An Environmental Performance Declaration of the Mathematics Building

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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.

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Civil Engineering

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Course: CIVL 498C – Life Cycle Assessment
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Executive Summary

This project is a coursework carried out by students of the CIVL 498C technical elective course in Civil Engineering at the University of British Columbia. It is part of a comparative study between the environmental performances of different institutional buildings within the Vancouver Campus, and its results will be used in the UBC LCA Database. In total, 17 buildings were assessed, including Chemistry, Chemistry North, Chemistry South, Henry Angus, Wesbrook, Geography, Earth Sciences, Allard Hall, Forest Science Center, Mathematics, Civil and Mechanical Engineering, Music, Lasserre, Pharmacy, Kaiser, Douglas Kenny and AERL. This paper focuses only in the Math building study and it is important to underline that the results presented here are not representative of the original construction of the building in 1925, but a LCA study of the materials and construction methods used.

The previous model and report by Nemec and the class notes were base for this study. The previous model was improved and analysed for product and construction stages. OnCenter's OnScreen Takeoff (OST) and the Athena Sustainable Materials Institute's Environmental Impact Estimator (EIE) were the softwares used in the modeling.

The results showed the efficiency of wood as building material in terms of environmental performance. The total Math building impacts are between 60% and 80% less than the average of the buildings analysed. However, to obtain a complete knowledge of the influence of wood in the environmental performance of buildings, conducting a LCA study through the whole life cycle, including use and end-of-life stages, is fundamental.

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1.0 General Information on the Assessment

Purpose of the Assessment

One of the firsts steps when conduction a Life Cycle Assessment (LCA) is to define the goal of the study. Based on ISO 14044:2006, the items that shall be included in the goal of an LCA are the intended application, the reasons for carrying out the study, the intended audience and whether the results are intended to be used in comparative assertions (7).

This LCA study aims to quantify the environmental performance in the manufacturing and construction stages of the Mathematics building at UBC and it is part of a comparative study for the course CIVL 498C – Life Cycle Assessment. The results of this study will integrate the UBC LCA Database, being accessible for the UBC community and helping decision-makers improve future buildings designs within the campus, as well as be an available tool for students to learn about green building and sustainability. In this study, the environmental performance of the Math building will be compared with other buildings within the UBC Vancouver Campus in order to evaluate different construction methods and materials. Given that this is a coursework, some simplifications are acceptable and they will be discussed later in this paper.

Identification of the Building

The Mathematics building is located at 1984 Mathematics Road, UBC Vancouver Campus. It has a two-story wood frame structure with a stucco finishing on the exterior and a total constructed area of approximately 2700 m^2. It is an institutional building with 18 classrooms, 21 offices, 6 bathrooms, 2 locker rooms, 2 faculty lounges and a large lecture room with seating for 250 people designed by the Provincial Department of Public Works. A total number of 650 occupants was estimated considering each class with capacity for 20 students. Figure 1 shows a view of the main entrance of the building.

Figure 1. Front entrance of Math building.

The building was built between 1924 and 1925 with an expected life span of 40 years, and it was one of the considered nine semi-permanent building at that time (University of British Columbia, *21st Anniversary*). The other eight semi-permanent buildings are Arts One, the Auditorium, Geography, Math Annex, Mining Metallurgy and Hydraulics, Mechanical Engineering Lab, Mechanical Engineering Annex and an Old administration. The building originally housed Departments of Classics, Economics, Sociology and Political Science, English, History, Mathematics, Modern Languages and Philosophy and was named Arts Building until 1960, when it began to be called Mathematics Building (University of British Columbia, *Archives*).

The original cost of all nine semi-permanent buildings was $ 500,000 (University of British Columbia, *Archives*). Considering all of them had the same kind of structure and similar patterns of use, the cost of the Math building in 1925 was estimated at $ 85,000, based on the constructed area of each building, taken from a campus map available at the UBC website. To be consistent when comparing costs between buildings, all students converted the cost to 2013 Canadian dollars. Due to lack of building escalation rate data, Canadian Consumer Price Index (CPI) was used to convert the cost from 1925 to 1979 (Government of Canada, Table 326-0021). From 1980 onwards, specific building information was used (Government of Canada, Table 327-0044). The 2013 cost for Math buildings obtained was $932,618.26.

Other Assessment Information

Table 1 below provides a summary of assessment information.

Table 1. Summary of assessment information.

Client for Assessment	Completed as coursework in CIVL 498C technical elective course in Civil Engineering at the University of British Columbia.
Name and qualification of the assessor	Henrique Falck Grimm and Dallas Nemec, Civil Engineering students.
Impact Assessment method	US EPA TRACI v 2.1 (2012) in the Athena Impact Estimator for Buildings v 4.2.0208
Point of Assessment	88 years since the building's construction.
Period of Validity	5 years.
Date of Assessment	Completed in December 2013.
Verifier	Coursework, study not verified.

2.0 General Information on the Object of Assessment

Functional Equivalent

One of the main objectives of this study is to compare the environmental performance of different types of buildings. In order to do so, it is necessary to define a measurable unit that we can use to normalize the results. This unit is what the ISO 14044:2006 names as "functional unit" (8). For this specific study, the functional unit chosen was per square meter of constructed area. This way it is possible to divide the impact results per area and obtain a normalized value able to be compared with the results from other buildings. A Math building's functional equivalent is presented in table 2.

Table 2. Functional Equivalent Definition Template.

Aspect of Object of Assessment	Description
Building Type	Institutional
Technical and functional requirements	When first designed, office, research, and lecture space for the departments of Classics, Economics, Sociology and Political Science, English, History, Mathematics, Modern Languages and Philosophy
Pattern of use	650 occupants, 18 classrooms, 21 offices, 1 large lecture room
Required service life	40 years

Reference Study Period

A complete LCA study assesses the whole life cycle of the product, from raw material acquisition to final disposal (ISO 14044:2006 2), including product, construction process, use and end of life stages, and recycling when applicable. In this case, the reference study period shall be defined as the required service life of the building. However, this specific study was focused in the material selection and construction of the building. Therefore, only product and construction process stages were considered in this project, and the reference study period was defined as a year, although the required service life of the building was 40 years.

Object of Assessment Scope

According to EN15978, the object of assessment should include the building, from its foundations to the external works enclosed within the area of the building's site, over the reference study period. In the case of this particular study, some works were not included, such as painting and floor finishes. This way, we were able to focus only in the structure and envelope of the building and get deeper into the details of these elements. For this purpose, we used a modified version of the CIQS Level 3 Elements in order to sort the model inputs. Table 3 below shows the elements used and correspondent functional unit, a description of what was considered and the quantity used in the model for each element category.

Table 3. Building Definition Template.

CIVL 498C Level 3 Elements	**Description**	**Quantity**	**Unit**
A11 Foundations	Includes all foundations. Measured by total area of the ground floor.	1,451.17	m^2
A21 Lowest Floor Construction	Ground floor and structure supporting it. Measured by total area of the ground floor.	1,451.17	m^2
A22 Upper Floor Construction	All upper floors and structures supporting them. Stairs were also included in this element category. Measured by the sum of area of all upper floors.	1,366.64	m^2
A23 Roof Construction	All roofs and structures supporting them. Measured by the sum of area of all roofs.	1,453.04	m^2
A31 Walls Below Grade	Sum of total surface area of the exterior walls below grade.	588.45	m^2
A32 Walls Above Grade	Sum of total surface area of the exterior walls above grade, including doors and windows.	2237.56	m^2
B11 Partitions	Sum of total surface area of the interior walls, including doors and windows.	2,580.13	m^2

The Math building’s foundations consist of small slabs-on-grade and strip and square footings made of concrete, instead of the usual big concrete slab-on-grade placed in the whole ground floor area used in many buildings. There are concrete stairs in each entrance of the building. The lowest floor is a wood-joist floor supported by a structure of wood posts and beams, and steel trusses support the wood-joist in the second floor. Wood stairs make the connection between the two floors. The walls below grade are cast-in-place concrete walls, while the remaining ones are wood-stud walls. Exterior walls have a stucco finish and the partitions received a lath and plaster finish. For the roof, they used 4 ply felt with gravel as material.

3.0 Statement of Boundaries and Scenarios Used in the Assessment

System Boundary

ISO 14044:2006 defines system boundary as criteria responsible for specifying which unit processes are part of a product system (5), defining what should be included or excluded from the study. Figure 2 shows all building life cycle modules indicated by EN 15798 to compose the system boundary.

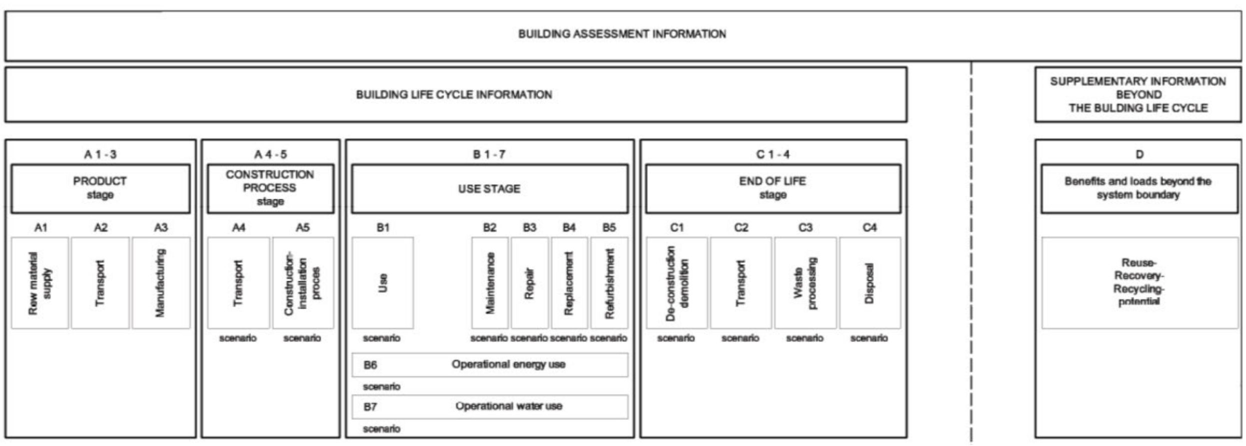


Figure 2. Display of modular information for the different stages of the building assessment.

However, as briefly stated earlier, this LCA study focus in the materials and construction methods in order to obtain a satisfactory level of detail. Therefore, the system boundary here defined only includes the product and construction stages. For these stages, we can describe upstream and downstream processes that support them. The upstream process would be the raw material supply necessary for the manufacturing in the product stage. After that, the products have to be transported to the construction site and the construction stage begins. The downstream processes are use and maintenance at the use stage until the final disposal at the end-of-life stage. In the following sections, we are going to describe better the scenarios used in this assessment.

Product Stage

The product stage includes the extraction of raw material, transport and manufacturing of the products and services to be used in the construction stage. For this reason, this stage is also known as “cradle to gate”. According to Athena Sustainable Materials Institute (“Technical Details”), extraction of raw material considers harvesting, mining or quarrying of a resource, reforestation, beneficiation (a mining technique that involves separating ore into valuable product and waste) and transportation of raw resources to the mill or plant. This is the end of extraction and the beginning of manufacturing, which is usually the stage with more influence in the embodied energy and emissions related to the product. Manufacturing stage starts with the delivery of raw resources and other materials to the mill or plant gate and ends with the finished product ready for shipment, including generation of the energy input, production of ancillary materials or pre-products and packaging. Although the transportation from cradle to the product gate is considered in the product stage, transportation leaving the mill or factory towards the construction site is taken into account in the construction stage.

Construction Stage

This stage begins at the production gates with the transportation of each manufactured building product to the construction site. Within the Impact Estimator, average or typical transportation distances to building sites within each city are applied. The processes included in this stage are building product transportation, waste generation, energy use of machines like cranes and mixers, transportation of equipment to and from the site, concrete formwork, and temporary heating and ventilation (Athena Sustainable Materials Institute, "Technical Details").

4.0 Environmental Data

Data Sources

To carry on an LCA study, we need a Life Cycle Inventory (LCI) database to rely on. LCI database is what allow us to measure all the flows crossing the system boundary. These flows are then converted into environmental impacts using an impact assessment method, better described in section 5.0. Data collection is based on researches and surveys filled out by the industry for each unit process, regarding material and energy inputs, water consumption and material outputs. After the collection, this data is analysed considering air, water and land emissions. The main problem in this process is that many companies are not willing to share their data, for fear of being exposed to the rivals.

The data sources behind the software used in this study, the Athena Impact Estimator, are the Athena LCI Database for material process data and the US LCI Database for energy combustion and pre-combustion processes for electricity generation and transportation. The Athena Institute manages the Athena LCI Database, developing an ever-growing set of comprehensive, comparable LCI databases for building materials and products. To date, they have invested more than $2 million in their researches (Athena Sustainable Materials Institute, "LCI Databases"). The US LCI Database is developed by the National Renewable Energy Laboratory (NREL). The U.S. Department of Energy enlisted them to review and harmonize LCAs of electricity generation technologies in order to understand the range of published results of LCAs of electricity generation technologies, reduce the variability in published results and clarify the central tendency of published estimates (NREL).

Data Adjustments and Substitutions

In the previous model, due to EIE limitations, interior walls finish was modeled as ½" regular gypsum board instead of the actual lath and plaster. In order to improve the model, some adjustments were made regarding this assumption. First, in order to find the contribution of gypsum board for the total impacts, 1 m^2 of it was modeled in the EIE. The software adds a waste factor of 10% and to obtain 1 m^2 the input used was 0.9091 m^2. Then, the results were multiplied by the total area of gypsum board and subtracted from the total impacts.

To substitute the impacts, it was necessary to find LCI data for plaster. However, the use of plaster over lath in interior finishes was replaced by gypsum boards about 30 or 40 years ago (Venta 2-6) and it is not common to find articles with this data. Thus, SimaPro 8.0 Demo was used to generate the impacts for 1 kg of plaster. The results were converted into m^2 using a thickness of ½" and a plaster density of 849 kg/m^3 (SImetric), giving us 10.78 kg of plaster per m^2. Then the impacts were multiplied by the previous gypsum board area and added back to the total impacts in the building.

Another possible inaccuracy is in the modeling of reinforced concrete. Information about the fly ash content, rebars and concrete stregth was guessed in the previous model. Unfortunately, the real information about them could not be found and these materials could not be improved in the model.

Data Quality

The results of a LCA study are always subject to uncertainties due to LCI data collection. They may be related specifically with the data itself, modeling, temporal and spatial variability and variability between sources, among others. Data uncertainty regards issues in collecting data, allocation methods and inaccuracy or lack of data. As mentioned previously, Athena Database has no information about plaster over lath finish, which caused inaccuracy in the previous model. Use of linear or non-linear modeling is another source of uncertainty. Temporal variability, such as difference in yearly factory emissions and data vintage, can also generate uncertainty for the impact results. The factories from where the data was collected can improve their environmental performances over the years and the data can easily become out-of-date. For this project, data available in 2013 was used to assess a building from 1925. Therefore, the results in this paper do not represent the impacts of the original Math building's construction, but of an identical building constructed nowadays. Spatial variability refers to the regional differences between factories, but this is well addressed by the Athena Database, which allows us to choose Vancouver, in the case of this study, as the region of the building. Uncertainty related with variability between sources is due to the differences between factories and the technologies they use to produce the same product.

The high complexity of the variables involved in a LCA generates an inherent degree of uncertainty to it. However, "The uncertainty in LCA is not an imperfection; there is no such thing as absolute certainty when evaluating life cycle environmental impacts across a complex and widespread value chain." (O'Connor, Meil and Baer 3). Therefore, LCI databases used in this study were considered satisfactory.

5.0 List of Indicators Used for Assessment and Expression of Results

After collecting the LCI data, we have to convert the flows into environment impacts. For this purpose, Athena Impact Estimator uses the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.1 (2012) developed by the U.S. Environmental Protection Agency (US EPA). This tool transforms the inputs and outputs of the system boundary into environmental performance and divides it in different impact categories, each one measured based on a category indicator. Table 4 shows the impact categories used by Impact Estimator, their category indicator and possible endpoint impacts.

Table 4. US EPA TRACI methodology.

Impact Category	Category Indicator	Endpoint Impact
Fossil Fuel Consumption	MJ	Natural resources depletion
Global Warming	kg CO_2 equivalent	Rising sea level
Acidification	moles of H^+ equivalent	Forests affected by acid rain
Human Health Criteria – Respiratory	kg particulate matter 10 µm equivalent	Respiratory issues
Eutrophication	kg N equivalent	Changing in marine life pattern
Ozone Layer Depletion	kg CFC-11 equivalent	Skin cancer
Smog	kg O_3 equivalent	Airport operation problems

6.0 Model Development

This project was based on the previous model and report studied by Nemec in 2010. According to his report (6-9), the sofwares he used for modeling the Math building were the OnCenter's OnScreen Takeoff (OST) and the Athena Sustainable Materials Institute's Environmental Impact Estimator (EIE).

A11 Foundations includes only the footing in the building. Strip footings for the exterior and interior foundation walls were measured in OST using a linear condition. Square footings were counted based on dimension and the depth was assumed to be 12" for all footings. Figure 3 shows a plan view of the foundations with the takeoffs of the footings.

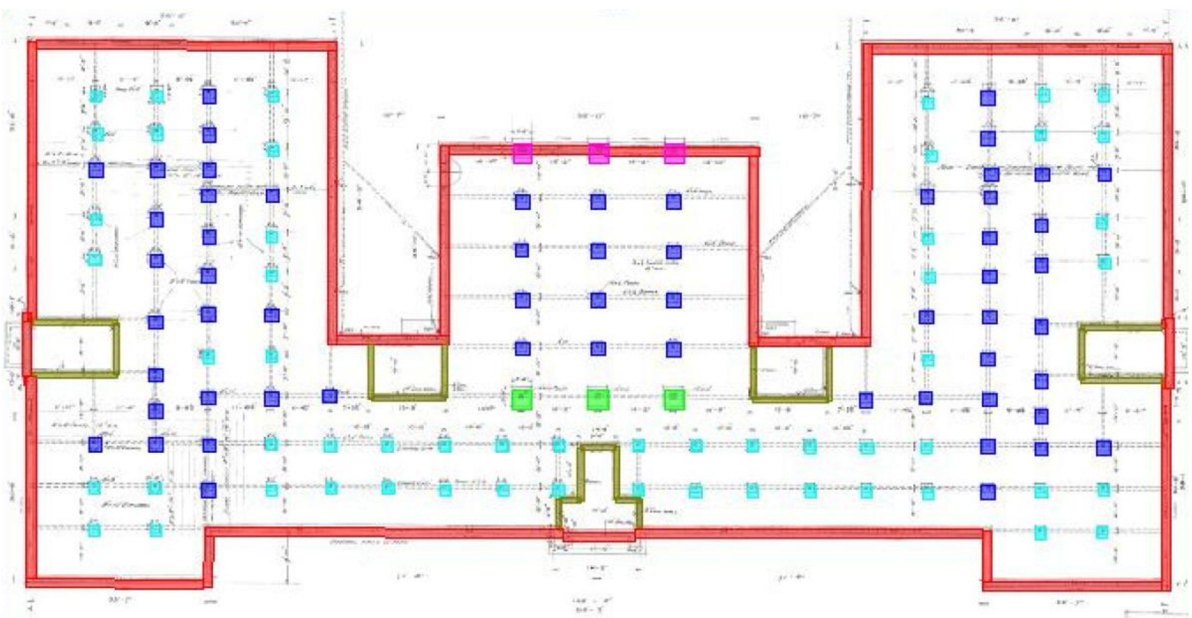


Figure 3. Foundation plan in OST showing footings takeoffs.

Slabs on grade and the ground floor were considered in A22 Lowest Floor Construction. Slabs on grade and floors were measured using an area condition. The concrete floor on the ground floor bathroom was also modeled as slab on grade. In the previous model, for floor, an average span was found for a floor by finding a weighted average span. Figure 4 shows the previous ground floor takeoff. This method was considered as a possible source of uncertainty and the ground floor was remodeled, taking each floor span individualy (Figure 5). However, the difference in the results were less than 1% compared with the previous model and upper floor modeling was kept the same. Posts and beams supporting the lowest floor were modeled as extra basic materials.

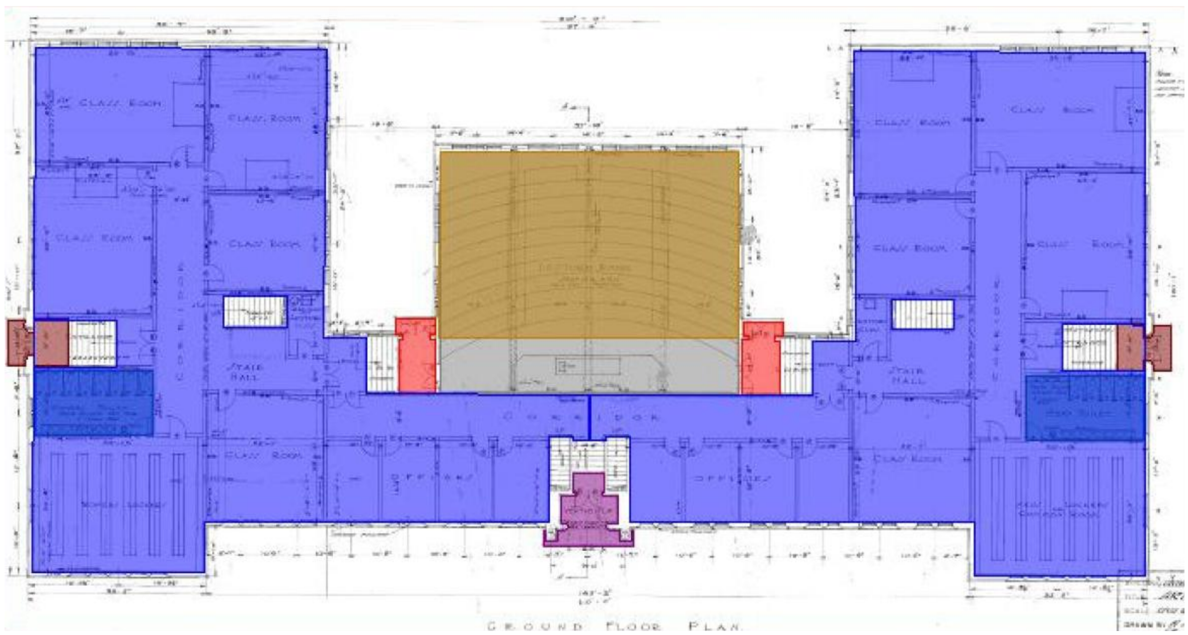


Figure 4. Previous ground floor takeoff.

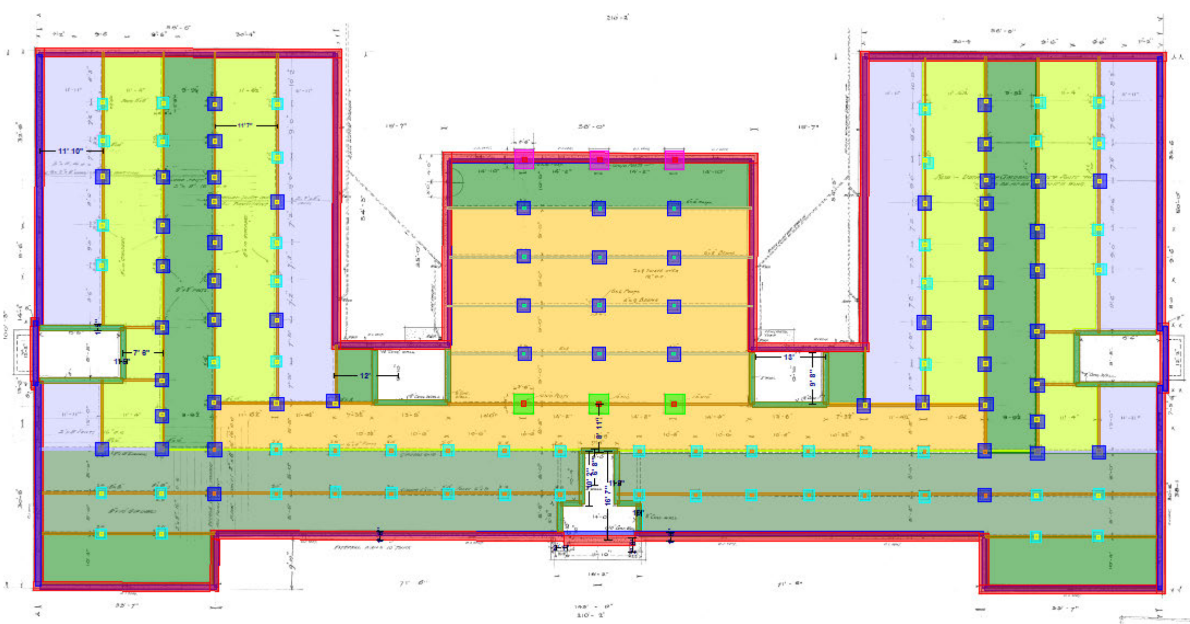


Figure 5. Remodeled ground floor.

Stairs, the sloped floor in the lecture room, the second floor and the structure supporting it are part of the A22 Upper Floor Construction. The entrance stairs were modeled as slabs on grade with the thickness taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. The stairs connecting the ground and the upper floor were modeled as extra basic materials. The wood joist floor modeling followed the same method used in the ground floor and the steel trusses supporting it were modeled as extra basic materials.

A23 Roof Construction includes the roof itself and the structure supporting it. Roofs were modeled similar to floors. The building's roof was divided into a section over the lecture room and a section over the rest of the building.

A31 Walls Below Grade, A32 Walls Above Grade and B11 Partitions were modeled in OST using a linear condition. Cast in place concrete walls are part of A31. All the other walls were wood stud walls and were divided in A32 and B11, respectively exterior and interior. Doors and windows belonging to these walls were modeled as part of them.

For further information regarding the EIE inputs and assumptions made, see Annex D – Impact Estimator Inputs and Assumptions.

After modeling the building using the inputs described above, we are able to measure the outputs from each process. This measure is what ISO 14044:2006 names as reference flow (5), and it is required to fulfil the function expressed by the functional unit. Table 5 below presents the Math building's bill of materials for each element category.

Table 5. Bill of materials.

Reference Flow	Material	Quantity	Unit
A11 Foundations	Concrete 30 MPa (fly ash av)	53.6197	m3
	Rebar, Rod, Light Sections	0.9804	Tonnes
A21 Lowest Floor Construction	Cedar Wood Shiplap Siding	1521.3523	m2

Reference Flow	**Material**	**Quantity**	**Unit**
	Concrete 30 MPa (fly ash av)	12.313	m3
	Galvanized Sheet	0.3308	Tonnes
	Large Dimension Softwood Lumber, Green	21.4461	m3
	Large Dimension Softwood Lumber, kiln-dried	35.2164	m3
	Nails	0.3348	Tonnes
	Water Based Latex Paint	163.6422	L
	Welded Wire Mesh / Ladder Wire	0.106	Tonnes
A22 Upper Floor Construction	Cedar Wood Shiplap Siding	1481.9757	m2
	Cold Rolled Sheet	0.797	Tonnes
	Concrete 30 MPa (fly ash av)	13.3248	m3
	Galvanized Sheet	0.254	Tonnes
	Large Dimension Softwood Lumber, kiln-dried	41.2643	m3
	Nails	0.3261	Tonnes
	Rebar, Rod, Light Sections	0.2473	Tonnes
	Small Dimension Softwood Lumber, Green	2.5245	m3
	Water Based Latex Paint	159.4067	L
	Welded Wire Mesh / Ladder Wire	0.0972	Tonnes
A23 Roof Construction	Ballast (aggregate stone)	91541.6798	kg
	Cedar Wood Shiplap Siding	1598.3468	m2
	Galvanized Sheet	0.2276	Tonnes
	Large Dimension Softwood Lumber, Green	4.4265	m3
	Large Dimension Softwood Lumber, kiln-dried	45.8487	m3
	Nails	0.3517	Tonnes
	Roofing Asphalt	11918.3898	kg
	Water Based Latex Paint	171.924	L
A31 Walls Below Grade	#15 Organic Felt	191.7109	m2
	Cedar Wood Shiplap Siding	171.276	m2
	Concrete 30 MPa (fly ash av)	89.3541	m3
	Double Glazed No Coating Air	4.4465	m2
	Galvanized Sheet	0.1573	Tonnes
	Nails	0.0344	Tonnes
	Rebar, Rod, Light Sections	3.1613	Tonnes

Reference Flow	Material	Quantity	Unit
	Screws Nuts & Bolts	0.0491	Tonnes
	Small Dimension Softwood Lumber, Green	4.3403	m3
	Stucco over metal mesh	171.276	m2
	Unclad Wood Window Frame	121.5861	kg
	Water Based Latex Paint	38.7435	L
A32 Walls Above Grade	#15 Organic Felt	2748.4089	m2
	1/2" Plaster	1671.6276	m2
	Cedar Wood Shiplap Siding	2455.4506	m2
	Concrete 30 MPa (fly ash av)	6.0103	m3
	Double Glazed No Coating Air	251.752	m2
	Galvanized Sheet	2.2546	Tonnes
	Joint Compound	1.6683	Tonnes
	Nails	0.4753	Tonnes
	Paper Tape	0.0191	Tonnes
	Rebar, Rod, Light Sections	0.1418	Tonnes
	Screws Nuts & Bolts	0.6738	Tonnes
	Small Dimension Softwood Lumber, Green	43.4634	m3
	Small Dimension Softwood Lumber, kiln-dried	0.4666	m3
	Stucco over metal mesh	2455.4506	m2
	Unclad Wood Window Frame	3452.2548	kg
	Water Based Latex Paint	586.3093	L
B11 Partitions	1/2" Plaster	4559.356	m2
	Concrete 30 MPa (fly ash av)	14.8273	m3
	Joint Compound	4.5503	Tonnes
	Nails	0.4303	Tonnes
	Paper Tape	0.0522	Tonnes
	Rebar, Rod, Light Sections	0.5246	Tonnes
	Small Dimension Softwood Lumber, Green	55.7373	m3
	Small Dimension Softwood Lumber, kiln-dried	5.9875	m3
	Water Based Latex Paint	53.9413	L

7.0 Communication of Assessment Results

Life Cycle Results

At this point, we are able to generate the results of the Math building's environmental performance for the product and construction stages using the improved model, which you can see in table 6. Product stage has only total results because the data used to improve the model did not distinguish manufacturing and transport process modules. The functional unit used to generate the total impact per m² was the total constructed area (ground floor + upper floor).

Table 6. Math building's environmental impacts.

	Life Cycle Stage	**PRODUCT**	**CONSTRUCTION PROCESS**			
	Process Module	**Total**	**Construction-installation Process**	**Transport**	**Total**	**Total per m²**
Fossil Fuel Consumption	(MJ)	2247997.18	120285.30	110203.85	230489.15	879.58
Global Warming	(kg CO2eq)	152375.08	9669.53	8156.12	17825.65	60.40
Acidification	(moles of H+eq)	1088.28	79.56	39.12	118.68	0.43
Human Health Criteria – Respiratory	(kg PM10eq)	483.08	26.42	1.20	27.61	0.18
Eutrophication	(kg Neq)	68.35	4.77	2.81	7.58	0.03
Ozone Layer Depletion	(kg CFC-11eq)	1.24E-03	2.35E-05	3.25E-07	2.38E-05	4.50E-07
Smog	(kg O3eq)	22739.88	1762.06	1383.42	3145.48	9.19

Below we can see the hotspots in each life cycle stage and Level 3 Element. For the life cycle stages (figure 6), we can see that production stage contributes with more than 90% of the total impacts. As shown in section 3.0, production includes raw material extraction, manufacturing and the transport between them. The high impacts of this stage are mainly due to high energy needed to extract and manufacture the products prior to be delivered in the construction site. Another possible reason is that sometimes the distance between extraction and industry can be long, requiring more fuel consumption to transport the raw material.

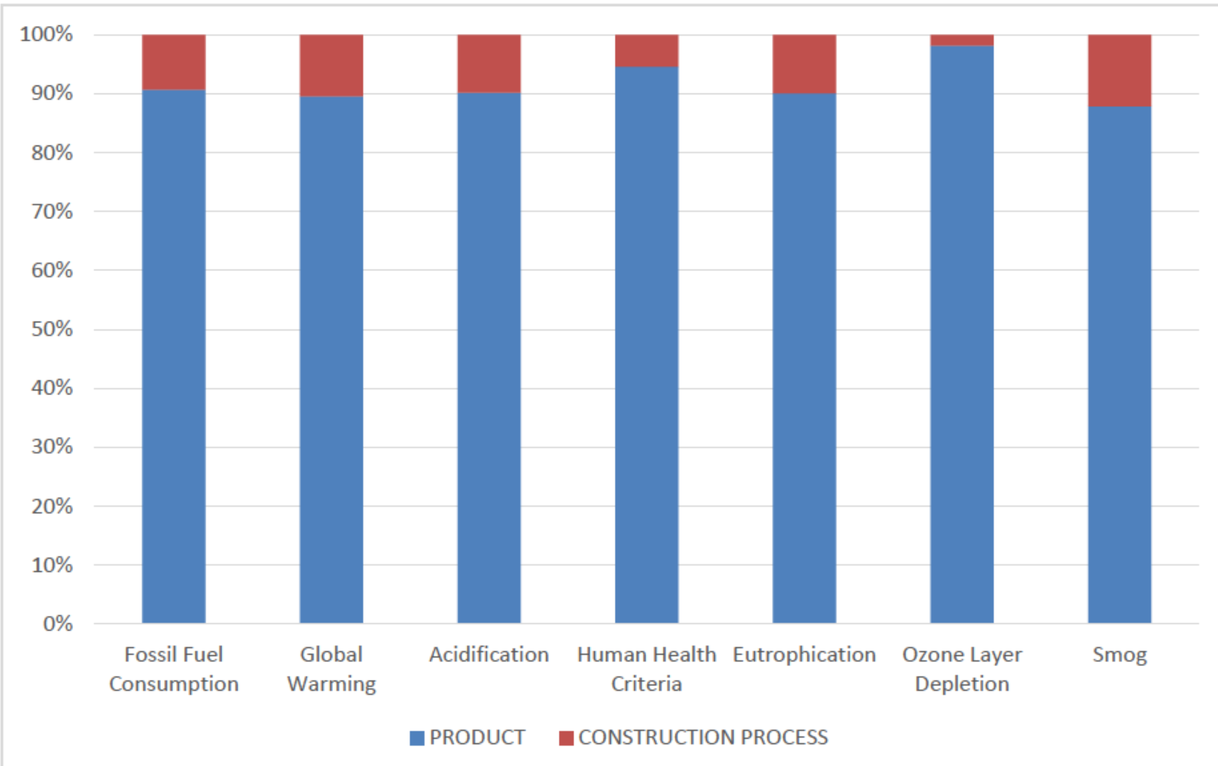


Figure 6. Life cycle stage hotspots.

Analysing the Level 3 Elements hotspots (figure 7), it is possible to see that A32 Walls Above Grade have a large participation in the Math building's environmental performance. Comparing the exterior wall with interior partitions, which has a similar constructed area, one of the differences is the exterior stucco finish. Therefore, this can be a possible origin for the higher impacts of the exterior walls. Another element that stands out is A23 Roof Construction. It has high contribution in fossil fuel consumption and human health criteria. One explanation for that could be the high impact of gravel extraction, used in the roof. Its extraction generates lots of particulate matter, causing respiratory issues. In addition, gravel is a heavy material and requires a lot of energy to be transported. It is also interesting to notice the relevant impact of A31 Walls Below Grade. Although their constructed area is about 25% of the walls above grade, walls below grade are made of concrete and have a significant impact in the total environmental performance of the building.

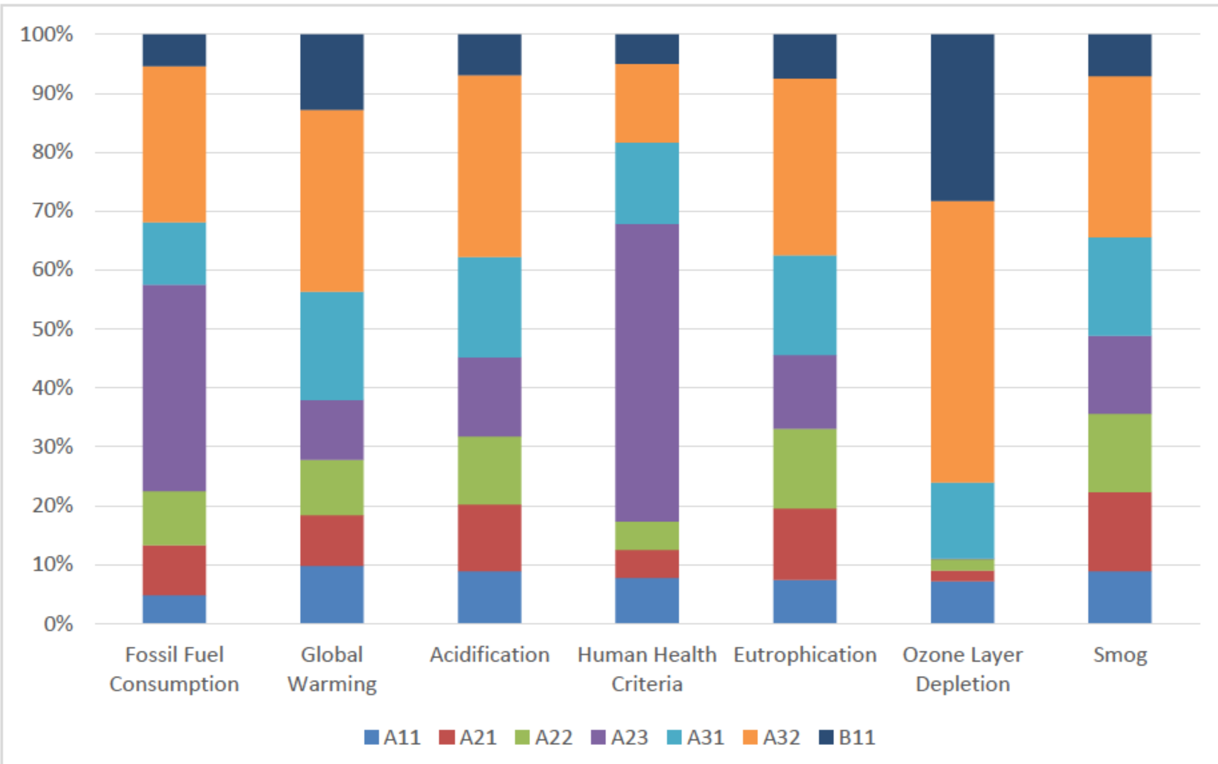


Figure 7. Level 3 Elements hotspots.

In order to provide the reader with further interpretation of the results, their use and reflections on the study, Annex A - Interpretation of Assessment Results, Annex B - Recommendations for LCA Use and Annex C - Author Reflection were included at the end of this paper.

Works Cited

Athena Sustainable Materials Institute. *LCI Databases*. 2013. 18 de November de 2013. <http://www.athenasmi.org/our-software-data/lca-databases/>.

—. *Technical Details*. 2013. 18 de November de 2013. <http://www.athenasmi.org/resources/about-lca/technical-details/>.

EN 15978:2011. *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*.

Government of Canada. *Statistics Canada*. 25 de January de 2013. Table. 17 de November de 2013. <http://www.statcan.gc.ca/start-debut-eng.html>.

ISO 14044:2006. *Environmental management – Life cycle assessment – Requirements and guidlines*.

Nemec, Dallas. *A Life Cycle Assessment of the Mathematics Building*. Vancouver, 2010.

NREL. *Energy Analysis - Life Cycle Assessment Harmonization*. 17 de October de 2013. 18 de November de 2013. <http://www.nrel.gov/analysis/sustain_lcah.html>.

O'Connor, Jennifer, et al. "LCA in construction - status, impacts and limitations." *White Paper* (2012): 8.

Sianchuk, Rob. *Class Notes*. Vancouver, 2013.

SImetric. *SImetric: Densitity of Materials*. 4 de April de 2011. 16 de November de 2013. <http://www.simetric.co.uk/si_materials.htm>.

University of British Columbia. "The University of British Columbia: Twenty-First Anniversary - 1915-1936." 1936. *UBC Library.* 13 de November de 2013.

—. *University Archives: Mathematics Building*. s.d. 13 de November de 2013. <http://www.library.ubc.ca/archives/bldgs/math.html>.

Venta, George J. "Life cycle analysis of gypsum board and associated finishing products." *The Athena Sustainable Materials Institute* (1997): 150.

Annex A - Interpretation of Assessment Results

Benchmark Development

One of the principal uses of the results of an LCA study applied to buildings is to compare the environmental performances of different building designs in order to choose the best one. If the results are analysed individually, it is very difficult to conclude whether they are performing well or not. Here is where we apply the benchmarking, to see how good a project is when compared to another one. For this study, the results were compared with the average of all analysed buildings. In order to do so, all students conducted their studies under the same Goal & Scope and the results were normalized using the same functional units, as indicated by ISO 14044:2006 (8).

UBC Academic Building Benchmark

Results and 2013 costs of all buildings were shared in an online document, which was used to calculate the average. Three buildings, Chemistry North, Pharmacy and AERL, were excluded from the benchmarking because presented inconsistencies. For costing considerations, Wesbrook, Geography, Chemistry South and Douglas Kenny buildings were excluded because their costs were not available. The document was accessed on November 17, 2013, and the results shown in the benchmarking may vary as students uploaded new results.

Figure 8 compares the Math building's results against the class benchmark. Positive values represent results above the average and negative, below. As expected, the Math building's impacts are below the average. This was already expected given that Math building has a wood structure and most of the other buildings are made of concrete. It is known that cement manufacture has great influence in the world carbon emissions and therefore, concrete buildings are expected to be higher environmental impacts. It is interesting to notice that A31 Walls Below Grade is the Level 3 Element closer to the average. Coincidently, these walls are all cast-in-place concrete walls.

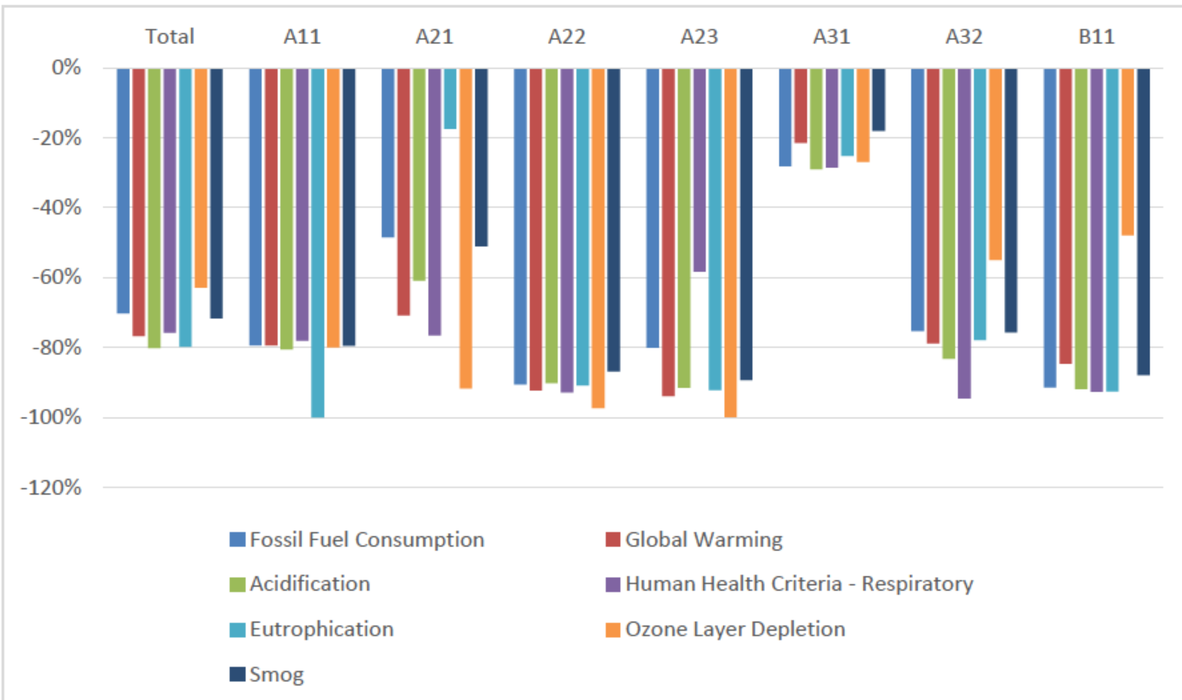


Figure 8. Percentage difference from average.

Figure 9 shows a scatter plot of total cost and global warming potential impacts of the studies. Global warming was chosen for its current importance in the environmental discussions. The upper-right corner in the plot indicates high cost and high carbon emissions, thus a not good investment. On the other hand, buildings in the lower-left corner have low cost and low emissions. Looking to the plot, wood buildings like Math seem to be a good investment for decreasing carbon emissions. However, it is important to underline that this study is only focused in product and construction stages. Thermal performance in the use stage, for example, shall be considered through the whole life of the building and can change completely the results presented in this plot.

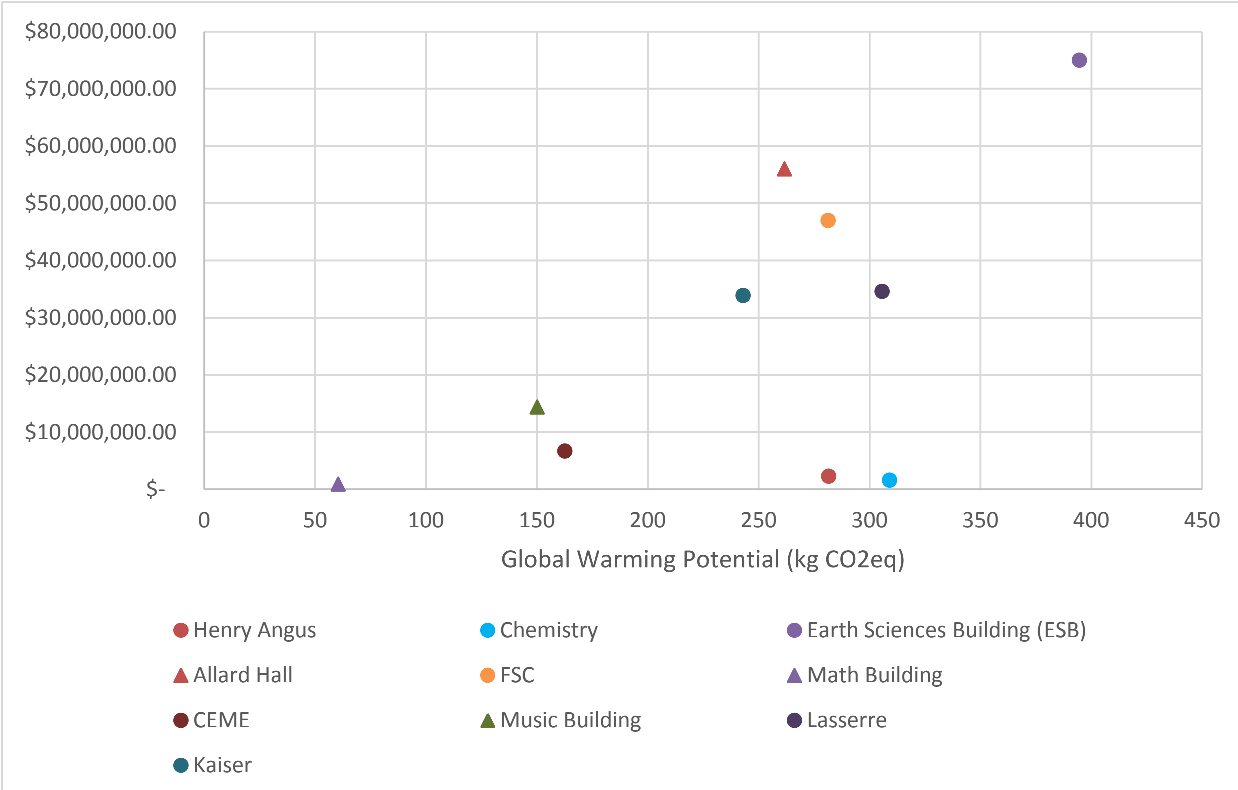


Figure 9. Global warming performance vs. 2013 cost.

Annex B - Recommendations for LCA Use

Although this study shows very important results for environmental performance of buildings, some caution should be taken when analysing its conclusions. Regarding life cycle stages, for example, the results presented here only consider product and construction stages. However, life cycle goes beyond this, with use and end-of-life stages. After the construction of the building, energy consumption and maintenance during the use stage have large influence in the total environmental impacts, and the choice of materials can drastically change the final building performance. Impacts produced by the disposal of these materials at the end of the building's life also have to be taken into account in a complete LCA.

This kind of comparative study is very important for decision-makers assess different design options and choose the most environmental friendly one. LCA studies shall be used prior to the construction, at the planning stage. At this point, changes in the design or materials have a minimum cost and maximum influence on the future performance of the building.

However, while such studies are not widely carried out in building construction, benchmarking data will remain poor. We already have many data available with good quality, and when LCA studies are more used they tend to be better. For this reason, the efforts UBC is making to collect data and apply it in new buildings design are so important. In my opinion, the next step for UBC is to verify studies like these one, completed as coursework in CIVL 498C technical elective course in Civil Engineering, and use them as a basis for developing more reliable LCA studies. Thereby, they can be used in new buildings within the campus, as well as publish them to be used by the industry and encourage the use of LCA in construction.

Annex C - Author Reflection

The CIVL 498C course and this final project were my first experience with LCA. I had already had some contact with environmental impacts and the importance of the decision-making stage in my home university, but LCA was a new and brilliant tool for green building with which I could learn how to deal. During the course, I could study ISO 14040 and 14044, guiding standards for LCA, and some organizations that develop LCA globally. In addition, this project gave me the opportunity to complete a LCA study based on ISO standards, conduct material takeoff from architectural and structural drawings, operate the Athena's Environmental Impact Estimator and interpret results of my LCA study on Math building.

The way the course was conducted was very exciting, allowing us to have contact and perform our own LCA study since the very beginning. Practicing while we learnt let it easier to understand the methods and standards, and performing your own LCA study is very stimulating. When I was assigned to study the Math building, a 1925 wood building, I did not know anything about it. However, because of it I learnt not only about LCA, but also about the campus history. I was also curious about the results my study would reveal. It is a building made primarily of wood, and I expected less environmental impacts due to the absence of cement. However, the results surprised me with such superiority of wood as building material. Unfortunately, part of my curiosity, regarding the thermal performance of Math building, will remain unanswered.

			Select the content code most appropriate for each attribute from the dropdown menue	Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.
	Graduate Attribute			
	Name	Description		
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	IDA = introduced, developed & applied	Specialized engineering knowledge was fundamental to analyse the results of the final project.
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.	IDA = introduced, developed & applied	Specialized engineering knowledge was fundamental to analyse the results of the final project.
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.	DA = developed & applied	Very necessary to find reasons for the differences in the results between the buildings.

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.	DA = developed & applied	
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.	IDA = introduced, developed & applied	Largely use of Excel, EIE and OnScreen Takoff.
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	DA = developed & applied	Necessary during the classes to have a better understanding of the topics.

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	Necessary to read references and write the final 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.	DA = developed & applied	Useful to understand the reasons for carrying out an LCA study.
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	DA = developed & applied	Useful to understand the reasons for carrying out an LCA study and the role of engineers in society.

		and development and environmental stewardship.		
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	DA = developed & applied	Useful to understand the role of engineers in society.
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.	DA = developed & applied	Necessary to calculate the cost of the building in 2013 dollars and to understand the role of LCA in decision-making.
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	Useful to integrate the learning in the final project, as well as to use it in my future professional life.

Annex D – Impact Estimator Inputs and Assumptions

Inputs Document

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
A11 Foundations	**1451.17**	**m²**					
			1.2 Concrete Footing				
				1.2.1 Footing_S2_20"_Strip_Interior			
					Length (ft)	191	191
					Width (ft)	1.67	1.67
					Thickness (in)	8	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
					Rebar	-	#4
				1.2.2 Footing_S1_20"_Strip_Exterior			
					Length (ft)	818	818
					Width (ft)	1.67	1.67
					Thickness (in)	8	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
					Rebar	-	#4
				1.2.3 Footing_F4_3'6"_Square			
					Length (ft)	3.5	5.68
					Width (ft)	3.5	5.68
					Thickness (in)	52	19
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
					Rebar	-	#4
				1.2.4 Footing_F3_3'8"_Square			
					Length (ft)	3.67	5.05
					Width (ft)	3.67	5.05
					Thickness (in)	36	19
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values Known/ Measured	Input Values EIE Inputs
					Rebar	-	#4
				1.2.5 Footing_F2_2'6"_Square			
					Length (ft)	19.2	19.2
					Width (ft)	19.2	19.2
					Thickness (in)	12	12
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
					Rebar	-	#4
				1.2.6 Footing_F1_2'0"_Square			
					Length (ft)	14.83	14.83
					Width (ft)	14.83	14.83
					Thickness (in)	12	12
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
					Rebar	-	#4
A21 Lowest Floor Construction	**1451.17**	**m²**					
			1.1 Concrete Slab-on-Grade				
				1.1.1 SOG_6"_Side_Entrance_Floor			
					Length (ft)	15.92	15.92
					Width (ft)	15.92	15.92
					Thickness (in)	6	4
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
				1.1.2 SOG_6"_Lecture_Entrance_Floor			
					Length (ft)	16.97	16.97
					Width (ft)	16.97	16.97
					Thickness (in)	6	4
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
				1.1.3 SOG_6"_Front_Entrance_Floor			
					Length (ft)	13.85	13.85
					Width (ft)	13.85	13.85
					Thickness (in)	6	4
					Concrete (psi)	-	4000
					Concrete fly	-	average

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
					ash %		
				1.1.4 SOG_4"_Ground_Floor_Bathroom			
					Length (ft)	23.00	23.00
					Width (ft)	23.00	23.00
					Thickness (in)	4	4
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
			3.1 Wood Joist				
				Floor_WoodJoist_GroundFloor_8'			
					Floor Width (ft)	387	387
					Span (ft)	8	8
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				Floor_WoodJoist_GroundFloor_9'			
					Floor Width (ft)	364	364
					Span (ft)	9	9
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				Floor_WoodJoist_GroundFloor_10'			
					Floor Width (ft)	267	267
					Span (ft)	10	10
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				Floor_WoodJoist_GroundFloor_11'			
					Floor Width (ft)	275	275
					Span (ft)	11	11
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				Floor_WoodJoist_GroundFloor_12'			
					Floor Width (ft)	235	235
					Span (ft)	12	12
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
			5.1 Wood				
				Total	Softwood Lumber (large, green) (Mbfm)	12.50	12.50
				5.1.1 - XBM_Foundation_Girder_Wood_8x12			
					Softwood Lumber (large, green) (Mbfm)	0.37	0.37
				5.1.2 - XBM_Foundation_Girder_Wood_8x10			
					Softwood Lumber (large, green) (Mbfm)	6.57	6.57

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
				5.1.3 - XBM_Foundation_Girder_Wood_6x8			
					Softwood Lumber (large, green) (Mbfm)	0.91	0.91
				5.1.4 - XBM_Foundation_Girder_Wood_6x10			
					Softwood Lumber (large, green) (Mbfm)	0.78	0.78
				5.1.5 - XBM_Foundation_Column_Wood_8X8			
					Softwood Lumber (large, green) (Mbfm)	2.24	2.24
				5.1.6 - XBM_Foundation_Column_Wood_8x10			
					Softwood Lumber (large, green) (Mbfm)	0.13	0.13
				5.1.7 - XBM_Foundation_Column_Wood_6X8			
					Softwood Lumber (large, green) (Mbfm)	0.56	0.56
				5.1.8 - XBM_Foundation_Column_Wood_6X6			
					Softwood Lumber (large, green) (Mbfm)	0.04	0.04
				5.1.9 - XBM_Foundation_Column_Wood_10X10			
					Softwood Lumber (large, green) (Mbfm)	0.89	0.89
A22 Upper Floor Construction	**1366.64**	**m²**					
			1.1 Concrete Slab-on-Grade				
				1.1.5 SOG_4"_First_Floor_Bathroom			
					Length (ft)	30.80	30.80
					Width (ft)	30.80	30.80
					Thickness (in)	4	4

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
				1.1.6 SOG_10"_Stairs_Side_Entrance			
					Length (ft)	10.36	10.36
					Width (ft)	10.36	10.36
					Thickness (in)	10	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
				1.1.7 SOG_10"_Stairs_Lecture_Entrance			
					Length (ft)	8.87	8.87
					Width (ft)	8.87	8.87
					Thickness (in)	10	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
				1.1.8 SOG_10"_Stairs_Front_Entrance			
					Length (ft)	4.76	4.76
					Width (ft)	4.76	4.76
					Thickness (in)	10	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	average
			3.1 Wood Joist				
				Floor_WoodJoist_Lecture_Sloped			
					Floor Width (ft)	340	340
					Span (ft)	6	6
					Decking Type	none	none
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category Material Thickness	Cladding Shiplap -	Cedar Shiplap Siding -
				Floor_WoodJoist_FirstFloor			
					Floor Width (ft)	-	833
					Span (ft)	21.8	14.96
					Decking Type	none	none

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Live load (psf)	45	45
					Decking Thickness	none	none
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
			5.1 Wood				
				Total	Softwood Lumber (small, green) (Mbfm)	1.51	1.51
				5.1.11 XBM_Stairs_Wood_Main			
					Softwood Lumber (Small, kiln dried) (Mbfm)	1.01	1.01
				5.1.12 XBM_Stairs_Wood_Entrance_landing-2nd			
					Softwood Lumber (Small, green) (Mbfm)	0.16	0.16
				5.1.13 XBM_Stairs_Wood_Entrance_1st-landing			
					Softwood Lumber (Small, green) (Mbfm)	0.33	0.33
			5.2 Steel				
				5.2.1 - XBM_Steel_First Floor Truss			
					Rebar Rod Light Sections (Tons)	0.27	0.27
					Cold Rolled Steel (Tons)	0.87	0.87
A23 Roof Construction	**1453.04**	**m²**					
			4.1 Wood Joist				
				4.1.1 Roof_WoodJoist_4-Ply_Truss_Lecture_Room			
					Roof Width (ft)	182.7	182.7
					Span (ft)	14.5	14.5
					Decking Type	-	None
					Live load (psf)	45	45

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
				Envelope	Decking Thickness	-	None
					Category	Roofing	Roofing
					Material	4 ply roof	roofing asphalt
					Thickness (in)	-	-
					Category	roofing envelopes	roofing envelopes
					Material	gravel	ballast
					Thickness (in)	-	-
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				4.1.2 Roof_WoodJoist_4-Ply_Joist_Main_Bldg			
				Envelope	Roof Width (ft)	868.4	868.4
					Span (ft)	14.96	14.96
					Decking Type	-	None
					Live load (psf)	45	45
					Decking Thickness	-	None
					Category	Roofing	Roofing
					Material	4 ply roof	roofing asphalt
					Thickness (in)	-	-
					Category	roofing envelopes	roofing envelopes
					Material	gravel	ballast
					Thickness (in)	-	-
					Category	Cladding	
					Material	Shiplap	Cedar Shiplap Siding
					Thickness	-	-
			5.1 Wood				
				5.1.10 XBM_Truss_Lecture_Room			
					Softwood Lumber (large, green) (Mbfm)	2.58	2.58
A31 Walls Below Grade	**588.45**	**m²**					

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
			2.1 Wood Stud				
				2.1.24 Wall_WoodStud_Basement_2x6			
					Length (ft)	347	347
					Height (ft)	5	5
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Window Opening	Number of Windows	10	10
					Total Window Area (ft2)	59	59
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
			2.2 Cast-In-Place				
				2.2.2 Wall_Cast-In-Place_W1_10"_External			
					Length (ft)	818	1022
					Height (ft)	4.5	4.5
					Thickness (in)	10	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	Average
					Rebar	-	#5
				Window Opening	Number of Windows	4	4
					Total Window Area (ft2)	19	19

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
A32 Walls Above Grade	**2237.56**	**m²**					
			2.1 Wood Stud				
				2.1.5 Wall_WoodStud_RoofStubWall			
				Envelope	Length (ft)	767	767
					Height (ft)	5	5
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.9 Wall_WoodStud_Lecture_Exterior_2x6			
					Length (ft)	127	127
					Height (ft)	22	22
					Sheathing Type	none	none

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Window Opening	Number of Windows	24	24
					Total Window Area (ft2)	365	365
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.14 Wall_WoodStud_Ground_Exterior_2x6+2x4			
					Length (ft)	195	195
					Height (ft)	13	13
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Window Opening	Number of Windows	34	34
					Total Window Area (ft2)	563	563
					Frame Type	Wood	Wood

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
						Frame	Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	5.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.15 Wall_WoodStud_Ground_Exterior_2x6			
					Length (ft)	477	477
					Height (ft)	13	13
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Door Opening	Number of Doors	4	4
					Door Type	Solid Wood	Solid Wood
				Window Opening	Number of Windows	72	72
					Total Window Area (ft2)	1032	1032
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Gypsum Board	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.16 Wall_WoodStud_Front_Entrance_2x4			
					Length (ft)	7	7
					Height (ft)	9.5	9.5
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Door Opening	Number of Doors	2	
					Door Type	Solid Wood, 20% Glazing	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.21 Wall_WoodStud_First_Exterior_2x6+2x4			
					Length (ft)	208	208
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Window Opening	Number of Windows	40	40
					Total Window Area (ft2)	599	599
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
				2.1.22 Wall_WoodStud_First_Exterior_2x6			
					Length (ft)	560	560
					Height (ft)	11	11
					Sheathing Type	none	none

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Exterior	Exterior
				Window Opening	Number of Windows	76	76
					Total Window Area (ft2)	1016	1016
					Frame Type	Wood Frame	Wood Frame
					Glazing Type	-	Standard Glazing
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Cladding	
					Material	Stucco Over Chicken Wire	Stucco Over Metal Mesh
					Thickness	-	-
					Category	Cladding	
					Material	Cedar Shiplap	Cedar Shiplap Siding
					Thickness	-	-
			2.2 Cast-In-Place				
				2.2.3 Wall_Cast-In-Place_Entrance			
					Length (ft)	14.67	14.67
					Height (ft)	14	14
					Thickness (in)	12	12
					Concrete (psi)	-	4000
					Concrete fly ash %	-	Average
					Rebar	-	#5
B11 Partitions	**2580.13**	**m²**					
			2.1 Wood Stud				
				2.1.1 Wall_WoodStud_Vestibule_Side_Walls_2x4			
					Length (ft)	31	31
					Height (ft)	16.5	16.5

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
				Envelope	Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing (in)	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.2 Wall_WoodStud_Vestibule_2x4			
					Length (ft)	24	24
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	2	2
					Door Type	Solid Wood, 20% Glazing	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.3 Wall_WoodStud_Support_Lecture_Slope_2x4			
					Length (ft)	168	168
					Height (ft)	3	3
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				2.1.4 Wall_WoodStud_Side_Entrance_2x6			
					Length (ft)	24	24
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	4	4
					Door Type	Solid Wood, 20% Glazing	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.6 Wall_WoodStud_MainStairwell_2x4			
					Length (ft)	67	67
					Height (ft)	4	4
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.7 Wall_WoodStud_Lecture_Interior_Bearing_2x6			
					Length (ft)	57	57
					Height (ft)	16	16
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.8 Wall_WoodStud_Lecture_Interior_Bearing_2x4			
					Length (ft)	21	21
					Height (ft)	22	22
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	4	4
					Door Type	Solid Wood, 20% Glazing	Solid Wood

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
				2.1.10 Wall_WoodStud_Ground_Interior_NonBearing_Janitors Closet			
					Length (ft)	38	38
					Height (ft)	8	8
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	2	2
					Door Type	Solid Wood	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	1.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	1.5
				2.1.11 Wall_WoodStud_Ground_Interior_NonBearing_2x4			
					Length (ft)	174	174

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Height (ft)	12	12
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	8	8
					Door Type	Solid Wood	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	1.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	1.5
				2.1.12 Wall_WoodStud_Ground_Interior_Bearing_2x6			
					Length (ft)	72	72
					Height (ft)	12	12
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
							Board
					Thickness	-	0.5
				2.1.13 Wall_WoodStud_Ground_Interior_Bearing_2x4			
					Length (ft)	634	634
					Height (ft)	12	12
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	26	26
					Door Type	Solid Wood	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	0.5
				2.1.17 Wall_WoodStud_First_Interior_NonBearing_2x4			
					Length (ft)	294	294
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Door Opening	Number of Doors	11	11
					Door Type	Solid Wood	Solid Wood
				Envelope	Category	Gypsum Board	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values: Known/ Measured	Input Values: EIE Inputs
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	0.5
				2.1.18 Wall_WoodStud_First_Interior_Bearing_2x6			
				Envelope	Length (ft)	44	44
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	0.5
				2.1.19 Wall_WoodStud_First_Interior_Bearing_2x4			
					Length (ft)	529	529
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
				Door Opening	Number of Doors	20	20
					Door Type	Solid Wood	Solid Wood
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	0.5
				2.1.20 Wall_WoodStud_First_Interior_Bathroom_Double2x4			
					Length (ft)	81	81
					Height (ft)	11	11
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
					Sheathing Type	none	none
					Stud Thickness	2x4	2x4
					Stud Spacing	-	16
					Stud Type	-	green
					Wall Type	Interior	Interior
				Envelope	Category	Gypsum Board	
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness (in)	-	0.5
					Category	Gypsum Board	

Element	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
						Known/ Measured	EIE Inputs
					Material	Lath and Plaster	1/2" Regular Gypsum Board
					Thickness	-	0.5
				2.1.23 Wall_WoodStud_CeilingLectureRoom_2x6			
					Length (ft)	45	45
					Height (ft)	56.33	56.33
					Sheathing Type	none	none
					Stud Thickness	2x6	2x6
					Stud Spacing	16	16
					Stud Type	-	green
					Wall Type	Interior	Interior
			2.2 Cast-In-Place				
				2.2.1 Wall_Cast-In-Place_W2_8"_Internal			
					Length (ft)	190	190
					Height (ft)	4	4
					Thickness (in)	8	8
					Concrete (psi)	-	4000
					Concrete fly ash %	-	Average
					Rebar	-	#5
			5.1 Wood				
				5.1.14 XBM_Cedar_Laths			
					Softwood Lumber (Small, green) (Mbfm)	14.39	14.39

Assumptions Document

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
A11 Foundations	The Impact Estimator limits the thickness of footings to be between 7.5” and 19.7” thick. Adjustments were made where necessary to make the thicknesses fit within these constraints while maintaining the same total volume. Concrete properties are not provided in the drawing set. Concrete strength is assumed to be 4000PSI and fly ash content was assumed to average.		
	1.2 Concrete Footing		

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		1.2.1 Footing_S2_20"_Strip_Interior	Rebar type not given. Assume rebar to be #4 Dimensions of strip footings given in drawings 518-06-009 and 518-06-008
		1.2.2 Footing_S1_20"_Strip_Exterior	Rebar type not given. Assume rebar to be #4 Dimensions of strip footings given in drawings 518-06-009 and 518-06-008
		1.2.3 Footing_F4_3'6"_Square	This Footing is a large bulk concrete footing supporting posts which support the Truss's spanning the lecture room. There are 3 footings. The dimensions were taken from drawing 518-06-008. To accommodate the maximum footing thickness input that can be put into the EIE, the following calculation was done: Length=Width=SQRT(Volume/Input Thickness) =SQRT((3 footingsx3'6"x3'6"x4'2")/(19"/12"/ft))=9.83ft Type of Rebar used was not given. Assumed #4 rebar
		1.2.4 Footing_F3_3'8"_Square	This Footing is a large bulk concrete footing supporting posts which support the Truss's spanning the lecture room. There are 3 footings. The dimensions were taken from drawing 518-06-008. To accommodate the maximum footing thickness input that can be put into the EIE, the following calculation was done: Length=Width=SQRT(Volume/Input Thickness) =SQRT((3 footingsx3'8"x3'8"x3')/(19"/12"/ft))=8.74ft Type of Rebar used was not given. Assumed #4 rebar
		1.2.5 Footing_F2_2'6"_Square	There are 59 of these footings. Thickness assumed to be same as ones shown in drawing 518-06-008. In order to input into EIE, an equivalent area square footing was calculated with the length and width being inputted. The calculation is as follows: Length=Width=SQRT(#footingsxArea/footing) =SQRT(59x(2'6"x2'6"))=19.2ft Type of Rebar used was not given. Assumed #4 rebar
		1.2.6 Footing_F1_2'0"_Square	There are 55 of these footings. Thickness assumed to be same as ones shown in drawing 518-06-008. In order to input into

<table>
<tr><th>Assembly Group</th><th>Assembly Type</th><th>Assembly Name</th><th>Specific Assumptions</th></tr>
<tr><td></td><td></td><td></td><td>EIE, an equivalent area square footing was calculated with the length and width being inputted. The calculation is as follows: Length=Width=SQRT(#footingsxArea/footing) =SQRT(55x(2'x2'))=14.83ft

Type of Rebar used was not given. Assumed #4 rebar</td></tr>
<tr><td>A21 Lowest Floor Construction</td><td colspan="3">For the Impact Estimator, SOG inputs are limited to being either a 4” or 8” thickness. Since some of the actual SOG thicknesses for the Math building were not exactly 4” or 8” thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. For purposes of calculating Length and Widths of SOG's all areas are square rooted to give the equivalent square area dimensions. This allows irregular shapes to be easily inputted into the EIE.
For the wood floor, Cedar Shiplap is added as decking material. Drawing 518-06-006 shows that shiplap is used as decking material. Cedar Shiplap is thus added as cladding in the envelope. Cedar is assumed because all the lath material for the building is cedar.
The Floor dimension inputs for the EIE are span and width. An area was found in OnScreen for each floor. Input width was found for each floor by dividing the total floor area by the input span. Calculations are shown for each floor condition.
The Live Load was not given in the Drawings. In the LCA report for the Geography building, which was built in the same year and by the same architect, it states, "An assumed live load of 45psf was used based on drawing 401-07-001, a list of specifications from a 2004 renovation." Based on this, an assumed live load of 45PSF was used for all floors</td></tr>
<tr><td></td><td colspan="3">1.1 Concrete Slab-on-Grade</td></tr>
<tr><td></td><td></td><td>1.1.1 SOG_6"_Side_Entrance_Floor</td><td>The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab;

= sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)]

= sqrt[(169 x (6”/12))/(4”/12)]

= 15.92ft</td></tr>
<tr><td></td><td></td><td>1.1.2 SOG_6"_Lecture_Entrance_Floor</td><td>The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab;</td></tr>
</table>

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
			= sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4"/12)] = sqrt[(192 x (6"/12))/(4"/12)] = 16.97ft
		1.1.3 SOG_6"_Front_Entrance_Floor	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4"/12)] = sqrt[(128 x (6"/12))/(4"/12)] = 13.85ft
		1.1.4 SOG_4"_Ground_Floor_Bathroom	The thickness for this floor was available for the EIE input. Just had to square root the area takeoff to get an input length and width. Length=Width= SQRT(Area)= =SQRT(529)=23ft
	3.1 Wood Joist		
		Floor_WoodJoist_GroundFloor_8'	The input width for the EIE is calculated as: Input Width= Total Area/Span =3096ft^2/8ft=387ft
		Floor_WoodJoist_GroundFloor_9'	The input width for the EIE is calculated as: Input Width= Total Area/Span =3276ft^2/9ft=364ft
		Floor_WoodJoist_GroundFloor_10'	The input width for the EIE is calculated as: Input Width= Total Area/Span =2670ft^2/10ft=267ft
		Floor_WoodJoist_GroundFloor_11'	The input width for the EIE is calculated as: Input Width= Total Area/Span =3025ft^2/11ft=275ft
		Floor_WoodJoist_GroundFloor_12'	The input width for the EIE is calculated as: Input Width= Total Area/Span =2820ft^2/12ft=235ft

XBM_Wood

5.1.1 - 5.1.9 - Girders and Columns

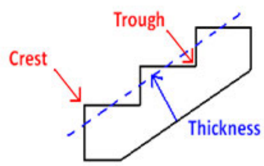
All of the calculations for the volume of wood in the columns and girders is shown in the table to the right. The actual wood used for the columns and girders is not specified in the drawings.
The wood is modelled as large dimension lumber. This is believed to be a better representation of the beams and columns than glulam beams, which is the only other reasonable input from the EIE.

For the 8x8, 8x10 and 6x8 columns, there were no drawings specifying heights. Drawings 518-06-008 and 518-06-007 were used to estimate the column heights based on the difference between foundation and floor height.

Drawing 518-07-001 had all girder lengths shown.

Type	**Count**	**Height(ft)**	**Total Linear Length (ft)**	**X sec Area (ft^2)**	**Volume (ft^3)**	**Volume (MBFM)**
Girder 8x12	-	-	46	0.67	30.67	0.37
Girder 8x10	-	-	986	0.56	547.78	6.57
Girder 6x8	-	-	227	0.33	75.67	0.91
Girder 6x10	-	-	156	0.42	65.00	0.78
Column 8x8	70	6	420	0.44	186.67	2.24
Column 8x10	4	5	20	0.56	11.11	0.13
Column 6x8	28	5	140	0.33	46.67	0.56
Column 6x6	12	1.17	14.04	0.25	3.51	0.04
Column 10x10	6	17.83	106.98	0.69	74.29	0.89
					Total =	12.50

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
A22 Upper Floor Construction	For each floor, an average span was found for a floor by finding a weighted average span. This can most easily be explained by showing the equation for the calculation as: Average Span=$(\sum\_(\text{floor area})_i \times (\text{floor span})_i)/(\sum\_(\text{floor area})_i)$ The EIE has a maximum span input of 14.96ft. For Spans that were larger than this, 14.96ft was used. Assumptions for A21 also apply here.		
	1.1 Concrete Slab-on-Grade		
		1.1.5 SOG_4"_First_Floor_Bathroom	The thickness for this floor was available for the EIE input. Just had to square root the area takeoff to get an input length and width. Length=Width= SQRT(Area)= =SQRT(949)=30.8ft
		1.1.6 SOG_10"_Stairs_Side_Entrance	The thickness of the stairs was assumed to be the same as for the front entrance stairs. The thickness of the stairs was taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Drawing 518-06-008 provides a clear view of a section of the stairs. Onscreen Takeoff was used to get the plan view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width: Length = Width= SQRT(Volume/(8in/12in/ft)) =SQRT(161ft^3/(8/12))=10.36ft
		1.1.7 SOG_10"_Stairs_Lecture_Entrance	The thickness of the stairs was assumed to be the same as for the front entrance stairs. The thickness of the stairs was taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Drawing 518-06-008 provides a clear view of a section of the stairs. Onscreen Takeoff was used to get the plan view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width: Length = Width= SQRT(Volume/(8in/12in/ft))

<table>
<tr><th>Assembly Group</th><th>Assembly Type</th><th>Assembly Name</th><th>Specific Assumptions</th></tr>
<tr><td></td><td></td><td></td><td>=SQRT(118ft^3/(8/12))=8.87ft</td></tr>
<tr><td></td><td></td><td>1.1.8
SOG_10"_Stairs_Front_Entrance

</td><td>The thickness of the stairs was taken as the approximate depth from the midpoint between stair crest and trough and the bottom of the stair. Drawing 518-06-008 provides a clear view of a section of the stairs. Onscreen Takeoff was used to get the plan view area, and a slope and thickness were then applied to get the volume of the stairs. Using 8" thickness, the following calculation gave the length and width:
Length = Width=
SQRT(Volume/(8in/12in/ft))
=SQRT(34ft^3/(8/12))=4.76ft</td></tr>
<tr><td></td><td colspan="3">3.1 Wood Joist</td></tr>
<tr><td></td><td></td><td>3.1.1
Floor_WoodJoist_Lecture_Sloped</td><td>This floor refers to the sloped bleachers in the lecture room. It is assumed that a wood joist floor reasonably approximates the material required for a stepped bleacher structure.
The span for this floor area was approximated as 6ft from examination of drawing 518-06-008.
The input width for the EIE is calculated as:
Input Width= Total Area/Span
=2039ft/6ft=340ft</td></tr>
<tr><td></td><td></td><td>3.1.4 Floor_WoodJoist_FirstFloor</td><td>The average span was found to be 21.8ft The max span that can be inputted into the EIE is 14.96ft. 14.96ft was used for the span.
The input width for the EIE is calculated as:
Input Width= Total Area/Span
=12465ft/14.96ft=833ft</td></tr>
</table>

XBM_Wood		
	5.1.11 - 5.1.13 - Wood Stairs	The takeoff for one of the main stairs (5.1.11 XBM_Stairs_Wood_Main) is shown to the right. The

Wood Per Stair

#	Section	Type	Length (ft)	X Sec Area (ft^2)	Volume (MBFM)
4	Carriage	2x12	1	0.16666667	0.008
1	Step	2x12	6	0.16666667	0.012

		takeoff is done for one stair from the main stairwell, shown in detail in drawing 518-06-037. The total takeoff is estimated by multiplying the number of stairs by the value for one stair. For all other wood stairs in the building, it is assumed they are built the same way and the same takeoff was used. The takeoff is for stairs 6ft wide. For other stairs the takeoff per stair was adjusted for different widths. Thus, Volume(Stair_Entrance_1st-landing)=Volume(Main Stair)*Width(Entrance Stair)/Width(Main Stair) For Stair_Entrance_1st-landing (4 feet wide), Volume=0.023MBFM/stair x 4ft/6ft x 7 stairs = 0.33MBFM The wood type is not specified in the drawings and is assumed to be small dimension lumber.	1	Step Front	1x6	6	0.04166667	0.003
							Total	**0.023**
XBM_Steel								
	5.2.1 -	The takeoff for	**Truss Steel Rods**					

	XBM_Steel_First Floor Truss	the steel used in the truss is shown to the right. The takeoff was divided into two parts: plate steel inputted as cold rolled steel, and rod sections inputted as rebar rod light sections The takeoff was based on details provided in drawing 518-06-008	See tables below

Per Truss

Type	Length (ft)	X Sec Area (ft^2)	Volume (ft^3)	Weight (tons)
1 5/8" rod	12.00	0.01	0.17	0.04
1 3/8" rod	12.00	0.01	0.12	0.03
7/8" rod	12.00	0.00	0.05	0.01
3/4" rod	6.00	0.00	0.02	0.00
			Total=	**0.09**

Steel Truss Plates

Per Truss

#	Type	Length (ft)	Volume (ft^3)	Weight (tons)
18.00	4" x 6" x 3/8"	-	0.19	0.05
-	2" x 8"	9.00	1.00	0.25
			Total=	**0.29**

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
A23 Roof Construction	For each roof, an average span was found for a floor by finding a weighted average span. This can most easily be explained by showing the equation for the calculation as: Average Span=(∑_(floor area)i×(floor span)i)/(∑_(floor area)i) The EIE has a maximum span input of 14.96ft. For Spans that were larger than this, 14.96ft was used. The roof has a small slope to it but it is modelled as being flat. Shiplap was added as the decking material. Drawing 518-06-006 shows that shiplap is used as decking material. Shiplap is thus added as cladding in the envelope. From Drawing 518-06-006 we know it is a 4 ply felt and gravel roof. Asphalt roofing and an aggregate ballast was used in the EIE. It is assumed that there is no insulation in the roof. The Live Load was not given in the Drawings. In the LCA report for the Geography building, which was built in the same year and by the same architect, it states, "An assumed live load of 45psf was used based on drawing 401-07-001, a list of specifications from a 2004 renovation." Based on this, an assumed live load of 45PSF was used for the roofs.		
	4.1 Wood Joist		

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		4.1.1 Roof_WoodJoist_4-Ply_Truss_Lecture_Room	The average span was found to be 14.5ft. The input width for the EIE is calculated as: Input Width= Total Area/Span =2649ft/14.5ft=182.7ft
		4.1.2 Roof_WoodJoist_4-Ply_Joist_Main_Bldg	The average span was found to be 21.8ft. The max span that can be inputted into the EIE is 14.96ft. 14.96ft was used for the span. The input width for the EIE is calculated as: Input Width= Total Area/Span =12991ft/14.96ft=868.4ft

XBM_Wood

	5.1.10 XBM_Truss_Lecture_Room	All of the calculations for the volume of wood in Truss is shown in the table to the right. The actual wood used for the Truss members is not specified in the drawings. The wood is modelled as large dimension lumber. This is believed to be a better representation of the beams and columns than glulam beams, which is the only other reasonable input from the EIE. The takeoff to right is for one truss. There are 3 total trusses.

Wood Each Truss				
Section	**Type**	**Length (ft)**	**X Sec Area (ft^2)**	**Volume (MBFM)**
Bottom Chord	8x10	46	0.56	0.31
Top Chord	8x10	34	0.56	0.23
Top Chord	2x10	46	0.14	0.08
Diagonal	8x10	13.33	0.56	0.09
Diagonal	8x8	13.33	0.44	0.07
Diagonal	6x8	13.33	0.33	0.05
Diagonal	4x6	13.33	0.17	0.03
Strut	2x8	9	0.11	0.01
			Total=	**0.86**

Assembly	Assembly	Assembly Name	Specific Assumptions

Group	Type		
A31 Walls Below Grade	All Walls were modeled in On Screen Takeoff using the linear condition. Cast in Place walls can only be inputted into the EIE as 8in or 12in thick. Calculations were made to adjust walls to fit within this constraint by changing the length of the wall. No rebar was specified for the walls and was assumed to be #5. Concrete strength was not specified for the walls and was assumed to be 4000PSI.		
	2.1 WoodStud		
		2.1.24 Wall_WoodStud_Basement_2x6	This wall extends from the top of the concrete foundation wall to the ground floor for the back (West) half the building The wall height is 5 feet and is approximated from drawings 518-06-007 and 518-06-008 Stucco on exterior and lath and plaster on the inside Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board.
	2.2 Cast-In-Place		
		2.2.2 Wall_Cast-In-Place_W1_10"_External	Height was estimated by dividing the total external wall area by the total length of the wall. This will give height. Height was found to be: Height=External Wall Area/Length=4407/818=4.5ft The EIE can only input walls 8 or 12" thick. In order to input the 10" wall as an 8" wall, the following calculation was done: Input Length=Total Volume/(Height x Input Thickness)= =(Actual Length x Height x Actual Thickness)/(Height x Input Thickness) =(818ft x 4.5ft x (10/12)ft)/(4.5ft x (8/12)ft)= 1022ft No rebar specified, assumed to be #5 No fly ash specified, assumed to be average. No strength specified, assumed to be 4000PSI Window glazing type was not

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
			defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
A32 Walls Above Grade	WoodStud Walls were assumed to be interior or exterior based on if they were in contact with the elements. Stud type was not known, assumed to be green wood. Stud spacing was not specified for majority of walls and was assumed to be 16in. Some doors had 20% glazing, and were modeled as solid wood due to EIE limitations. All doors assumed to be solid wood. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not, although all are modelled as operable. For exterior envelope system, drawings show that 3 coat stucco sits overtop chicken wire, cedar laths, vertical battens, paper, and shiplap. In the EIE, this envelope system was modeled as stucco over metal mesh and cedar shiplap siding. Shiplap is assumed to be cedar because all lath material used in building is cedar. Vertical battens are assumed to be negligible and paper cannot be modeled in EIE.		
	2.1 WoodStud		
		2.1.5 Wall_WoodStud_RoofStubWall	This roof stub wall is modelling the exterior wall that juts up above the first floor ceiling and sticks up above the flat roof. The height of 5ft is estimated from drawings 518-06-007 and 518-06-008. Stucco is modelled on both sides of wall. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding. Shiplap assumed to be cedar because all lath material in building is cedar.

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		2.1.9 Wall_WoodStud_Lecture_Exterior_2x6	Height is 22ft and is floor to underside of roof height. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.14 Wall_WoodStud_Ground_Exterior_2x6+2x4	The height of this wall is taken as the floor to floor height for the ground floor. The reason it was taken as floor to floor is to account for the potentially high impact stucco material in between floors on the exterior. The floors, as a result, are only modelled to the inside of exterior walls. This wall is made up of a 2x6 wall and a 2x4 wall on the inside of it. The 2x6 wall is modelled as exterior and the 2x4 wall is modelled as interior One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		2.1.15 Wall_WoodStud_Ground_Exterior_2x6	The height of this wall is taken as the floor to floor height for the ground floor. The reason it was taken as floor to floor is to account for the potentially high impact stucco material in between floors on the exterior. The floors, as a result, are only modelled to the inside of exterior walls. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. All doors assumed to solid wood. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.16 Wall_WoodStud_Front_Entrance_2x4	Height of wall estimated from drawing 518-06-008 One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Doors have 20% glazing, modelled as solid wood doors due to EIE limitations
		2.1.21 Wall_WoodStud_First_Exterior_2x6+2x4	Height is floor to ceiling height for first floor. The roof stub wall accounts for wall above this wall. This wall is made up of a 2x6 wall and a 2x4 wall on the inside of it. The 2x6 wall is modelled as exterior and the 2x4 wall is modelled as interior One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
			Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
		2.1.22 Wall_WoodStud_First_Exterior_2x6	Height is floor to ceiling height for first floor. The roof stub wall accounts for wall above this wall. One side of wall lath and plaster and one side stucco and shiplap. Stucco envelope system modeled as stucco over metal mesh and cedar shiplap siding Plaster was modeled as 1/2in regular gypsum board. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not. All were modeled as operable.
	2.2 Cast-In-Place		
		2.2.3 Wall_Cast-In-Place_Entrance	Volume for the Concrete Entrance Structure was found by taking details from drawing 518-06-009 and adding up simplified geometric segments to get the overall volume. The volume was found to be 206 ft^3. Due to the input constraints for thickness in the EIE, the wall was inputted as having a 12in thickness and the linear takeoff in OnScreen was found to be 14ft 8in. The height was then calculated to be: Height=Volume/(Input thickness x Length)=206ft/(1ft x 14.67ft)= 14ft No rebar specified, assumed to be #5 No fly ash specified, assumed to be average.

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
			No strength specified, assumed to be 4000PSI
B11 Partitions	Stud type was not known, assumed to be green wood. Stud spacing was not specified for majority of walls and was assumed to be 16in. Lath and Plaster was used to finish all interior walls. Due to IE limitations, Lath and plaster was modeled as 1/2 in of regular gypsum and cedar laths which are accounted for with an additional condition in XBM's. After modeling improvement, impacts of gypsum boards were excluded and impacts of plaster were added instead. Some doors had 20% glazing, and were modeled as solid wood due to EIE limitations. All doors assumed to be solid wood. Window glazing type was not defined and was assumed to be standard glazing. Know from site visits that all window frames are wood, and were modeled as such. Some windows are operable and some are not, although all are modelled as operable.		
	2.1 WoodStud		
		2.1.1 Wall_WoodStud_Vestibule_Side_Walls_2x4	Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Height of wall estimated from drawing 518-06-008
		2.1.2 Wall_WoodStud_Vestibule_2x4	Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		2.1.3 Wall_WoodStud_Support_Lecture_Slope_2x4	These walls are used to support the sloped bleachers in the lecture room. Assumed no envelope. Wall Height is approximated from averaging 3 such walls as shown in drawing 518-06-008
		2.1.4 Wall_WoodStud_Side_Entrance_2x6	One side of wall is has lath and plaster, one side butts up to exterior wall, and has no envelope material. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations
		2.1.6 Wall_WoodStud_MainStairwell_2x4	This wall was modeled to take into account the side of the main stair structure as well as the stub wall that serves as a guard wall around the top of the stairs. One side has lath and plaster. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.7 Wall_WoodStud_Lecture_Interior_Bearing_2x6	Height is 16ft and is floor to ceiling height. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.8 Wall_WoodStud_Lecture_Interior_Bearing_2x4	Height is 22ft and is floor to underside of roof height. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors have 20% glazing, modeled as solid wood due to EIE limitations

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		2.1.10 Wall_WoodStud_Ground_Interior_NonBearing_JanitorsCloset	Height taken from drawing 518-06-037 Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.11 Wall_WoodStud_Ground_Interior_NonBearing_2x4	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.12 Wall_WoodStud_Ground_Interior_Bearing_2x6	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.13 Wall_WoodStud_Ground_Interior_Bearing_2x4	Height taken as floor to ceiling height for ground floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.17 Wall_WoodStud_First_Interior_NonBearing_2x4	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
		2.1.18 Wall_WoodStud_First_Interior_Bearing_2x6	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.19 Wall_WoodStud_First_Interior_Bearing_2x4	Height taken as floor to ceiling height for First floor. Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's Doors are assumed to be solid wood
		2.1.20 Wall_WoodStud_First_Interior_Bathroom_Double2x4	This wall is made up of 2 2x4 wood stud walls with a cavity in the middle for venting and plumbing Lath and Plaster on both sides of wall. Plaster was modeled as 1/2in regular gypsum board. Laths are modeled in XBM's
		2.1.23 Wall_WoodStud_CeilingLectureRoom_2x6	This wall is modelling the ceiling that is above the lecture room. The ceiling is not structural, stud spacing and stud thickness are known. No envelope is modelled since the System Boundary of this LCA does not include ceiling finishing material. Single wall with length being the length of the lecture room and a height the width of the lecture room is modelled
	2.2 Cast-In-Place		
		2.2.1 Wall_Cast-In-Place_W2_8"_Internal	Height was not explicitly shown in any of the drawings. A height of 4ft was estimated from examining topography as well as stair and floor heights above the foundation walls. No rebar specified, assumed to be #5 No fly ash specified, assumed to be average. No strength specified, assumed to be

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
			4000PSI

XBM_Wood		
	5.1.14 XBM_Cedar_Laths	To calculate laths, the total net wall area which has lath and plaster was measured in onscreen takeoff. This is done by adding an additional surface area quantity calculation for all lath and plaster walls in Onscreen. Surface area of both sides was calculated for walls with two sided lath and plaster. Windows and door area were subtracted from the gross wall area to give the net wall area. Laths are assumed to be 1/4in thick, 2in wide and separated by 1/4in. This means that 8/9 of the wall is covered in laths. Thus 8/9 of the net wall area is assumed to be covered in solid laths. The Volume calculation to the right is based on this assumption. Although it is known that the laths are cedar, it is thought to be more accurate to model the lath as small dimension lumber than the cedar siding. The cedar siding does not specify a thickness, and so this way the volume takeoff is more accurately inputted into the EIE.

Wall Area(ft^2)	Window Area (ft^2)	Door Area (ft^2)	Net Area (ft^2)	Lath Area (8/9 of Net Area)	Lath Volume (MBFM)
68925	3634	516	64775	57577	14.39