the other set of column and beam which is modeled in the IE as the Column_Concrete_fourth Floor small bay size has different number of columns and beams with different bay and span size. Because of the variability of bay and span sizes in the fourth floor, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(7101 SF) / (70)] = 10.1 ft
	Slab		
		SOG Roof Plan Area 4" & 8"	8" slab lies within the 4" perimeter. 8" area was subtracted from 4"+8" area and then 4" Length and adjusted area were used to determine an effective 4" width of 44.3'
A31 Walls Below Grade			

Walls		
The length of the concrete cast-in-place walls needed adjusting to accommodate the wall thickness limitation in the Impact Estimator. It was assumed that interior steel stud walls were light gauge (25Ga) and exterior steel stud walls were heavy gauge (20Ga).		
	Wall_Cast in Place _Strip Footing_ Basement_M_M	• This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator for Cast in Place walls. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8”] = (44’) * [(10”)/8”] = 55 (ft) • 6 mm vapour barrier were assumed for all of the Footing_ Strip_ Basement foundations.
	Wall_Cast in Place _Strip Footing_ Basement_ G	• This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator for Cast in Place walls. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8”] = (27’) * [(10”)/8”] = 33.75 (ft)

			• 6 mm vapour barrier were assumed for all of the Footing_ Strip_ Basement foundations.
		Wall_Cast in Place _Strip Footing_ Basement_ C_C	• This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator for Cast in Place walls. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8”] = (362’) * [(10”)/8”] = 452.5 (ft) • 6 mm vapour barrier were assumed for all of the Footing_ Strip_ Basement foundations.
		Wall_Cast in Place _Strip Footing_ Basement_ P_P	• This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator for Cast in Place walls. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8”] = (121’) * [(10”)/8”] = 151.25 (ft) • Since the dimensions and material for Footing_Strip_Basement_ F K_K is the same as Footing_Strip_Basement_ F P_P .I have accounted K_K the same as P_P.

			• 6 mm vapour barrier were assumed for all of the Footing_ Strip_ Basement foundations.
		All Walls Below Grade	3/4" Gypsum, on 1" EPS insulation and 6 mm vapour barrier were assumed for all below grade walls.
A32 Walls Above Grade			
		Wall _Concrete Block_MainFloor_Exterior	The entrance doors for the main floor exterior walls were assumed as windows because they are doors made out of glass.
		All	Assembly assumed as 2" Fibreglass batt with 1/2" gypsum board and brick cladding
B11 Partitions			

	Wall_ConcreteBlock_Main Floor_Interior	• The interior walls were assumed to be concrete block the same as the exterior walls. • The ½” gypsum board were assumed on both sides of the interior walls. • The main floor plan was very vague and unreadable. Therefore the interior walls length is what I picked up by walking through the building.
	Wall_ConcreteBlock_Second Floor_Interior	• The interior walls were assumed to be concrete block the same as the exterior walls. • The ½” gypsum board were assumed on both sides of the interior walls.
	Wall_ConcreteBlock_Third Floor_Interior	• The interior walls were assumed to be concrete block the same as the exterior walls. • The ½” gypsum board were assumed on both sides of the interior walls.
	Wall_ConcreteBlock_Fourth Floor_Interior	• The interior walls were assumed to be concrete block the same as the exterior walls. • The ½” gypsum board were assumed on both sides of the interior walls.