A Life Cycle Analysis of the Geography Building

Zahra Hosseini

University of British Columbia

CIVL 498C

November 25, 2013

PROVISIO

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

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

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

A Life Cycle Analysis of the Geography Building

CIVL 498C
November 25, 2013

Zahra Hosseini

Executive Summary

This life cycle analysis was performed on the UBC Geography Building, a 51,883 sf, wood-frame academic building built in 1924, for the purpose of establishing a materials inventory and environmental impact reference to be applied in the assessment of potential upgrades. It was also completed simultaneously with 20 other institutional buildings at UBC for creating a benchmark as a standard against which existing buildings and new constructions assess and interpret. The benchmark is assessed for each environmental impact category through calculating the average impact per square meter of the element.

The Takeoff model, developed by last year student[1], and the original architectural drawings of the Geography Building are used to check the accuracy of the quantity of materials (length, area, and number) used as the IE input data. In this project, IE Inputs are sorted based on a modified version of level 3 of Canadian Institute of Quantity Surveyors (CIQS) format. From the improved model and using Athena Sustainable Materials Institute's Impact Estimator Bill of Materials was and Environmental impacts of each level 3 element were determined. The largest quantities of material were gypsum board, softwood plywood, 6mil polyethylene, cedar wood shiplap, and stucco.

The summary of environmental impact measures for different level 3 CIQS categories were also obtained from IE software and the hotspots for each environmental impact category among different lifecycle stages and among different level 3 CIQS categories were identified. Roof Constructions, Walls above Grade, and Foundations have the highest impacts respectively. There are only very small basement areas in the building and the ground floors are inclined wood joist floors which are included in Upper level construction elements. Thus, the Lowest floor construction and Walls below grade, does not have a significant environmental impact. The comparisons also indicate that the Construction stage has much more environmental impacts that Production stage.

In comparison with CIVL 498C 2013 benchmark (date: 11/24/2013), the total environmental impacts of Geography building, its impacts for Production and Construction stages, and also its impacts for all the CIQS level 3 elements are way below average, except for the Foundation and Walls below grade elements. This difference can be related to the fact that the building is modeled based on its primary drawing from 1924 which was intended to be a temporary building. Thus, the quantity of materials used in the project is minimal. There is no heating insulation material in the drawings and very minimal concrete work. The building does not have slab on grade in the ground level and all the structure is wooden. A reason for the higher impacts for the foundation in this building is that the quantity of this element is much less that other projects, because the building does not have slab on grade. Hence, the environmental impacts of the foundation elements are divided to the floor area of the footings and crawlspace walls, while in other projects the impacts are divided into the slab on grade area, which covers most of the building site. An important lesson that can be learned from comparing this old building with its more recent equivalents is the significant role of wood in decreasing the environmental impacts of a project, as oppose to concrete or metal structures. Further, detailed LCA analysis of structural elements in UBC buildings can help reducing the environmental impacts in future projects.

---

[1] (Connaghan, 2009)

Table of Contents

Executive Summary 1

Table of Contents 2

List of Figures 4

1. General Information on the Assessment 6
   - 1.1. Purpose of the assessment 6
   - 1.2. Identification of building 6
   - 1.3. Other Assessment Information 8
2. General Information on the Object of Assessment 8
   - 2.1. Functional Equivalent 8
   - 2.2. Reference Study Period 9
   - 2.3. Object of Assessment Scope 9
3. Statement of Boundaries and Scenarios Used in the Assessment 11
   - 3.1. System Boundary 11
     - 3.1.1. Product Stage 12
     - 3.1.2. Construction Stage 12
4. Environmental Data 13
   - 4.1. Data Sources 13
   - 4.2. Data Adjustments and Substitutions 14
   - 4.3. Data Quality 14
5. List of Indicators Used for Assessment and Expression of Results 16
6. Model Development 17
   - 6.1. A11 Foundation 18
   - 6.2. A21 Lowest Floor Construction 19
   - 6.3. A22 Upper Floor Construction 19
   - 6.4. A23 Roof Construction 20
   - 6.5. A31 Walls below Grade 20
   - 6.6. A32 Walls above Grade 21
   - 6.7. B11 Partitions 21
   - 6.8. Bill of materials for CIQS level 3 elements 22
7. Communication of Assessment Results 23
   - Life Cycle Results 23

References 32
Annex A - Interpretation of Assessment Results 34
    Benchmark Development 34
    UBC Academic Building Benchmark 34
Anex B - Recommendations for LCA Use 38
Annex C - Author Reflection 39
Annex D – Impact Estimator Inputs and Assumptions 40

List of Figures

Figure 1 Construction of the "temporary" Geography Building circa 1925. ©UBC................................ 6
Figure 2 Ground plan highlighting the sections of building torn down for firewall installation 7
Figure 3 Full list of CIQS Elements at all four levels 10
Figure 4 Display of modular information for the different stages of the building assessment............ 11
Figure 5 Concrete stairs thickness assessment.. 19
Figure 6 Roof detail for the Geography Building 20
Figure 7 Four separate roof area in which their upper portion was modeled as wall sections 20
Figure 8 Fossil Fuel Consumption Comparison Between level 3 elements 26
Figure 9 Global Warming Comparison Between level 3 elements 26
Figure 10 Acidification Comparison Between level 3 elements 26
Figure 11 Eutrophication Comparison Between level 3 elements 27
Figure 12 Ozone Layer Depletion Comparison Between level 3 elements.. 27
Figure 13 Smog Comparison Between level 3 elements 27
Figure 14 Human Health Criteria Comparison Between level 3 elements 27
Figure 15 Fossil Fuel Consumption Comparison in product and construction stage for level 3 elements 28
Figure 16 Global Warming Comparison in product and construction stage for level 3 elements 28
Figure 17 Human Health Criteria (Respiratory) Comparison in product and construction stage for level 3 elements 29
Figure 18 Acidification Comparison in product and construction stage for level 3 elements 29
Figure 19 Eutrophication Comparison in product and construction stage for level 3 elements........... 30
Figure 20 Ozone Layer Depletion Comparison in product and construction stage for level 3 elements 30
Figure 21 Smog Comparison in product and construction stage for level 3 elements......................... 31
Figure 22 Global Warming Benchmarking for Life Cycle Stages and level 3 elements......................... 34
Figure 23 Fossil Fuel Consumption Benchmarking for Life Cycle Stages and level 3 elements............ 35
Figure 24 Acidification Benchmarking for Life Cycle Stages and level 3 elements.............................. 35
Figure 25 Human Health Criteria (Respiratory) Benchmarking for Life Cycle Stages and level 3 elements 36
Figure 26 Eutrophication Benchmarking for Life Cycle Stages and level 3 elements 36
Figure 27 Ozone Layer Depletion Benchmarking for Life Cycle Stages and level 3 elements 37
Figure 28 Smog Benchmarking for Life Cycle Stages and level 3 elements 37
Figure 29 Scatter plot of Total Cost and GWP impacts of CIVIL 498C 2014 studies 38

List of Tables

Table 1 Summary of assessment information 8
Table 2 Functional Equivalent Definition 8
Table 3 Building Characteristics of the Geography Building 9
Table 4 Geography Building Definition 11
Table 5 Upstream and downstream processes supporting each LCA module 12
Table 6 Material type and property inaccuracies in Geography building IE model 15
Table 7 A11 Foundations List of Materials 22
Table 8 A21 Lowest Floor Construction List of Materials 22
Table 9 A22 Upper Floor Construction List of Materials 22
Table 10 A23 Roof Construction List of Materials 22
Table 11 A31 Walls Below Grade List of Materials 23
Table 12 A32 Walls Above Grade List of Materials 23
Table 13 B11 Partitions List of Materials 23
Table 14 Summary of environmental impact of each level 3 element 25
Table 15 Level 3 Sorted Impact Estimator Inputs 53
Table 16 Level 3 Sorted Assumptions 57
Table 17 Ground Lecture Room Stairs 57
Table 18 Ground Interior Stairs Up 58
Table 19 First Floor Interior Stairs Down 58
Table 20 Ground Lecture Room Steps 58
Table 21 Laths quantity measurements 58
Table 22 Extra wood for the first floor truss 58
Table 23 First Floor Truss steel Rods 59
Table 24 First Floor Truss steel Plates 59

1. General Information on the Assessment

1.1. Purpose of the assessment

The initial stage of a life cycle analysis study is to clearly define the goal and scope. Conclusions and recommendations can then be made in accordance with the goal and scope, which affects the detail and time frame of the LCA. This LCA of the Geography Building at the University of British Columbia was carried out to determine the environmental impact of its design[2]. This LCA of the Geography Building is also part of UBC LCA database, an inventory of the environmental impact of UBC buildings that is intended to be used to stimulate this area and transform green building practices in North America[3]. The data base is mainly developed by UBC students in CIVL 498C course.

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the Geography Building. An exemplary application of these references is in the assessment of potential future performance upgrades to the structure and envelope of the Geography Building. When this study is considered in conjunction with other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions. Furthermore, by identifying hot spots in the value chain, this LCA study can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects[4]. The study is also aim to provide a benchmark for all the buildings that are studied in this class (CIVL 498C, 2013), based on the average environmental impacts per square meter.

The intended core audiences of this LCA study are those involved in building development related policy making at UBC, such as the Project Services, UBC Properties Trust, and Campus Sustainability, who are involved in creating policies and frameworks for sustainable development on campus. Other potential audiences include developers, architects, engineers and building owners involved in design planning, as well as external organizations such as governments, private industry and other universities whom may want to learn more or become engaged in performing similar LCA studies within their organizations[5].

Figure 1 Construction of the "temporary" Geography Building circa 1925. ©UBC

1.2. Identification of building

When the University of British Columbia moved to its present Point Grey site in the Fall of 1925 the Department of Geology and Geography was placed in a "temporary"

---

[2] (Connaghan, 2009)
[3] (UBC Sustainability, n.d.)
[4] (Connaghan, 2009)
[5] (Connaghan, 2009)

building. That 51,883 sf wood-frame building is the present Geography Building, completely rebuilt inside during the late 1970s, and still standing after more than 60 years as a "temporary" building[6] (Figure 1). The building is made from wood-frame and stucco by Provincial Department of Public Works (The architect). The building is located at 1984 West Mall, Vancouver on the University of British Columbia campus and was originally named the Applied Science Building, renamed Forestry and Geology in 1951[7]. It was built in conjunction with eight other buildings—the old forestry, agriculture, arts and administration buildings, the electrical and mechanical laboratories, the auditorium, and the mining, metallurgy and hydraulics building — all of which were built as semi-permanent buildings, and the total cost for all nine buildings was $500,000. The function of the building was to house the academic needs of Geology, Civil Engineering, Zoology, Forestry and Botany, and was originally composed of 13 laboratories, 17 offices, 13 research and prep rooms, 12 lecture rooms, eight storage rooms, five lavatories and three locker rooms, as well as a library, museum and common room[8]. Nowadays the building is only used by Geography Department and has 12 classrooms, 1 main lecture room, 2 computer labs, 19 staff offices, 17 graduate student offices, 36 faculty offices, 18 research labs, 2 lounges, and 4 washrooms[9].

Since its original construction, the Geography Building has undergone many renovations for a total of six phases of alterations. Some major alterations included wall, ceiling and room changes, additional fire exit stairwells, and the installation of two firewalls through the cross section of the building. The firewalls in particular required the two main stairwells to be demolished, as well as the walls on the ground and first floors between the front and rear entrances to be torn out (Figure 2). Overall, the building's floors and exterior walls remain intact, but many of the interior walls have been altered to accommodate floor plan changes and new building requirements. This model, however, will represent the Geography Building as it was built in 1924, as if it were built today [10].

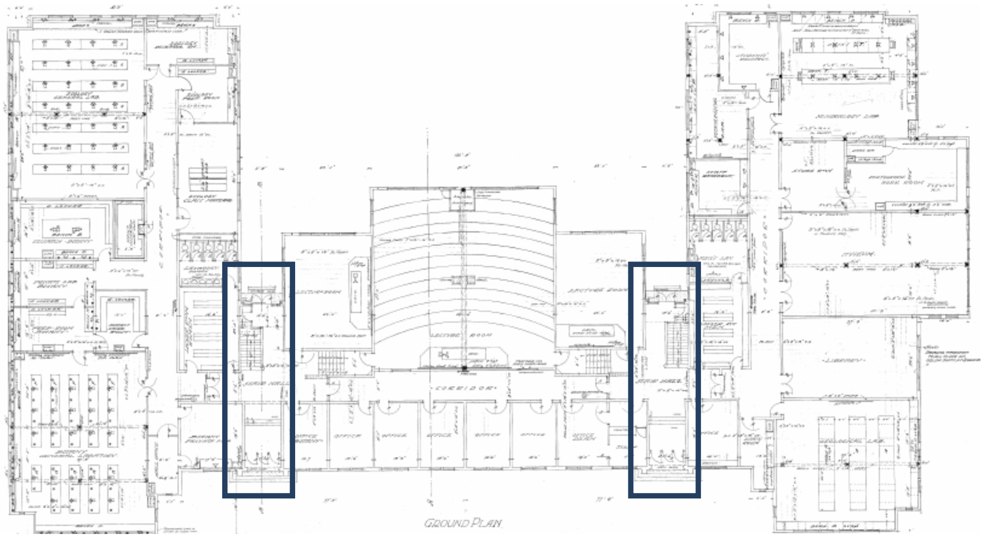


Figure 2 Ground plan highlighting the sections of building torn down for firewall installation

---

[6] (University of British Columbia, 2009)

[7] (The University of British Columbia Library, 2013)

[8] (Connaghan, 2009)

[9] (Department of Geography - UBC, n.d.)

[10] (Connaghan, 2009)

Client for Assessment	Completed as coursework in Civil Engineering technical elective course at the University of British Columbia.
Name and qualification of the assessor	Completed as coursework in CIVL 498C technical elective course in Civil Engineering at the University of British Columbia.
Impact Assessment method	Zahra Hosseini (MASA Student: 2013), Jessica Connaghan (Previous Auther: 2009)
Point of Assessment	US EPA TRACI methodology
Period of Validity	88 years
Date of Assessment	5 years.
Verifier	Completed in December 2013.

Table 1 Summary of assessment information

1.3.Other Assessment Information

Table 1 provides a summary of assessment information.

2. General Information on the Object of Assessment

2.1. Functional Equivalent

The functional unit in this study is square meter floor/surface area. Considering the area as functional unit provide the possibility of comparing different building studied by other students in the CIVL498C course and also provide the benchmark for these buildings, against which the impact of new projects can be assessed. Table 2 describes Geography Building's functional equivalent.

Aspect of Object of Assessment	Description
Building Type	Institutional - Post Secondary Education
Technical and functional requirements	Codes: CSA CAN3-G40.21-MB1 (Steel and Hollow structural materials), ASTM A325-M79 (Nuts, Washers and Bolts), CISC/CMPA Standard (Coat), NLGA Standard (Sawn Timber), 1998 British Columbia Building Code/ functional: Lab, Store room, Library, Office, Museume, Vault, research room, Lavatory, Locker room, Lecture room, class,
Pattern of use	"The building was originally composed of 13 laboratories, 17 offices, 13 research and prep rooms, 12 lecture rooms, eight storage rooms, five lavatories and three locker rooms, a library, museum and common room. Use pattern: Monday-Friday 07:30-20:30, Saturday/Sunday/Holidays - Closed"
Required service life	In the Fall of 1925 the Department of Geology and Geography was placed in a "temporary" building. That building is the present Geography Building, completely rebuilt inside during the late 1970s. The building is currently under drainage, envelope, exterior painting, roof, and seismic upgrading seismic improvement.

Table 2 Functional Equivalent Definition

Building System	Specific Characteristics of Geography
Structure	Wood posts, girders and beams throughout
Floors	Foundation: Concrete Slab on grade; Ground and First Floors: Wood joists, Concrete suspended slab
Exterior Walls	Foundation: Cast-in-place walls; Ground and First Floors: Wood stud walls with stucco, cedar shiplap, laths on both sides, and plaster
Interior Walls	Foundation: Cast-in-place walls; Ground and First Floors: Lath and plaster on both sides of wood stud walls with plywood sheathing on hallway and lecture room walls
Windows	All windows fixed with wood frame and no glazing
Roof	Wood joist roof overlain by 2"x4" stud walls with cedar shiplap, roofing asphalt, and a 6mil polyethylene vapour barrier

Table 3 Building Characteristics of the Geography Building[11]

2.2.Reference Study Period

Assessments are carried out on the basis of a chosen reference study period. According to EN 15978, the default value for the reference study period shall be the required service life of the building. Assessments are carried out on the basis of a chosen reference study period.

The Geography Building was built in the fall of 1925 as a "temporary" building; however, it completely rebuilt inside during the late 1970s. The building which is 88 old is currently under drainage, envelope, exterior painting, roof, and seismic upgrading seismic improvement[12]. In order to focus on design related impacts, previous report of the Geography Building LCA encompasses a cradle-to-gate scope that includes the raw material extraction, manufacturing of construction materials, and construction of the structure and envelope of the Geography Building, as well as associated transportation effects throughout the manufacturing and construction stages. Thus, the reference study period in this project is considered to be 1 year. So that the assessment only includes cradle-to-gate scope, i.e. the raw material extraction, manufacturing of construction materials, and construction of the structure and envelope, as well as associated transportation effects throughout the manufacturing and construction[13]. The maintenance, operating energy and end-of-life stages of the building's life cycle are left outside the scope of assessment, which also makes the comparison of different studied buildings more feasible, as they may have different required service life.

2.3.Object of Assessment Scope

Table 3 describes materials and components used in the geography building, from its foundations to the external works that are enclosed within the area of the building's site. To manage the material used in the project and create a standardized list of elements in the building, this study uses a modified version of the Canadian Institute of Quantity Surveyors (CIQS) Level 3 to sort the materials. IN CIQS the

---

[11] (Connaghan, 2009)

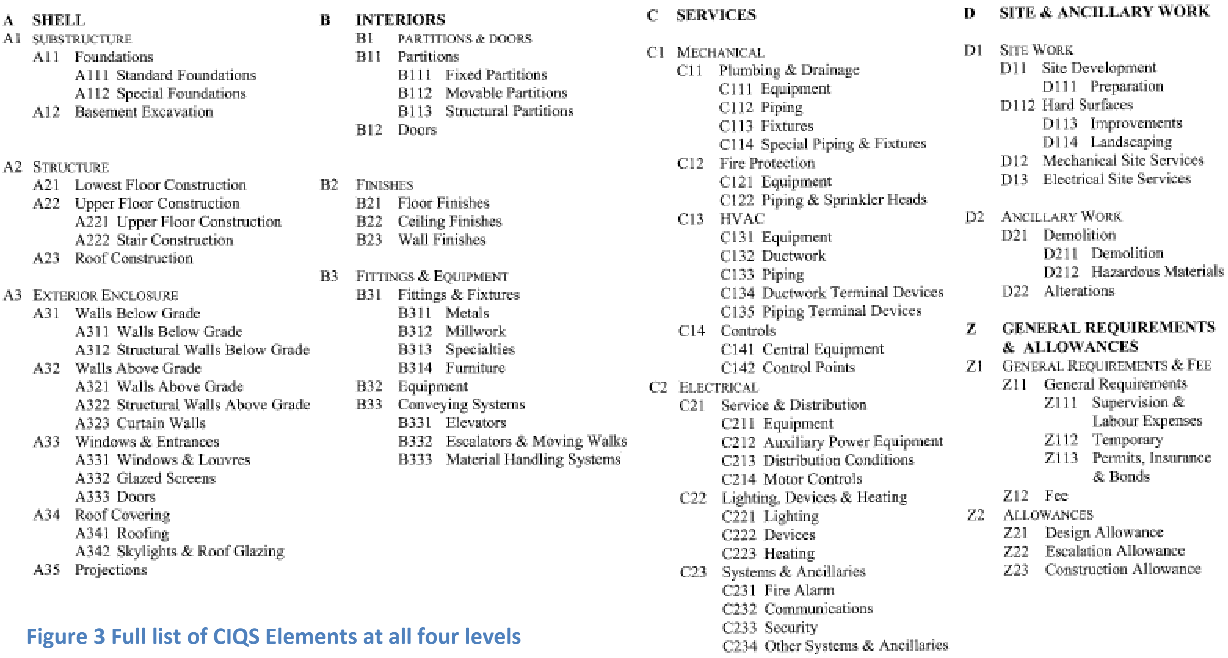
[12] (Geography Students Association, 2013)

[13] (Connaghan, 2009)

elements ordered hierarchically into four levels to allow different levels of aggregation and summarization as follows:

- Level 1 elements are referred to as 'Major Group Elements'.
- Level 2 elements are referred to as 'Group Elements'
- Level 3 elements are referred to as 'Elements'
- Level 4 elements are referred to as 'Sub-Elements'

The full version of the CIQS Level 3 Elements is not applied as the study refers to the previous report of the Geography building[14] to acquire the information about the materials used in the building. Therefore, the report excludes the elements which are not assessed in the previous report, i.e. A12 Basement Excavation, B2 Finishes, B3 Fittings & Equipments, C Services, D Site & Ancillary works (Figure 3). The decision to omit these building components, are associated with the limitations of available data and the IE software[15], as well as to minimize the uncertainty of the model[16]. Moreover, to simplify the study some elements are merged into one element group: Doors and windows are included in the walls element group rather than having their separate group (A33). Table 4 provides a list of components included in each element category in Geography Building.



A SHELL
A1 SUBSTRUCTURE
  A11 Foundations
    A111 Standard Foundations
    A112 Special Foundations
  A12 Basement Excavation

A2 STRUCTURE
  A21 Lowest Floor Construction
  A22 Upper Floor Construction
    A221 Upper Floor Construction
    A222 Stair Construction
  A23 Roof Construction

A3 EXTERIOR ENCLOSURE
  A31 Walls Below Grade
    A311 Walls Below Grade
    A312 Structural Walls Below Grade
  A32 Walls Above Grade
    A321 Walls Above Grade
    A322 Structural Walls Above Grade
    A323 Curtain Walls
  A33 Windows & Entrances
    A331 Windows & Louvres
    A332 Glazed Screens
    A333 Doors
  A34 Roof Covering
    A341 Roofing
    A342 Skylights & Roof Glazing
  A35 Projections

B INTERIORS
B1 PARTITIONS & DOORS
  B11 Partitions
    B111 Fixed Partitions
    B112 Movable Partitions
    B113 Structural Partitions
  B12 Doors

B2 FINISHES
  B21 Floor Finishes
  B22 Ceiling Finishes
  B23 Wall Finishes

B3 FITTINGS & EQUIPMENT
  B31 Fittings & Fixtures
    B311 Metals
    B312 Millwork
    B313 Specialties
    B314 Furniture
  B32 Equipment
  B33 Conveying Systems
    B331 Elevators
    B332 Escalators & Moving Walks
    B333 Material Handling Systems

C SERVICES

C1 MECHANICAL
  C11 Plumbing & Drainage
    C111 Equipment
    C112 Piping
    C113 Fixtures
    C114 Special Piping & Fixtures
  C12 Fire Protection
    C121 Equipment
    C122 Piping & Sprinkler Heads
  C13 HVAC
    C131 Equipment
    C132 Ductwork
    C133 Piping
    C134 Ductwork Terminal Devices
    C135 Piping Terminal Devices
  C14 Controls
    C141 Central Equipment
    C142 Control Points
C2 ELECTRICAL
  C21 Service & Distribution
    C211 Equipment
    C212 Auxiliary Power Equipment
    C213 Distribution Conditions
    C214 Motor Controls
  C22 Lighting, Devices & Heating
    C221 Lighting
    C222 Devices
    C223 Heating
  C23 Systems & Ancillaries
    C231 Fire Alarm
    C232 Communications
    C233 Security
    C234 Other Systems & Ancillaries

D SITE & ANCILLARY WORK

D1 SITE WORK
  D11 Site Development
    D111 Preparation
  D112 Hard Surfaces
    D113 Improvements
    D114 Landscaping
  D12 Mechanical Site Services
  D13 Electrical Site Services

D2 ANCILLARY WORK
  D21 Demolition
    D211 Demolition
    D212 Hazardous Materials
  D22 Alterations

Z GENERAL REQUIREMENTS & ALLOWANCES
Z1 GENERAL REQUIREMENTS & FEE
  Z11 General Requirements
    Z111 Supervision & Labour Expenses
    Z112 Temporary
    Z113 Permits, Insurance & Bonds
  Z12 Fee
Z2 ALLOWANCES
  Z21 Design Allowance
  Z22 Escalation Allowance
  Z23 Construction Allowance

Figure 3 Full list of CIQS Elements at all four levels

---

[14] (Connaghan, 2009)

[15] Athena IE does not have data on finishes, electrical, plumbing or HVAC materials (Athena Institute, 2013).

[16] (Connaghan, 2009)

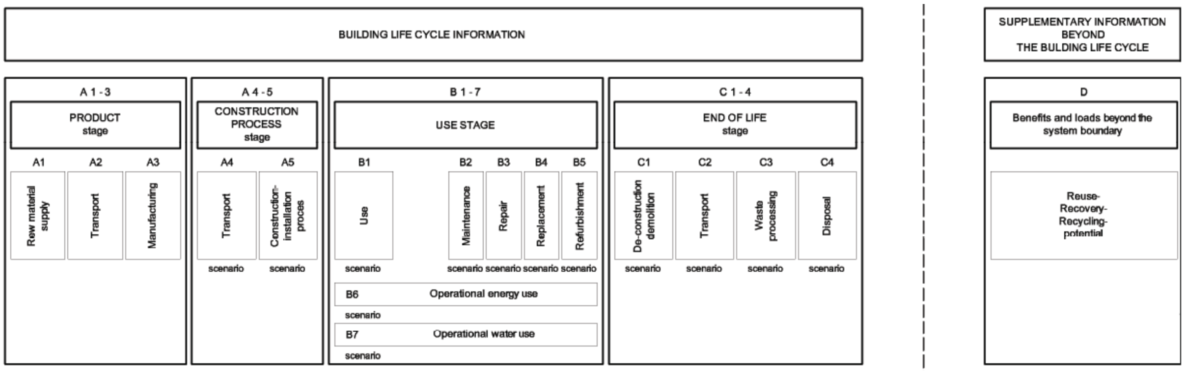


Figure 4 Display of modular information for the different stages of the building assessment

3. Statement of Boundaries and Scenarios Used in the Assessment

3.1.System Boundary

The system boundary determines the processes that are taken into account for the object of assessment. EN 15798 prefers that the system boundary include all building life cycle modules and all the upstream and downstream processes needed to establish and maintain the function(s) of the object of assessment, from the acquisition of raw materials to their disposal or to the point where materials exit the system boundary during the defined reference study period (Figure 4). Upstream includes energy and resource extraction (Product and Construction stages) and downstream include resource use and waste generation (Use and End of life stages).

This LCA study includes only Product and Construction stages in the building life cycle, i.e. A1-5 modules. Table 5 indicates upstream and downstream processes supporting modules included in this study over the reference study period (1 year).

CIVL 498C Level 3 Elements		Description	Quantity (Amount)	Units
A11	Foundations	Columns concrete footings, Exterior walls strip footings, Crawl space walls	272.39	m2
A21	Lowest Floor Construction	Tank Room, Neutralizing Tank, Store room, and Ground Concrete floors	80.83	m2
A22	Upper Floor Construction	Suspended Slabs, wood joist floors (Inclined and stepped floors), stairs construction, ground floor beams, foundation and ground posts, and girders	4,854.65	m2
A23	Roof Construction	First floor beams, posts, truss, two layer wood joist roof (the top layer is inputted as stud wall in IE)	2,394.58	m2
A31	Walls Below Grade	Basement level concrete walls for Tank Room, Neutralizing Tank, and Store room (See Drawing 406-06-016)	54.26	m2
A32	Walls Above Grade	Ground and first floor exterior walls, walls laths (extra materials), doors and windows	3,188.65	m2
B11	Partitions	Ground and first floor interior walls, interior walls laths (extra materials), doors and windows	3,935.37	m2

Table 4 Geography Building Definition

3.1.1. Product Stage[17]

The product stage is also known as 'cradle to gate' for the building products and services that are reference flows for the construction stage of the object of assessment. Product Stage in Athena LCI is developed by tracking energy use and emissions to air, water and land for each of the following modules:

3.1.1.1. Raw Material Supply

For this module, resource use and emissions are assessed per unit of raw resources such as timber, iron ore, coal, limestone, aggregates and gypsum. In addition to the actual harvesting, mining or quarrying of a resource, data from the extraction phase includes activities such as reforestation and beneficiation (a mining technique that involves separating ore into valuable product and waste).

3.1.1.2. Transport

This module includes the transportation of raw resources to the mill or plant, which defines the boundary between extraction and manufacturing.

3.1.1.3. Manufacturing

Manufacturing, typically accounts for the largest proportion of embodied energy and emissions associated with the life cycle of a building product. In Athena inventory studies, this 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. The Impact Estimator software combines resource extraction and manufacturing into a single activity stage (Product) for results reporting purposes.

3.1.2. Construction Stage[18]

The on-site construction stage is like an additional manufacturing step where individual products, components and sub-assemblies come together in the manufacture of the building. This stage covers the processes from the factory gate of the different construction products to the practical completion of the construction work.

Life Cycle Stage	**Product**		**Construction processes**		
Life Cycle Module	**A1 Raw Material Supply**	**A2 Transport**	**A3 Manufacturing**	**A4 Transport**	**A5 Construction-Installation Processes**
Upstream Processes	Raw material, Fuel, water consumption	Fuel production and consumption	Raw material, water and fuel consumption	Fuel production and consumption	Raw material, Fuel, water consumption
Downstream Processes	Solid waste, air and water pollutions	Air pollutions	Solid waste, air and water pollutions	Air pollutions	Solid waste, air and water pollutions

Table 5 Upstream and downstream processes supporting each LCA module

---

[17] (Athena Sustainable Materials Institute, 2013a)

[18] (Athena Sustainable Materials Institute, 2013a)

3.1.2.1. Transport

In the Athena tools, this stage starts with the transportation of individual products and sub-assemblies from manufacturing facilities to distributors in various Canadian and US regions. Average or typical transportation distances to building sites within each city are applied. This is an important life cycle stage that is often overlooked in life cycle assessments for products alone. Transportation of materials is based on a weighted average of the distances from which materials are sourced, by different modes of transportation (diesel road, diesel rail, RFO barge, RFO ship). For example, if LA gets a certain percentage of it's wood from BC, the pacific northwest and the south east, the distances travelled, for each mode of transport are summed up and averaged according to the percentage from each region. All our data is North American, and is assumed to manufactured in the US or Canada, as of yet we don't account for materials coming from overseas[19].

3.1.2.2. Construction-Installation Processes

The on-site construction activity stage also includes storage of products, site clearing, waste generation and management until disposal, the energy use of machines like cranes and mixers, the transportation of equipment to and from the site, concrete form-work, ancillary materials, and temporary heating and ventilation.

4. Environmental Data

4.1. Data Sources

This study uses of 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.

Athena Institute has developed their own life cycle inventory (LCI) databases for building materials to be used in their Impact Estimator software for buildings. These databases are built from the ground up using several actual mill or engineered process models across the continent and are not reliant on trade or government data sources. This way, a good cross-sectional industry average formulation and environmental profile for each material is produced. The manufacturing effects of that average formulation are then regionalized for each location by applying manufacturing technology, recycled content differences for products produced in various regions, local electricity, energy and transportation grids. The data has developed not only for building materials and products but also for energy use, transportation, construction and demolition processes including on-site construction of a building's assemblies, maintenance, repair and replacement effects through the operating life, and demolition and disposal[20].

U.S. Life Cycle Inventory (LCI) Database is a publicly available database developed by the National Renewable Energy Laboratory (NREL) and its partners to help life cycle assessment (LCA) practitioners answer questions about environmental impact. This database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the

---

[19] (Athena Institute, 2013)

[20] (Athena Institute, 2013), (Athena Sustainable Materials Institute, 2013b)

environment that are associated with producing a material, component, or assembly in the U.S. This LCI Database Project was initiated on May 1, 2001, and gained national prominence at a meeting of interests hosted by the Ford Motor Company. Funding agencies and representatives of industrial, academic, and consulting communities voiced strong support for the project. As a result, an advisory group with 45 representatives from manufacturing, government, and nongovernment organizations, as well as LCA experts, worked together to create the database[21].

4.2.Data Adjustments and Substitutions

Table 6 presents the material type and property inaccuracies found in Geography Building Impact Estimator model.

"Lath and Plaster" which is the interior cladding material for interior and exterior walls is replaced with "Gypsum board". To improve the model, literature should be researched to find a LCA study on "Lath and Plaster" material as a wall cladding. However, we cannot access the IE database to add the new cladding material. An option is to not add any interior cladding for the wall in IE and add the impacts found for "Lath and Plaster" in the literature in the final results. Impacts should be multiplied to the wall area that is calculated in our study.

4.3.Data Quality

The primary source of data for this LCA is the original architectural drawings from when the Geography Building was initially constructed in 1924. Additional structural drawings from 2004 were also used to determine the live loading on the building. Two main software tools are to be utilized to complete the study; On Center's On- Screen Takeoff and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

The drawings used in this study lack some sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further in Table 16 in Appendix D.

Here are some examples of uncertainties exist in this study:

- Lath and plaster is considered to be ½" regular gypsum board on the inside of all exterior walls, as well as both sides of all interior walls (Appendix D). This assumption used on such a widely used material can then greatly affect the environmental impacts that this building will have. This assumption could be a potential source of uncertainty in the model's results[22].

---

[21] (NREL, 2013)
[22] (Connaghan, 2009)

Level 3 Element	Description of Inaccuracy(ies)	IE Input(s) Effected	Improvement Strategy(ies)
A11 Foundations	- The real concrete (psi) is unknown - The real concrete flyash % is unknown - The real rebar numbers is unknown	All foundation concrete footings and crawl walls	Look into building original detail drawings or as built maps in UBC Archives
A21 Lowest Floor Construction	- The real concrete (psi) is unknown - The real concrete flyash % is unknown	Foundation and ground Concrete Floor	Look into building original detail drawings or as built maps in UBC Archives
	Live load are not based on known/measured data (45 psf)	Ground Concrete Floor	Changed to 50 psf, based on the 2nd floor live load mentioned in Drawing 401-07-001
A22 Upper Floor Construction	The specific decking wood type and thickness is unknown	Ground and first Floor Floor Area	Look into building original detail drawings
	Concrete (psi), Concrete flyash %, Rebar number Inputs are unknown	Entrance stairs	Look into building original detail drawings or as built maps in UBC Archives
A23 Roof Construction	Roof envelope vapor Barrier material and decking thickness is unknown	Roof Area	Look into building original data or check on site
	Roof envelope Cladding material is not entered in IE	Roof Area	The material is added to IE
	Live load are different from known/measured data (entered 50 instead of 35 psf mentioned in Drawing 401-07-00 for roof area)	Roof Area	IE limits
A31 Walls Below Grade	Concrete (psi), Concrete flyash %, Rebar number Inputs are unknown	All foundation walls	Look into building original detail drawings or as built maps in UBC Archives
A32 Walls Above Grade	Wall sheathing is not entered. Instead wood shiplap siding is added as a cladding material.	Ground Exterior Wall	Based on Drawing 401-07-001 note G.5 sheathing is added (plywood)
	Door type and door glazing type are not known	Ground Exterior Wall First Floor Exterior Wall	Look into building original drawings or check on site
	Interior cladding material is not consistent with known data due to IE limits	Ground Exterior Wall First Floor Exterior Wall	Find an LCA study on Lath and Plaster and replace it with Gypsum board in IE
B11 Partitions	Door type are not known	Ground and first floor Walls	Look into building original drawings or check it in the building
	Envelope material is not consistent with known data due to IE limits	All interior walls	Find an LCA study on Lath and Plaster and replace it with Gypsum board in IE

Table 6 Material type and property inaccuracies in Geography building IE model

- Not all characteristics of emissions are taken into account when doing an impact assessment. The impact assessment software converts specified amounts masses of emissions into their equivalent environmental and human impacts. Although this data had been collected through many environmental and health studies, the impacts are still dependent on an infinite number of factors—such as time, temperature, environment sensitivity, etc.— compromising the accuracy of these impact equivalencies. In addition, there are a number of chemicals within the environment that can react together to produce other chemicals. This reaction could potentially create more or less hazardous chemicals. Overall, this lack of detail could result in over- or underestimation of environmental impacts[23].
- The way that the emissions are converted to impacts can also cause uncertainty in the summary measures. TRACI, the impact assessment methodology used for this study, relates emissions to impacts through characterization factors. These factors, however, are linear and do not take into account the initial amount that the environment is able to absorb without effects, as well as the drop off of effects when there are so many emissions that further emissions do not cause any more harm. This could cause over- or underestimations of the impacts, depending on the relationship the each emission has with the environment[24].
- Finally, the way in which the impact assessment methodology allocates impacts to different products along the line of production can affect the overall results. Co-products from the same unit process can be quantified by mass, volume, economic value, etc. Depending on which method of quantification is used, the impacts allocated to each co-product will differ[25].

5. List of Indicators Used for Assessment and Expression of Results

Using Athena IE for buildings, this study measures resources, material and energy flows to and from nature over the raw material extraction and supply, transport, manufacturing, and construction modules for the Geography Building and assesses the potential impact of those flows on ecosystems and human health. Potential effects are assessed and categorized through the following “mid-point” metrics developed by the US Environmental Protection Agency (US EPA), the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2: fossil fuel consumption, global warming (“carbon footprint”), acidification (“acid rain”), eutrophication (“algal bloom”), human health criteria (respiratory), photochemical oxidant creation (“summer smog”), and ozone depletion (“ozone hole”)[26]. While the indicators do not directly address the ultimate environmental impacts, they do provide a convenient way to summarize and compare the masses of inventory data, and at least make decisions on the basis of whether an alternative is likely to result in a reduction of flows from and to nature[27].

---

[23] (Connaghan, 2009)
[24] (Connaghan, 2009)
[25] (Connaghan, 2009)
[26] (Connaghan, 2009), (O’Connor, Meil, Baer, & Koffler, 2012), (W. Trusty, 2009)
[27] (Wayne B Trusty & Horst, 2003)

Fossil Fuel consumption, measured by MJ of fuel consumed, is the potential to lead to the reduction of the availability of low cost/energy fossil fuel supplies. Fossil fuel shortages leading to use of other energy sources, which may lead to other environmental or economic effects[28]

Global warming potential, measured in kg CO_2 equivalent, is the potential for the earth's climate to change based on the build-up of chemicals, and subsequent heat entrapment. The chemicals that affect this summary measure include greenhouse gases, and the total effect is based on their "radiative forcing and lifetime"[29].

Acidification, measured in moles of H+ equivalent, is the potential for an increase of acidity of water and oil systems to occur. This can occur through both wet and dry depositions, and is caused by SO_2 and NO_x emissions[30].

Human Health respiratory effects potential is affected by the "total suspended particulates, particulate material (PM) less than 10µm in diameter (PM_{10}), PM less than 2.5µm in diameter ($PM_{2.5}$), and by emissions of SO2 and NOx", and is measured in kg PM2.5 equivalent. These particles can have toxic effects on human health, including "chronic and acute respiratory symptoms, as well as mortality"[31]

Eutrophication potential, which is measured in kg N equivalent, is the potential for materials and their emissions to fertilize surface waters with previously scarce nutrients. This can then cause an expansion of aquatic photosynthetic plant species, leading to possible odours, decrease in marine habitat and production of chemicals that could be a health hazard[32].

Ozone depletion potential, measured in kg CFC-11 equivalent, is the potential for reduction of the protective ozone due to accelerated destructive chemical reactions caused by chlorofluorocarbons (CFCs), halons and other chemicals. This reduction can cause lower level ozone level, which can cause increased UVB levels and harmful effects on marine life, crops and human health—including cancer[33].

Smog potential, which is measured in kg NO_x equivalent, is the potential for material emissions to cause smog. This can cause harmful effect on human health, including asthma and mortality, and can be deleterious to plant life[34].

6. Model Development

The quantity of materials consumed in the project is assessed, using the model which last year student has developed in On-Screen Takeoff version 3.9.0.6, a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its

---

[28] (Bare, Norris, Pennington, & Mckone, 2003)
[29] (Bare et al., 2003)
[30] (Bare et al., 2003)
[31] (Bare et al., 2003)
[32] (Bare et al., 2003)
[33] (Bare et al., 2003)
[34] (Bare et al., 2003)

users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities.

In the last year study, the measurements generated are formatted into the inputs required for the IE building LCA software, i.e. Foundations, Floors, Walls, Roofs, and extra materials. The Takeoff model and the original architectural drawings from when the Geography Building are used to check the accuracy of the quantity of materials (length, area, and number) used as the IE input data. In this project, IE Inputs are sorted based on a modified version of level 3 of CIQS format as described in section 2.3 (Table 4).

Overall, the drawings were high quality, allowing the takeoffs to be performed with ease. There was lack of information concerning concrete properties, foundation assembly heights and wall cross-sections, and assumptions were made based on research. In addition, some material quantities required assemblies to be factored due to limitations with the IE software[35]. Further detailed information and calculations on all assumptions made as well as the formatted IE inputs can be found in Appendix D.

Here is a description of how each of your Level 3 elements was modeled, including assumptions and challenges associated with each of the programs:

6.1.A11 Foundation

The Foundation element consist of columns concrete footings, Exterior walls strip footings, and Crawl space walls.

For the foundation element, concrete footings were calculated using all three measurement conditions, and were assumed to be composed of concrete with 4000psi strength, #4 rebar reinforcement and average fly ash content. Column footings on the foundation were measured using the count condition with the width and length provided from drawing 401-06-016, and the thickness provided from drawing 401-06-17. They were then labeled based on the dimensions—e.g. 4’x4’ Concrete Footing. The strip footing below the exterior concrete wall was modeled using the width provided from drawing 401-06-016 and the linear condition used to measure the Foundation Exterior Wall with Footings, and was labeled accordingly.

Crawlspace walls are the walls in the foundation level which are not the exterior walls for the basement, but rather raise the ground floor (Section Drawings: 401-06-19/20). Crawlspace walls on the foundation levels were modeled using linear conditions labeled based on their thickness, material, floor level and if they were interior or exterior walls (e.g. Foundation 8” Interior Concrete Wall). They were assumed to have a height of 3.5ft, based on an average of measurements from drawings 401-06-019 and 401-06-020, as well as concrete with 4000psi strength, #5 rebar reinforcement and average fly ash content[36].

For the foundation exterior crawlspace wall with footings, thickness of 10” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (10”/8”) for a total length of 1363.75’ to meet the concrete volume.

---

[35] (Connaghan, 2009)

[36] (Connaghan, 2009)

6.2.A21 Lowest Floor Construction

Based on Drawing 401-07-001 section D, the building does not have any slab-on-grade. The only surfaces that are built on the site ground are Tank Room, Neutralizing Tank, Store room, and Ground Concrete floors.

The floors were modeled using the area condition, and were labeled based on their material, floor level and location (e.g. Ground Concrete Floor). For all the floors, an assumed live load of 50psf was also used based on drawing 401-07-001, a list of specifications from a 2004 renovation. Foundation Concrete Floor was modeled as a slab on grade using the area condition, with a thickness measurement of 4”. The concrete for the slab was assumed to have strength of 4000psi and average fly ash content[37].

6.3.A22 Upper Floor Construction

Upper Floor Construction includes suspended Slabs, wood joist floors (Inclined and stepped floors), stairs construction, ground floor beams, foundation and ground posts, and girders. Although, Ground Floor Area and Ground Level Lecture Room are the lowest floor in most of the building area, they are included in A22 rather than A21. It is due to the CIQS categorization which includes the Suspended floors and decks and Inclined and stepped floors in A22 element category.

The floors in the Geography building were modeled using the area condition, and were labeled based on their material, floor level and location (Ground Sloped Lecture Room). For all the floors, an assumed live load of 50psf was also used based on drawing 401-07-001. An assumed span of 16ft was also used to fit within the 11.8ft - 32.0ft span limitation of the IE software. The wood joist floors were assumed to have ½” thick plywood decking based on knowledge of the decking being wood. In addition, the spans were assumed to be 10ft to fit within the 0.98ft - 15.0ft span limitation of the IE software. Finally, the sloped section of the lecture room was modeled to have a slope based on the dimensions of the risers and treads of the steps, as seen in drawing 401-06-019. A sloped wood joist floor was modeled, and the addition material used for the steps was added as extra basic material. This volume of material was calculated based on the number of steps, and the dimensions of the risers and treads. In addition, it was assumed that the steps had a width of 50ft, based on a drawing measurement, and the wood steps were ½” thick[38].

The beams and girders were modeled in On-Screen Takeoff using linear conditions combined with cross section dimensions given by the drawing 401-06-016, 401-06-017 and 401- 06-18. The posts were also modeled using dimensions from the above drawings and drawing 401-06-020 for post heights, as well at count conditions. All beams, girders and posts included in A21 and A22 were labeled based on dimensions, floor level and material, and were modeled using extra basic materials to simplify calculations. The difference

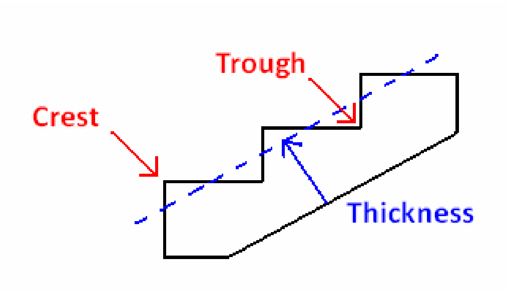


Figure 5 Concrete stairs thickness assessment

---

[37] (Connaghan, 2009)
[38] (Connaghan, 2009)

between measured data and IE input for Ground 8''x18'' Wood Beam and Ground 6''x8'' Wood Beam (5.1.1 and 5.1.4 in Table 15) in last year model, which were due to a typo mistake, was corrected.

The ground level concrete stairs are on the lowest level. However, they are not included in A21 as stair structure is only included in A22 element category of modified version of CIQS. They were measured using the area condition. Concrete thickness assumed to be linear by estimating the average thickness between the crest and the trough of the step, estimated from the cross section as shown in drawing 401-06-020, as seen in Figure 5. The wood stairwells were modeled using extra basic material based on the drawing 401-06-018. Volumes calculated basic on the number of steps, the dimensions of the risers and treads, and an assumed thickness of ½”. 2”x8” stringer boards were also considered in the quantity takeoff of the steps[39].

6.4.A23 Roof Construction

The roof of the building was made up of two wood joist sections, as seen in Figure 6. The lower portion was modeled as a wood joist roof with a span of 10ft due to IE limitations, while the upper portion was modeled as 4 separate wall sections with 2”x4” wood studs (Figure 7). In addition, for sloped sections of the “wall sections,” the section was assumed to be flat. From the roof detail, cedar shiplap was added to the envelope, as well as roof asphalt based on site inspections. In addition, it was assumed there was a 6mil polyethylene layer to meet the vapor barrier requirements of a roof.

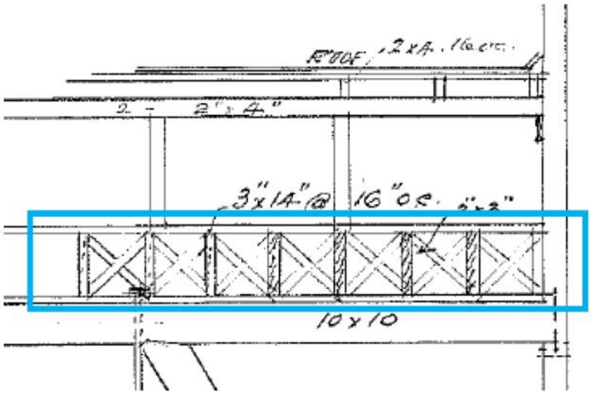


Figure 6 Roof detail for the Geography Building

The First Floor Truss, were modeled using extra basic material. The wood, steel rod and steel sheets of the truss were modeled based on the drawing 401-06-018.

6.5.A31 Walls below Grade

Walls Below Grade includes basement level concrete walls for Tank Room, Neutralizing Tank, and

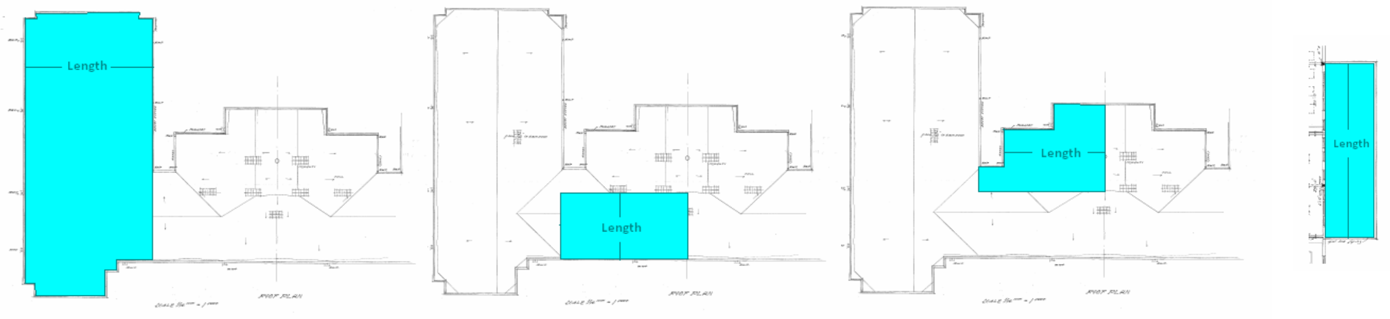


Figure 7 Four separate roof area in which their upper portion was modeled as wall sections

---

[39] (Connaghan, 2009)

Store room (See Drawing 406-06-016).

Basement walls on the foundation levels were modeled using linear conditions labeled based on their thickness, material, floor level and if they were interior or exterior walls (e.g. Foundation 6" Interior Concrete Wall). They were assumed to have a height of 3.5ft, based on an average of measurements from drawings 401-06-019 and 401-06-020, as well as concrete with 4000psi strength, #5 rebar reinforcement and average fly ash content[40].

Thickness of 6" and 7" was given for walls below grade, however 8" was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (6",7"/8") for a total length of 66.00' and 69.125' to meet the concrete volume.

6.6.A32 Walls above Grade

The exterior walls on ground and first floor levels were modeled using linear conditions labeled based on their thickness, material, floor level and if they were interior or exterior walls (e.g. Ground exterior Wall). The exterior walls on the ground and first floors appeared to have no insulation installed when the building was initially constructed, and were therefore assumed to have no insulation. All doors, except for the steel vestibule which was assumed to be a 32"x7' steel interior door, were assumed to be 32"x7' solid wood doors. The windows were assumed to be fixed windows with standard glazing, and were modeled as wood frames based on site inspections. Total lath volumes for the exterior and interior walls (walls above grade and partitions) were calculated by multiplying the calculated lath volume per 1'x1' area—as seen in Table 7 with assumed lath dimensions and spacing—by the twice the total area of the wall, to account for laths on both sides of the walls. Finally, all wood stud walls with lath and plaster required ½" of regular gypsum to be used as a surrogate material for the plaster, with the laths modeled as extra basic material based on 4'x2"x¼" dimensions and ¼" spacing[41].

In the last year model the number of windows, length of the wall, and total area of the windows in Ground and First Floor Exterior Walls (2.2.5 and 2.2.6 in Table 16) were divided by 4 (and modeled 4 times) to accommodate limits on the number of windows. As this limitation is resolved in IE version 4.2.0.208, used in this study, the IE inputs are changed to real quantities.

6.7.B11 Partitions

The interior walls on ground and first floor levels were modeled using linear conditions labeled based on their thickness, material, floor level and if they were interior or exterior walls (e.g. Ground 2"x4" Stud Interior Wall, etc.). Hallway walls were also assumed to have plywood sheathing, based on drawing 401-06-030, a drawing from a building renovation in 1963. The doors and windows within the ground and first floor walls were modeled using count conditions. All doors were assumed to be 32"x7' solid wood doors. Finally, all wood stud walls with lath and plaster required ½" of regular gypsum to be used as a surrogate material for the plaster, with the laths modeled as extra basic material based on 4'x2"x¼" dimensions and ¼" spacing[42].

---

[40] (Connaghan, 2009)
[41] (Connaghan, 2009), (Wikipedia, n.d.)
[42] (Connaghan, 2009), (Wikipedia, n.d.)

6.8.Bill of materials for CIQS level 3 elements

A reference flow is a quantified amount of the product(s), including product parts, necessary for a specific product system to deliver the performance described by the functional unit. The purpose of the reference flows is to translate the abstract functional unit into specific product flows for each of the compared systems, so that product alternatives are compared on an equivalent basis, reflecting the actual consequences of the potential product substitution[43]. Geography building's bill of materials in metric units for each Level 3 Element, taken from reordered building model, in IE version 4.2.0.208, is presented in Table 7-13.

Material	Quantity	Unit
Concrete 30 MPa (flyash av)	187.8902	m3
Rebar, Rod, Light Sections	5.794	Tonnes

Table 7 A11 Foundations List of Materials

Material	Quantity	Unit
Concrete 30 MPa (flyash av)	10.4564	m3
Rebar, Rod, Light Sections	0.2886	Tonnes
Welded Wire Mesh / Ladder Wire	0.0463	Tonnes

Table 8 A21 Lowest Floor Construction List of Materials

Material	Quantity	Unit
Concrete 30 MPa (flyash av)	8.7282	m3
Galvanized Sheet	1.1034	Tonnes
Large Dimension Softwood Lumber, kiln-dried	152.1387	m3
Nails	1.0241	Tonnes
Rebar, Rod, Light Sections	0.0526	Tonnes
Small Dimension Softwood Lumber, kiln-dried	2.5429	m3
Softwood Plywood	5967.6581	m2 (9mm)

Table 9 A22 Upper Floor Construction List of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	2039.2711	m2
Cedar Wood Shiplap Siding	2039.2711	m2
Double Glazed No Coating Air	601.4763	m2
Joint Compound	2.0352	Tonnes
Nails	0.4949	Tonnes
Paper Tape	0.0234	Tonnes
Screws Nuts & Bolts	0.7751	Tonnes
Small Dimension Softwood Lumber, kiln-dried	67.4235	m3
Softwood Plywood	2588.9689	m2 (9mm)
Stucco over porous surface	2039.2711	m2
Unclad Wood Window Frame	4851.0436	kg
Water Based Latex Paint	571.874	L

Table 10 A23 Roof Construction List of Materials

---

[43] (Weidema, Wenzel, Petersen, & Klaus Hansen, 2004)

Material	Quantity	Unit
Concrete 30 MPa (flyash av)	9.2268	m3
Rebar, Rod, Light Sections	0.3264	Tonnes

Table 11 A31 Walls Below Grade List of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	2039.2711	m2
Cedar Wood Shiplap Siding	2039.2711	m2
Double Glazed No Coating Air	601.4763	m2
Joint Compound	2.0352	Tonnes
Nails	0.4949	Tonnes
Paper Tape	0.0234	Tonnes
Screws Nuts & Bolts	0.7751	Tonnes
Small Dimension Softwood Lumber, kiln-dried	67.4235	m3
Softwood Plywood	2588.9689	m2 (9mm)
Stucco over porous surface	2039.2711	m2
Unclad Wood Window Frame	4851.0436	kg
Water Based Latex Paint	571.874	L

Table 12 A32 Walls Above Grade List of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	8093.9854	m2
Galvanized Sheet	0.0619	Tonnes
Joint Compound	8.0779	Tonnes
Nails	0.69	Tonnes
Paper Tape	0.0927	Tonnes
Small Dimension Softwood Lumber, kiln-dried	76.8397	m3
Softwood Plywood	1554.9361	m2 (9mm)
Solvent Based Alkyd Paint	0.2948	L
Water Based Latex Paint	86.1659	L

Table 13 B11 Partitions List of Materials

7. Communication of Assessment Results

Life Cycle Results

Environmental impacts of each level 3 CIQS category is assessed by reordering and improving previously generated whole building LCA model, in IE version 4.2.0.208. IE utilizes the Athena Life Cycle Inventory (LCI) Database, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results focus on the manufacturing and transportation of materials and their installation in to the initial structure and envelope assemblies. As this study is a cradle-to-gate assessment, the expected service life of the Geography Building is set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building’s life cycle being left outside the scope of assessment. Table 15 summarizes the environmental impacts of Geography Building for each. Figure 8-14 illustrate hotspots for each environmental impact category among different level 3 CIQS categories. Figure 15-21 show the hotspots for each environmental impact category among different lifecycle stages.

Level 3 Elements	life cycle stages	Process Module	Impact Assessment metrics						
			Fossil Fuel Consumption (MJ)	Global Warming (kg CO2eq)	Acidification (moles of H+eq)	Human Health Criteria – Respiratory (kg PM10eq)	Eutrophication (kg Neq)	Ozone Layer Depletion (kg CFC-11eq)	Smog (kg O3eq)
A11 Foundations	**Product**	Manufacturing	382293.43	53191.64	348.72	132.437	20.86	0.00030499	7084.963
		Transport	27140.94	1598.19	10.23	0.285	0.71371426	0.00000007	362.2357
		Total	409434.37	54789.83	358.95	132.722	21.57421	0.00031	7447.199
	Construction Process	Construction-installation Process	49460.02	4840.13	34.96	6.765	1.89408003	0.00001525	1013.930
		Transport	32109.54	2445.65	11.44	0.353	0.82462679	0.0000001	404.5892
		Total	81569.56	7285.78	46.4	7.118	2.718707	0.000015	1418.519
	Total	Non-Transport	431,753.45	58,031.77	383.68	139.20	22.75	0.000320	8,098.89
		Transport	59,250.48	4,043.84	21.67	0.64	1.54	0.00000017	766.82
		Total	**491,003.93**	**62,075.61**	**405.35**	**139.84**	**24.29**	**0.0003204**	**8,865.72**
A21 Lowest Floor Construction	**Product**	Manufacturing	21764.03829	2997.061972	19.62189787	7.391938489	1.170463235	1.69731E-05	395.2683
		Transport	1517.757107	89.22978733	0.571566504	0.015898087	0.039872569	3.64571E-09	20.23806
		Total	23281.79539	3086.291759	20.19346437	7.407836576	1.210335804	1.69768E-05	415.5063
	Construction Process	Construction-installation Process	3439.578956	310.0167803	2.265753894	0.380143492	0.125950162	8.48645E-07	67.57603
		Transport	1835.015245	136.9825871	0.653300245	0.020018018	0.046976723	5.46648E-09	23.1018
		Total	5274.594201	446.9993674	2.919054139	0.40016151	0.172926885	8.54111E-07	90.67784
	Total	Non-Transport	25,203.62	3,307.08	21.89	7.77	1.3	1.78217E-05	462.84
		Transport	3,352.77	226.21	1.22	0.04	0.09	9.11219E-09	43.34
		Total	**28,556.39**	**3,533.29**	**23.11**	**7.81**	**1.38**	**1.78309E-05**	**506.18**
A22 Upper Floor Construction	**Product**	Manufacturing	218620.9638	14873.75553	157.1053041	41.74899925	17.0772458	1.44211E-05	3858.053
		Transport	24885.02864	1876.73284	8.856197888	0.272464175	0.637652539	7.49063E-08	313.1889
		Total	243505.9925	16750.48837	165.961502	42.02146343	17.71489834	0.000014496	4171.241
	Construction Process	Construction-installation Process	14528.25482	1827.04894	14.52604271	2.256462536	1.143693432	7.25534E-07	390.7883
		Transport	10448.8563	735.2749322	3.702821922	0.111218219	0.264558676	2.93672E-08	130.9264
		Total	24977.11112	2562.323873	18.22886463	2.367680755	1.408252108	7.54902E-07	521.7147
	Total	Non-Transport	233,149.22	16,700.80	171.63	44.01	18.22	0	4,248.84
		Transport	35,333.88	2,612.01	12.56	0.38	0.9	0	444.12
		Total	**268,483.10**	**19,312.81**	**184.19**	**44.39**	**19.12**	**0**	**4,692.96**
A23 Roof Construction	**Product**	Manufacturing	3623340.814	54938.59494	428.2836425	169.2028255	23.02873221	6.00073E-06	5651.402
		Transport	15190.05274	1104.543513	5.35144469	0.163090844	0.384131581	4.41776E-08	189.2782
		Total	3638530.867	56043.13845	433.6350872	169.3659164	23.41286379	6.04491E-06	5840.68
	Construction Process	Construction-installation Process	65544.28345	2777.608805	23.96001123	8.345909645	1.351995055	3.81585E-07	528.2405
		Transport	22361.46347	1364.30266	7.8852817	0.225912882	0.555097407	5.46847E-08	278.7892
		Total	87905.74691	4141.911466	31.84529293	8.571822527	1.907092462	4.36269E-07	807.0297
	Total	Non-Transport	3,688,885.10	57,716.20	452.24	177.55	24.38	0	6,179.64

		Transport	37,551.52	2,468.85	13.24	0.39	0.94	0	468.07
		Total	**3,726,436.61**	**60,185.05**	**465.48**	**177.94**	**25.32**	**0**	**6,647.71**
A31 Walls Below Grade	**Product**	Manufacturing	19424.05456	2636.099818	17.29457602	6.51350592	1.081798689	1.49774E-05	349.3773
		Transport	1342.584312	79.21609601	0.505895999	0.014084029	0.035300926	3.23566E-09	17.91258
		Total	20766.63887	2715.315914	17.80047202	6.527589949	1.117099615	1.49806E-05	367.2899
	Construction Process	Construction-installation Process	3111.276795	283.6056354	2.131579544	0.336518089	0.119713362	7.48857E-07	64.53647
		Transport	1579.780997	120.3273071	0.562906561	0.01737292	0.040571364	4.79972E-09	19.90560
		Total	4691.057792	403.9329424	2.694486105	0.353891009	0.160284726	7.53656E-07	84.44207
	Total	Non-Transport	22,535.33	2,919.71	19.43	6.85	1.20	0.000016	413.91
		Transport	2,922.37	199.54	1.07	0.03	0.08	0.000000008	37.82
		Total	**25,457.70**	**3,119.25**	**20.49**	**6.88**	**1.28**	**0.000016**	**451.73**
A32 Walls Above Grade	**Product**	Manufacturing	631612.5969	48182.98028	447.4894123	67.5204599	27.13864743	0.001031771	6692.724
		Transport	26072.1485	1855.052692	9.186875522	0.277799096	0.657786674	7.43E-08	324.9645
		Total	657684.7454	50038.03297	456.6762878	67.79825899	27.79643411	0.001031845	7017.688
	Construction Process	Construction-installation Process	32475.33864	2508.920627	21.52191619	3.635458662	1.495172609	3.51061E-06	475.9976
		Transport	41403.08889	3170.997285	14.70818972	0.455364603	1.061173405	1.26419E-07	520.0933
		Total	73878.42753	5679.917912	36.23010592	4.090823265	2.556346014	3.63703E-06	996.0909
	Total	Non-Transport	664,087.94	50,691.90	469.01	71.16	28.63	0	7,168.72
		Transport	67,475.24	5,026.05	23.9	0.73	1.72	0	845.06
		Total	**731,563.17**	**55,717.95**	**492.91**	**71.89**	**30.35**	**0**	**8,013.78**
B11 Partitions	**Product**	Manufacturing	308037.0487	18678.30968	168.6496474	35.07972162	17.03204313	3.89498E-05	1874.165
		Transport	34543.75451	2189.12222	11.7679071	0.345965257	0.835086295	8.82167E-08	416.4193
		Total	342580.8032	20867.4319	180.4175545	35.42568687	17.86712942	0.000039038	2290.584
	Construction Process	Construction-installation Process	29596.05985	2092.806094	16.96219833	2.813114431	1.575608201	3.8834E-06	196.4491
		Transport	32562.49891	2454.580992	11.52189103	0.355155713	0.830101305	9.79301E-08	407.4446
		Total	62158.55876	4547.387086	28.48408935	3.168270144	2.405709506	3.98133E-06	603.8937
	Total	Non-Transport	337,633.11	20,771.12	185.61	37.89	18.61	0	2,070.61
		Transport	67,106.25	4,643.70	23.29	0.7	1.67	0	823.86
		Total	**404,739.36**	**25,414.82**	**208.9**	**38.59**	**20.27**	**0**	**2,894.48**
Total	**Product**	Manufacturing	9548936.305	314084.9224	2530.628792	781.8951431	174.1191312	0.001683792	40973.68
		Transport	216670.8429	14536.28439	76.87734089	2.27245384	5.46481879	5.84939E-07	2720.127
		Total	9765607.148	328621.2068	2607.506133	784.1675969	179.58395	0.001684377	43693.80
	Construction Process	Construction-installation Process	345991.7566	24875.4428	196.8144262	41.82864182	13.07420374	4.01477E-05	4609.942
		Transport	223400.2537	16255.93974	79.20846516	2.407869995	5.681078943	6.4895E-07	2800.856
		Total	569392.0103	41131.38254	276.0228914	44.23651181	18.75528269	4.07966E-05	7410.797
	Total	Non-Transport	9,894,928.06	338,960.37	2,727.44	823.72	187.19	0.00172	45,583.62
		Transport	440,071.10	30,792.22	156.09	4.68	11.15	0.0000012	5,520.98
		Total	**10,334,999.16**	**369,752.59**	**2,883.53**	**828.40**	**198.34**	**0.00173**	**51,104.60**

Table 14 Summary of environmental impact of each level 3 element

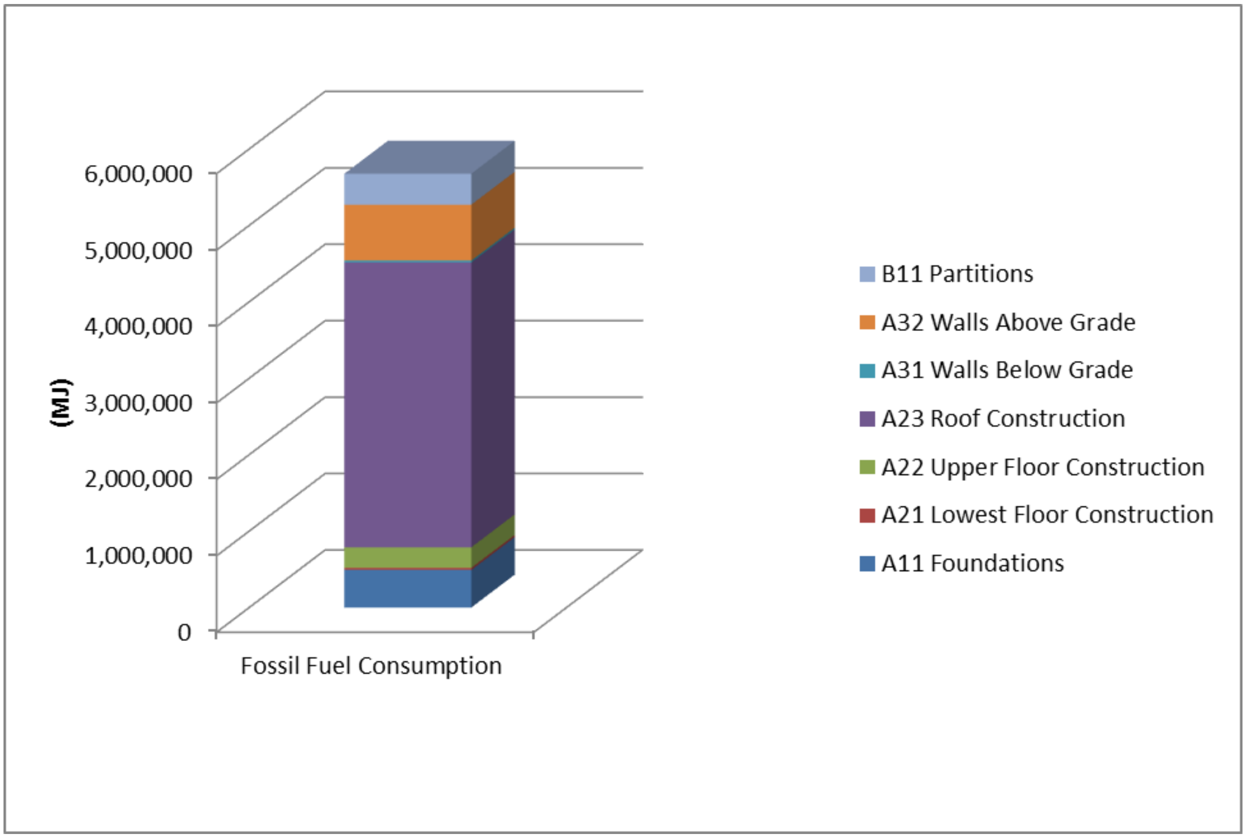


Figure 9 Fossil Fuel Consumption Comparison Between level 3 elements

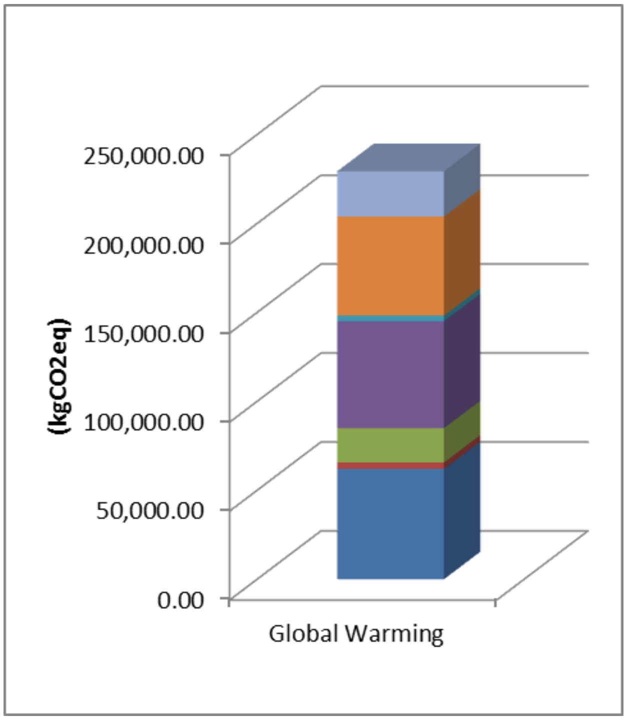


Figure 10 Global Warming Comparison Between level 3 elements

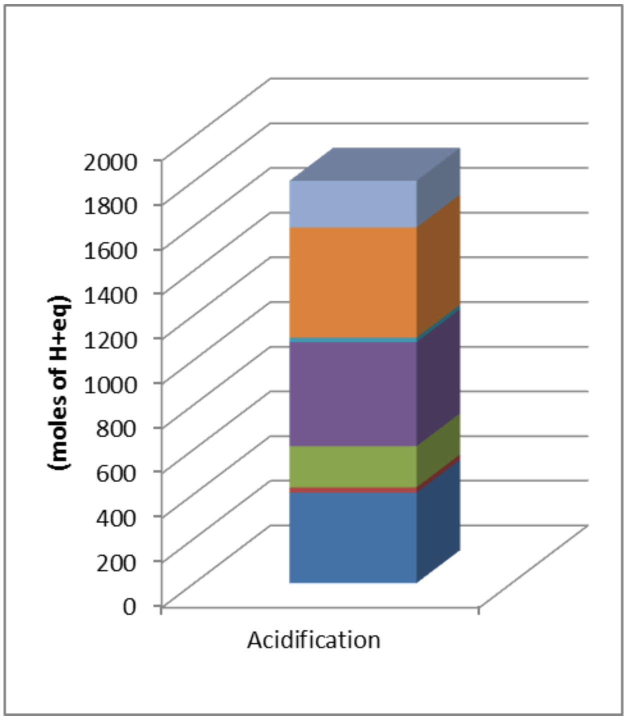


Figure 8 Acidification Comparison Between level 3 elements

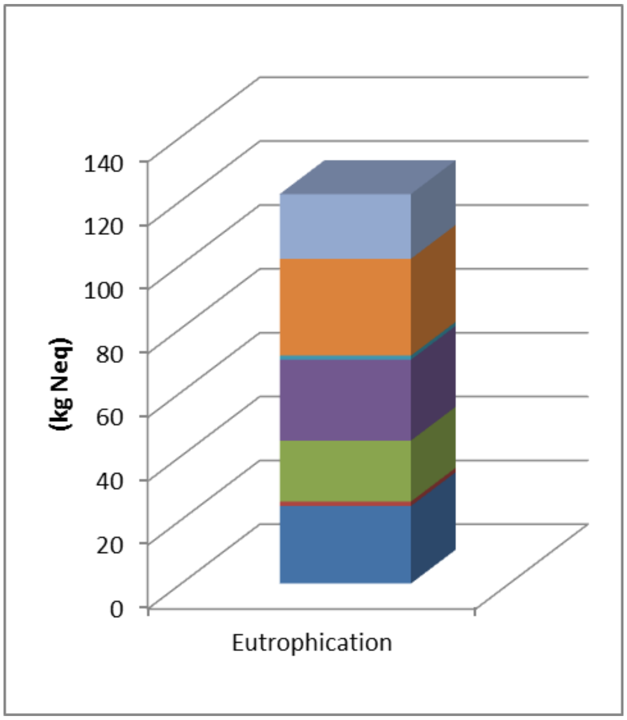


Figure 11 Eutrophication Comparison Between level 3 elements

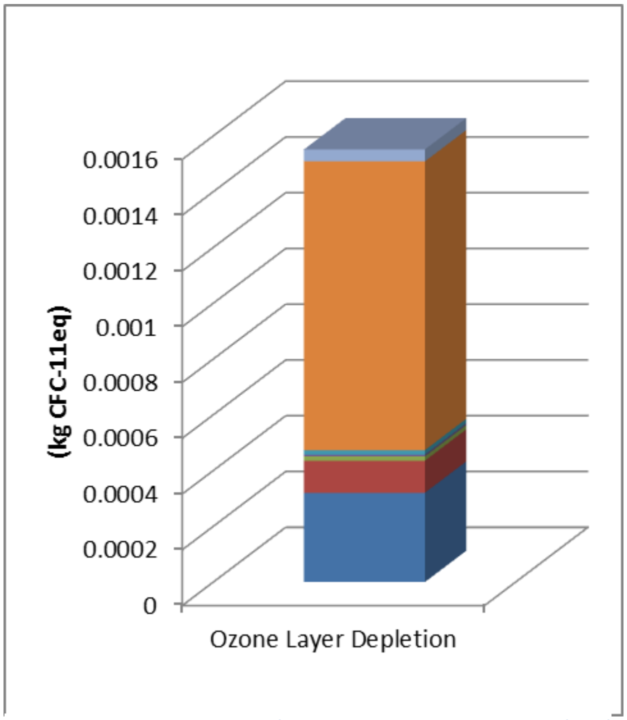


Figure 12 Ozone Layer Depletion Comparison Between level 3 elements

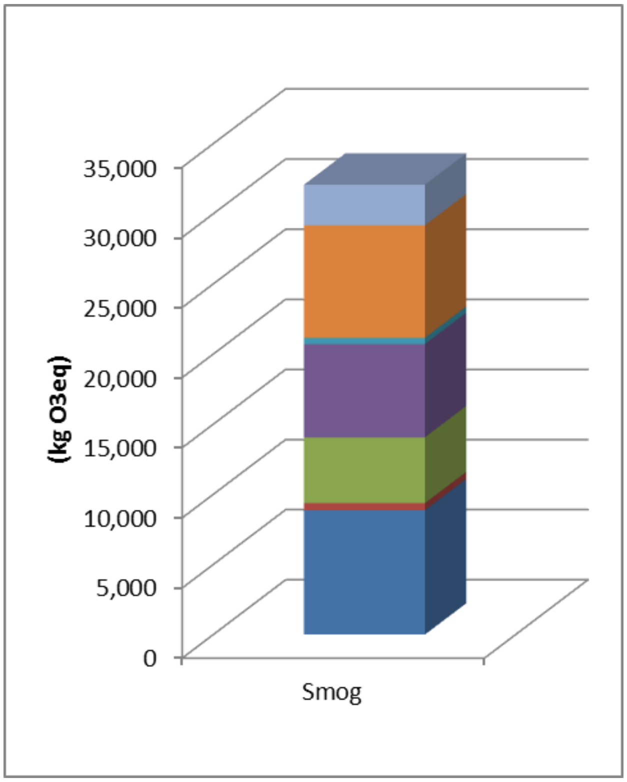


Figure 13 Smog Comparison Between level 3 elements

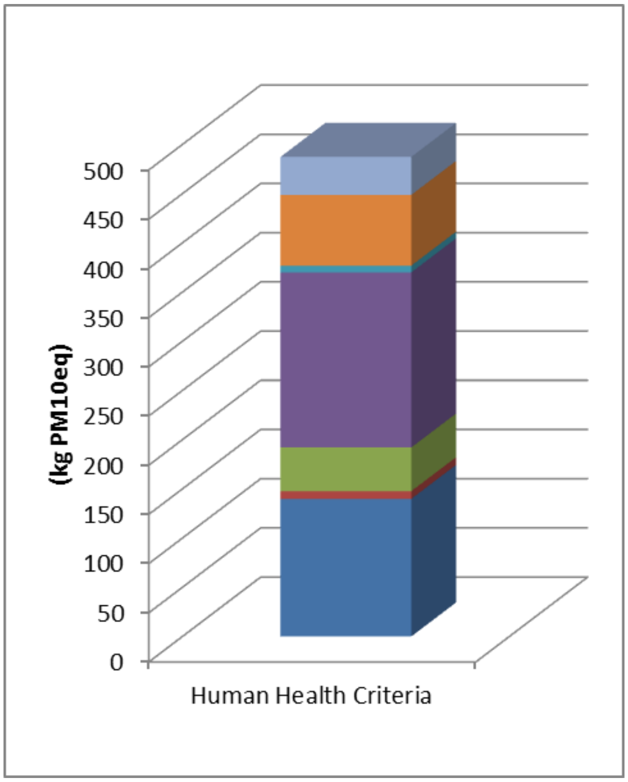


Figure 14 Human Health Criteria Comparison Between level 3 elements

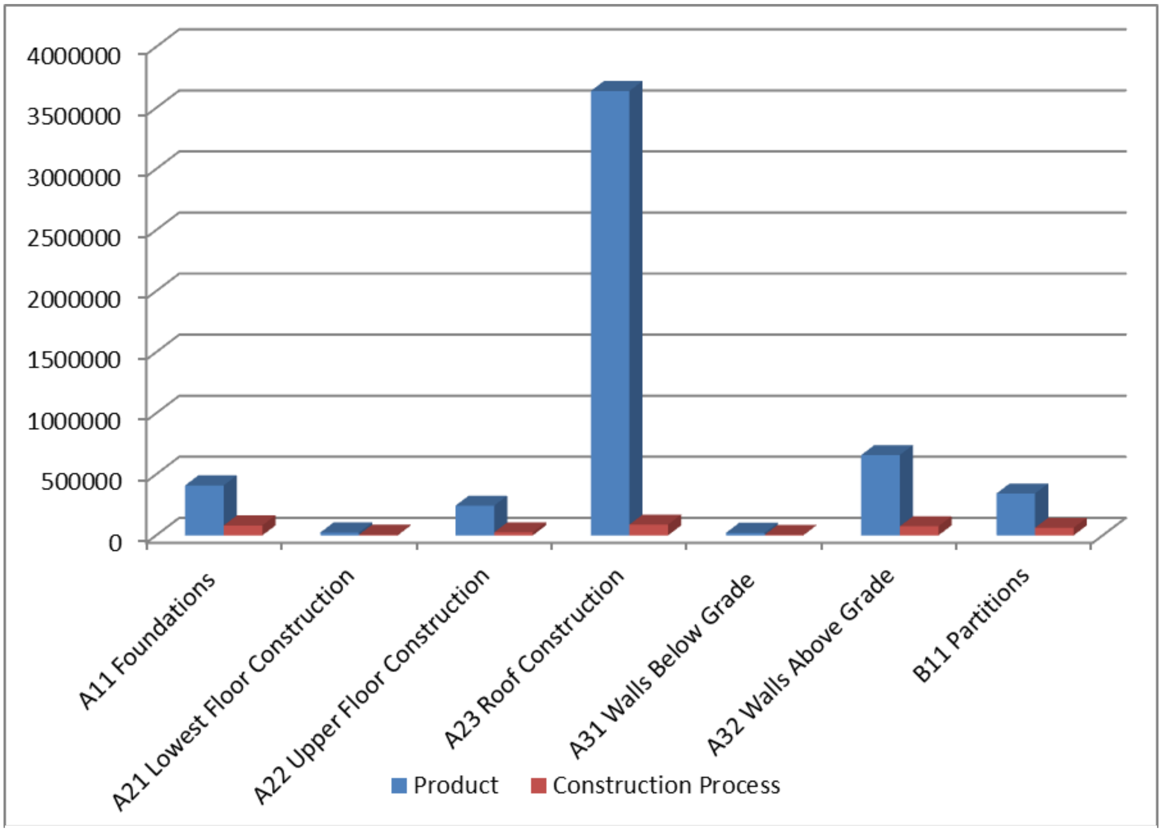


Figure 15 Fossil Fuel Consumption Comparison in product and construction stage for level 3 elements

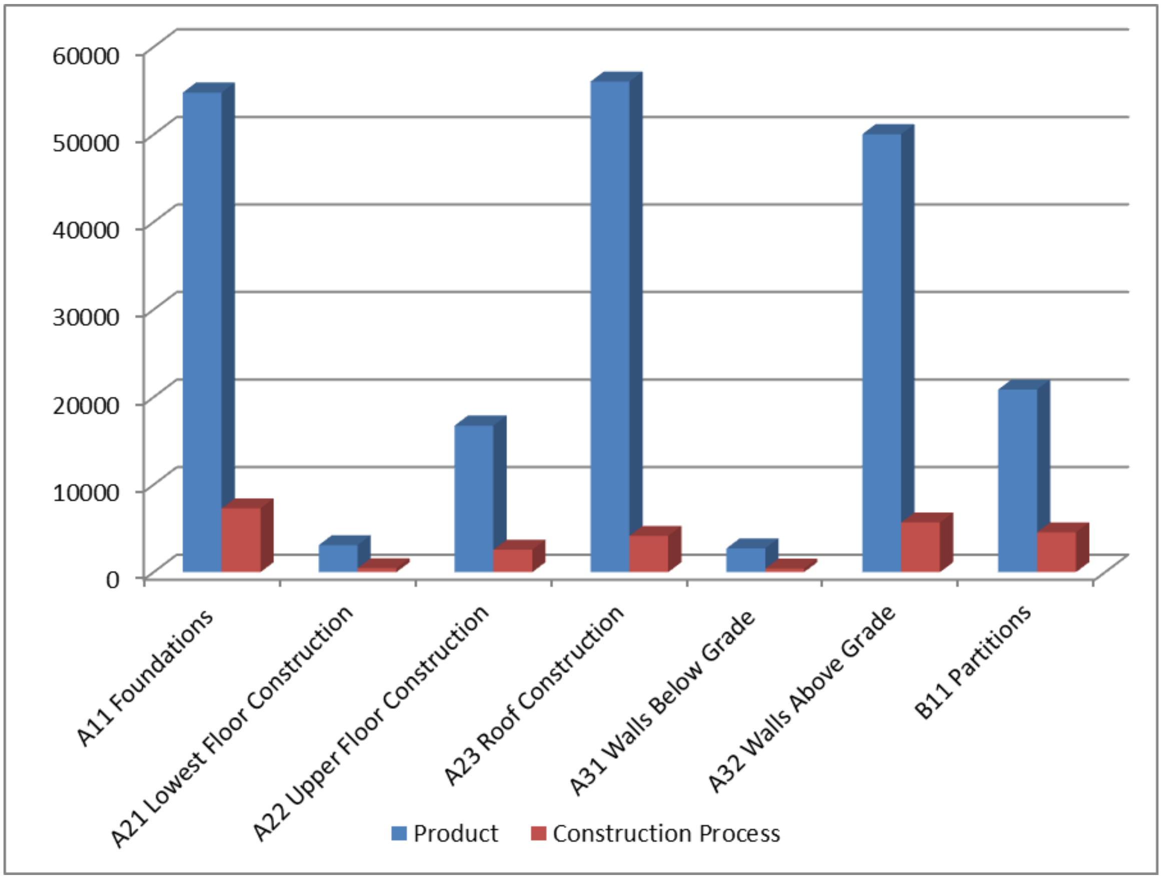


Figure 16 Global Warming Comparison in product and construction stage for level 3 elements

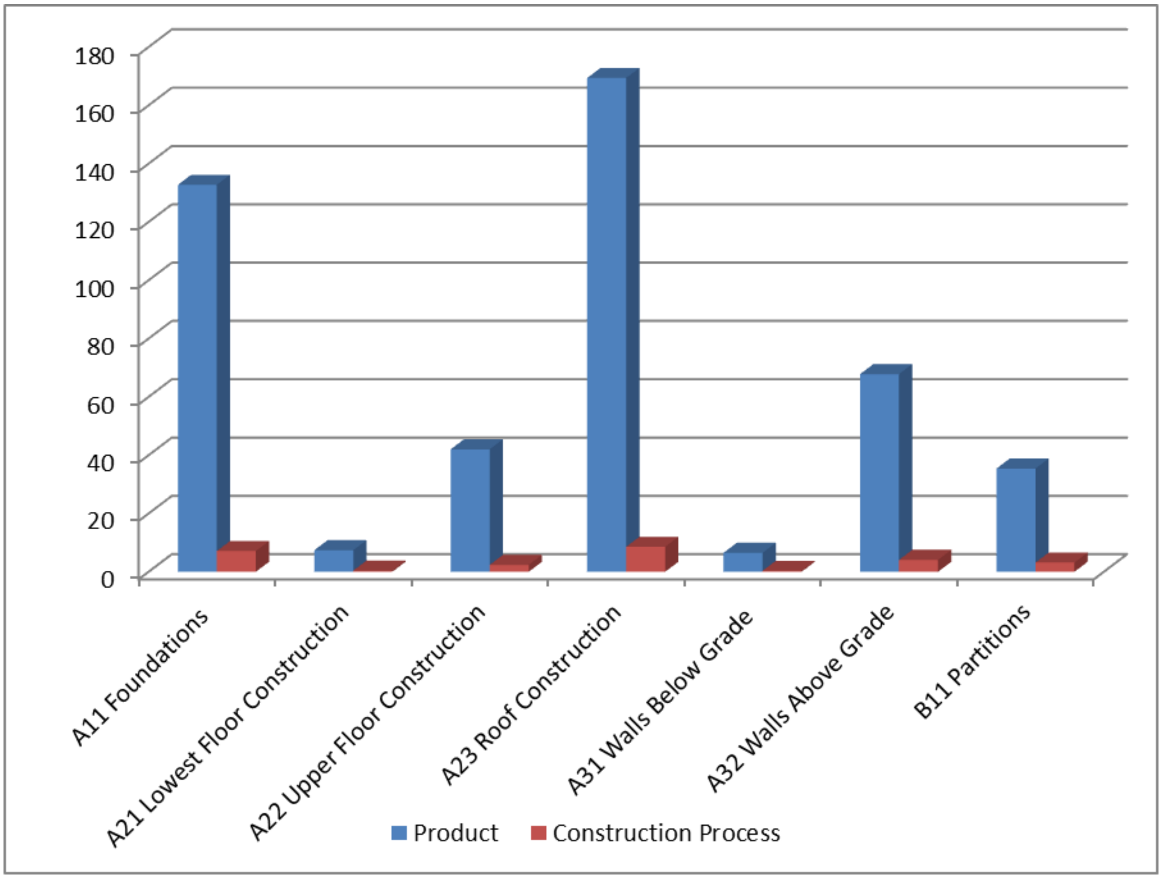


Figure 17 Human Health Criteria (Respiratory) Comparison in product and construction stage for level 3 elements

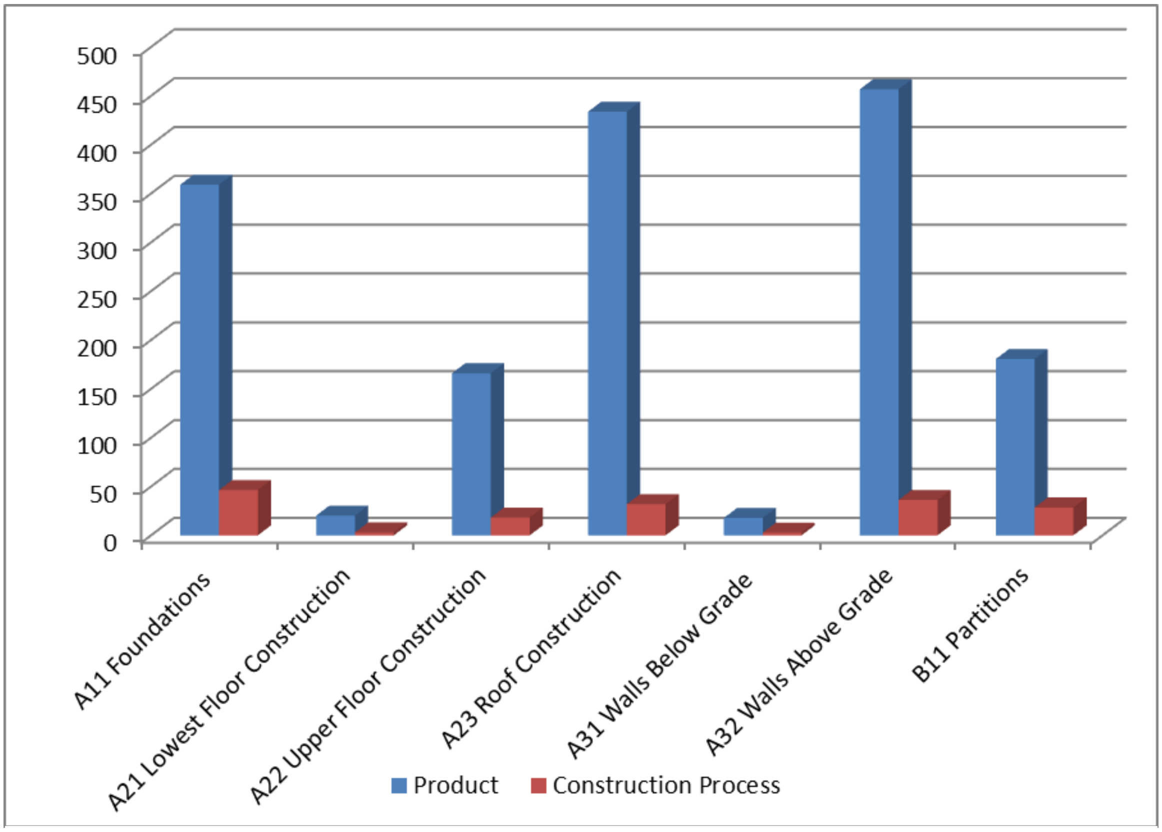


Figure 18 Acidification Comparison in product and construction stage for level 3 elements

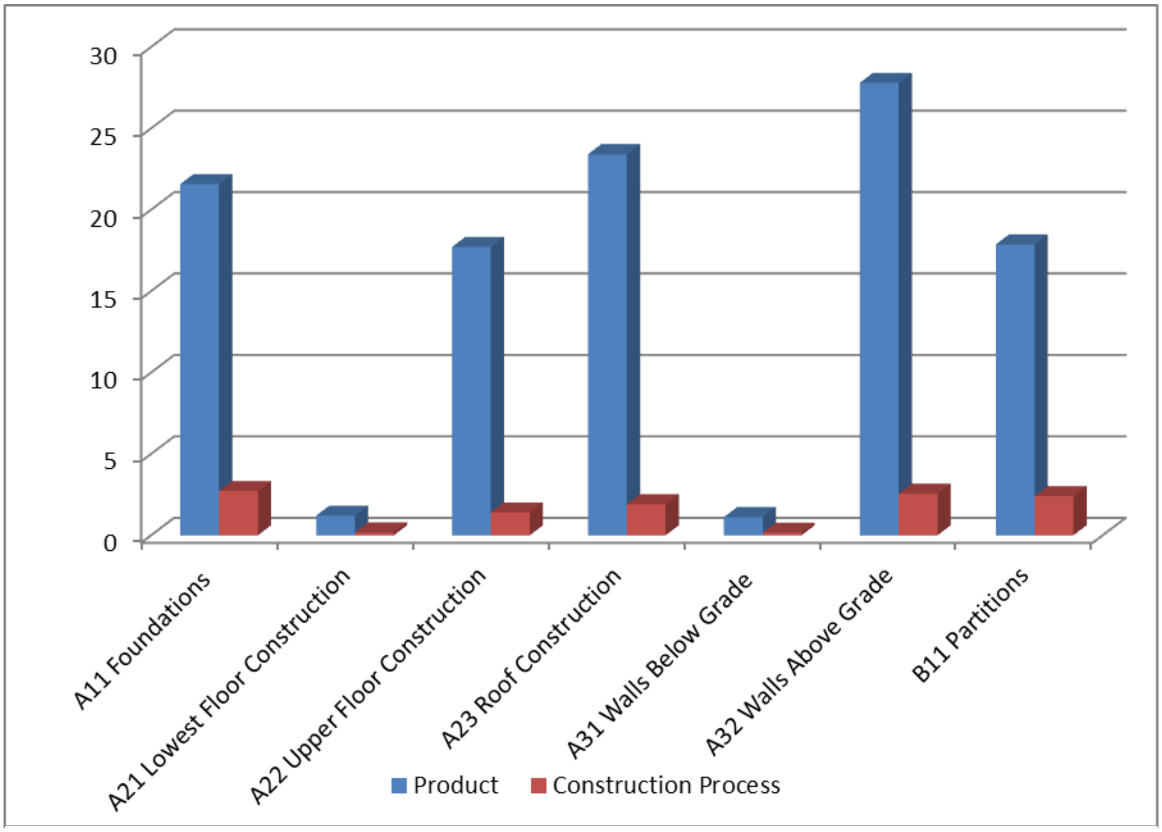


Figure 20 Eutrophication Comparison in product and construction stage for level 3 elements

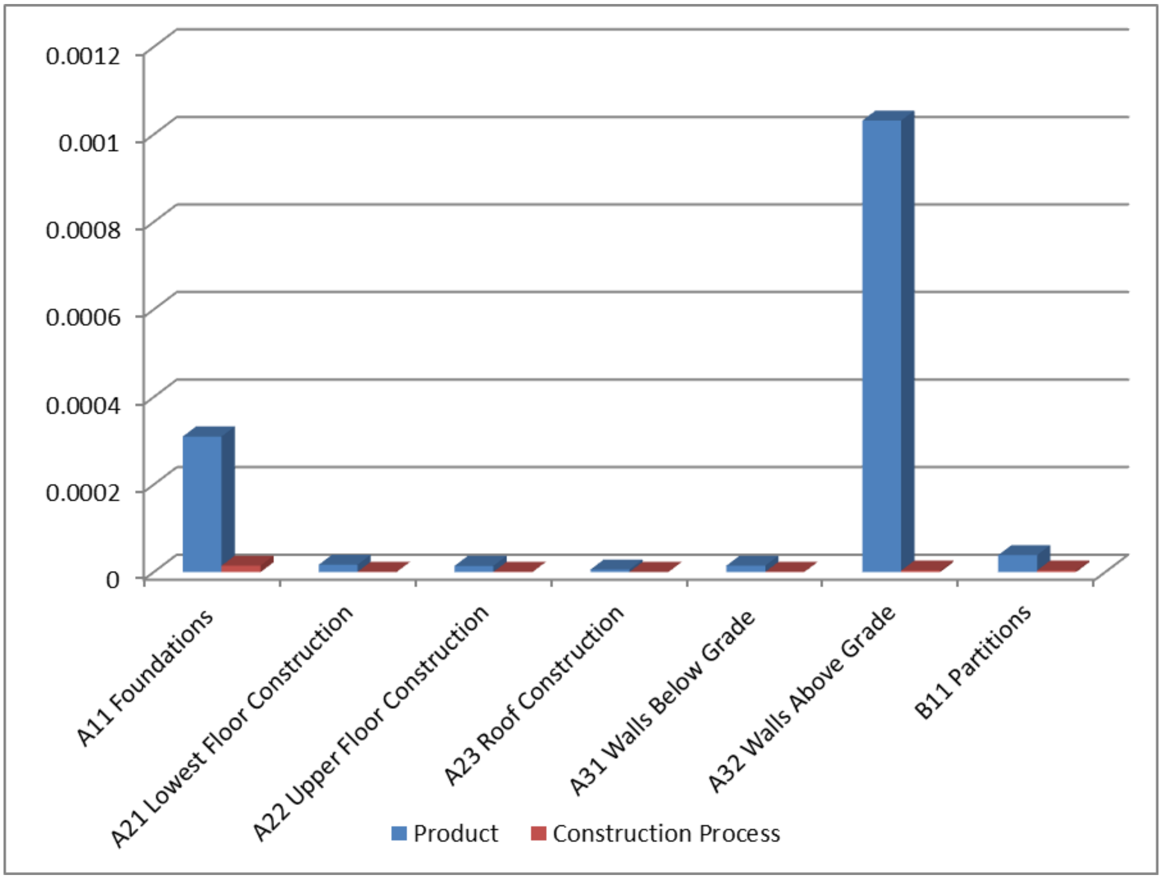


Figure 19 Ozone Layer Depletion Comparison in product and construction stage for level 3 elements

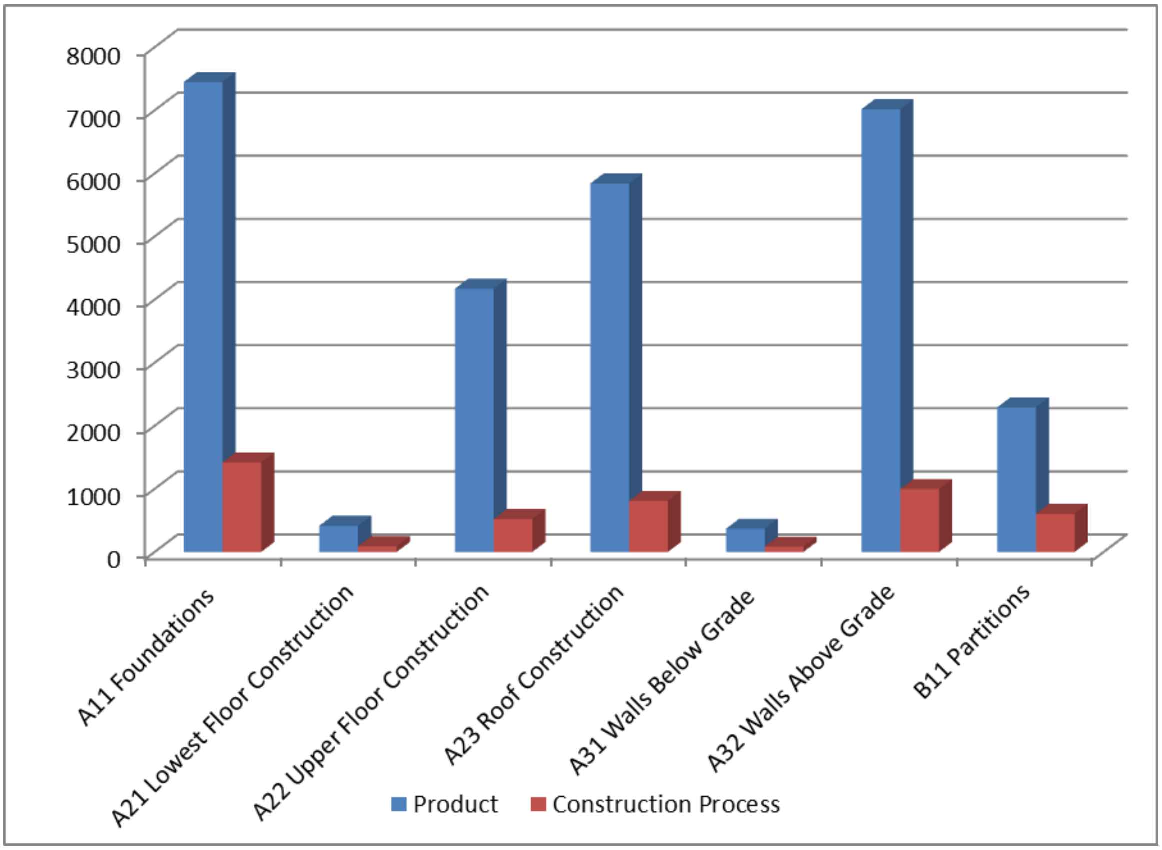


Figure 21 Smog Comparison in product and construction stage for level 3 elements

References

Athena Institute. (2013). Frequently Asked Questions. Retrieved from http://calculatelca.com/faqs/

Athena Sustainable Materials Institute. (2013a). Technical Details. Retrieved from http://www.athenasmi.org/our-software-data/lca-databases/

Athena Sustainable Materials Institute. (2013b). LCI Databases. Retrieved from http://www.athenasmi.org/our-software-data/lca-databases/

Bare, J. C., Norris, G. A., Pennington, D. W., & Mckone, T. (2003). The Tool for the Reduction and Assessment Impacts. *Journal of industrial ecology*, *6*(3/4), 49–78.

Connaghan, J. (2009). *A Life Cycle Analysis of the Geography Building* (p. 68). Vancouver. Retrieved from http://hdl.handle.net/2429/23522

Department of Geography - UBC. (n.d.). Geography Floorplans. *The University of British Columbia*. Retrieved from http://www.geog.ubc.ca/department/floorplans.html

European Commission Research & Innovation Environment. (2012). G-06 (Buildings) / G-07 (Products) Functional equivalent. *EeBGuide Project*. Retrieved from http://www.eebguide.eu/?p=1715

Geography Students Association. (2013). Building Construction. *Geography Students Association*. Retrieved from http://www.ubcgsa.ca/about/building-construction-2/

NREL. (2013). U.S. Life Cycle Inventory Database. Retrieved from http://www.nrel.gov/lci/

O'Connor, J., Meil, J., Baer, S., & Koffler, C. (2012). LCA in construction : status , impact , and limitations. Athena Sustainable Materials Institute,PE INTERNATIONAL, Inc.

Saghafi, M. D., & Hosseini Teshnizi, Z. S. (2011). Recycling value of building materials in building assessment systems. *Energy and Buildings*, *43*(11), 3181–3188. doi:10.1016/j.enbuild.2011.08.016

The University of British Columbia Library. (2013). Geography Building Floorplans. *UBC Library Archives*. Retrieved November 11, 2013, from http://www.library.ubc.ca/archives/bldgs/geog.html

Todd, J. A. (2013). Life Cycle and LEED. *Environmental Design & Construction*, *16*(1), 43–47. Retrieved from http://web.ebscohost.com.ezproxy.library.ubc.ca/ehost/pdfviewer/pdfviewer?sid=017e3eeb-8c49-4700-af3e-342f388f68ac%40sessionmgr10&vid=1&hid=12

Trusty, W. (2009). Incorporating LCA in Green Building Rating Systems. *Environmental Managers Magazine*, (december), 19–22.

Trusty, W. B., & Meil., J. K. (1999). Building life cycle assessment: residential case study. In *Mainstreaming Green: Sustainable Design for Buildings and Communities*. Chattanooga, TN.

Trusty, Wayne B, & Horst, S. (2003). Integrating LCA Tools in Green Building Rating Systems. In *USGBC Greenbuilding International Conference & Expo.* Austin.

UBC Sustainability. (n.d.). CIVL 498C: North America's largest building environmental impact study. Retrieved from http://sustain.ubc.ca/stories/civl-498c-north-america%E2%80%99s-largest-building-environmental-impact-study

UBC Sustainability. (2013). Campus as a Living Laboratory. Retrieved from http://sustain.ubc.ca/our-commitment/campus-living-lab

University of British Columbia. (2009). Fifty Years of Geography at UBC. *UBC Department of Geography*. Retrieved November 11, 2013, from http://www.geog.ubc.ca/department/history.html

Weidema, B., Wenzel, H., Petersen, C., & Klaus Hansen. (2004). *The Product , Functional Unit and Reference Flows in LCA* (pp. 1–47).

Wikipedia. (n.d.). Lath and plaster - Wikipedia, the free encyclopedia. Retrieved from http://en.wikipedia.org/wiki/Lath_and_plaster

Annex A - Interpretation of Assessment Results

Benchmark Development

There is a need for a standard against which to measure and interpret the performance of a system. This is the basis of benchmarking. It is crucial that the projects which are used to develop a benchmark have common goal & scope and model development, so that they include similar criteria in their assessments. Moreover, in comparative studies between different systems/options it is essential to define the functional equivalent. Functional equivalent is a representation of the required and quantified functional and/or technical requirement for a building or an assembled system (part of works), which is used as a basis for comparison. Functional equivalent needs to include building type, relevant technical and functional requirements, the pattern of use and the required service life[44].

UBC Academic Building Benchmark

In this study, the benchmarking for institutional building on UBC Vancouver campus where obtained by assessing the average impact for each TRACI environmental impact category per square meter of the level 3 CIQS elements and the building total area. Figures 24-30 draw comparisons between the environmental impacts of the Geography Building and the CIVL498C 2013 students' projects benchmarks for their lifecycle stages and for their level 3 elements. Figure 31 is a scatter plot of total cost and global warming potential impacts of all studies. Geography building is highlighted among the other buildings.

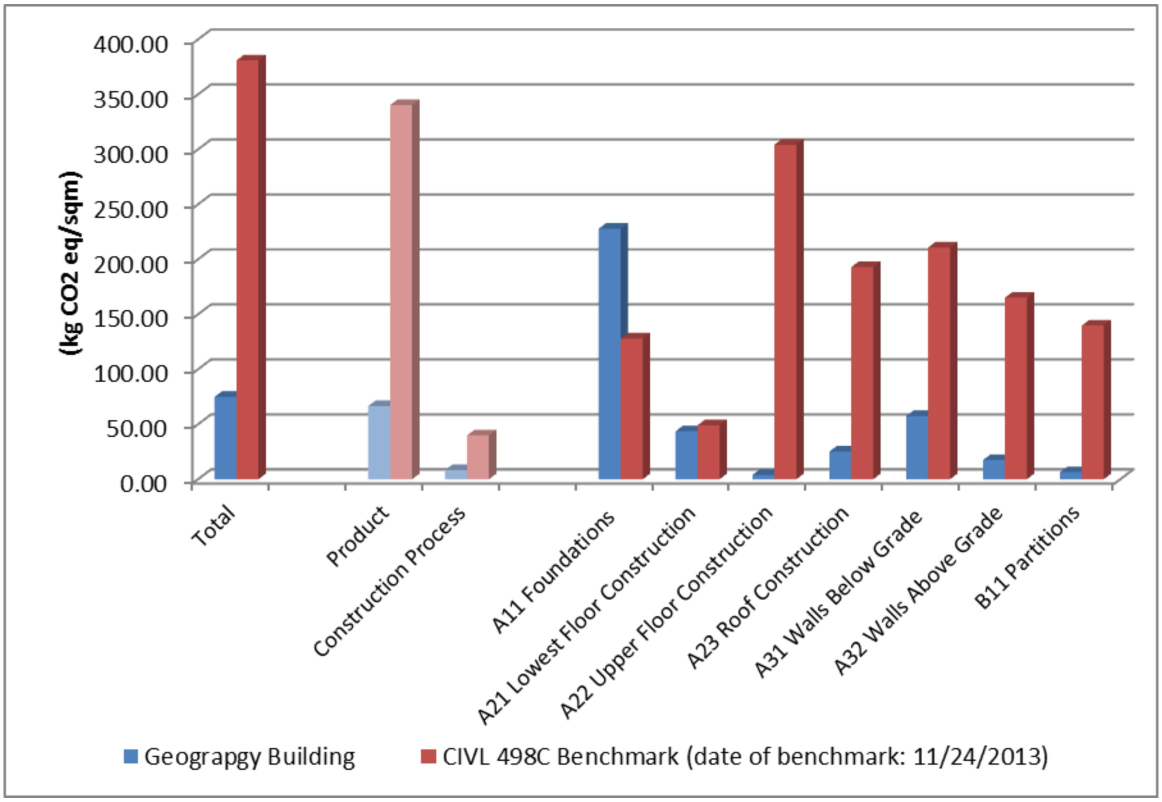


Figure 22 Global Warming Benchmarking for Life Cycle Stages and level 3 elements

---

[44] (European Commission Research & Innovation Environment, 2012; W. B. Trusty & Meil., 1999)

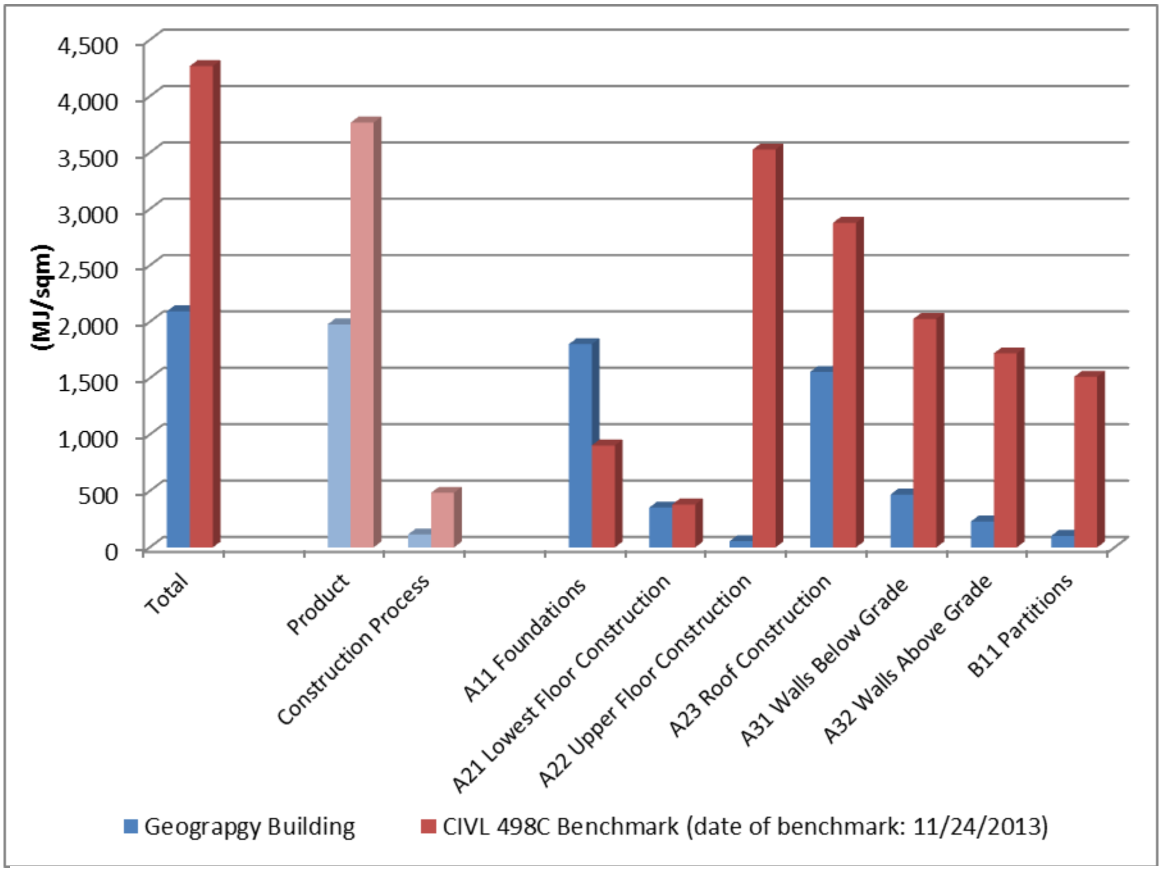


Figure 23 Fossil Fuel Consumption Benchmarking for Life Cycle Stages and level 3 elements

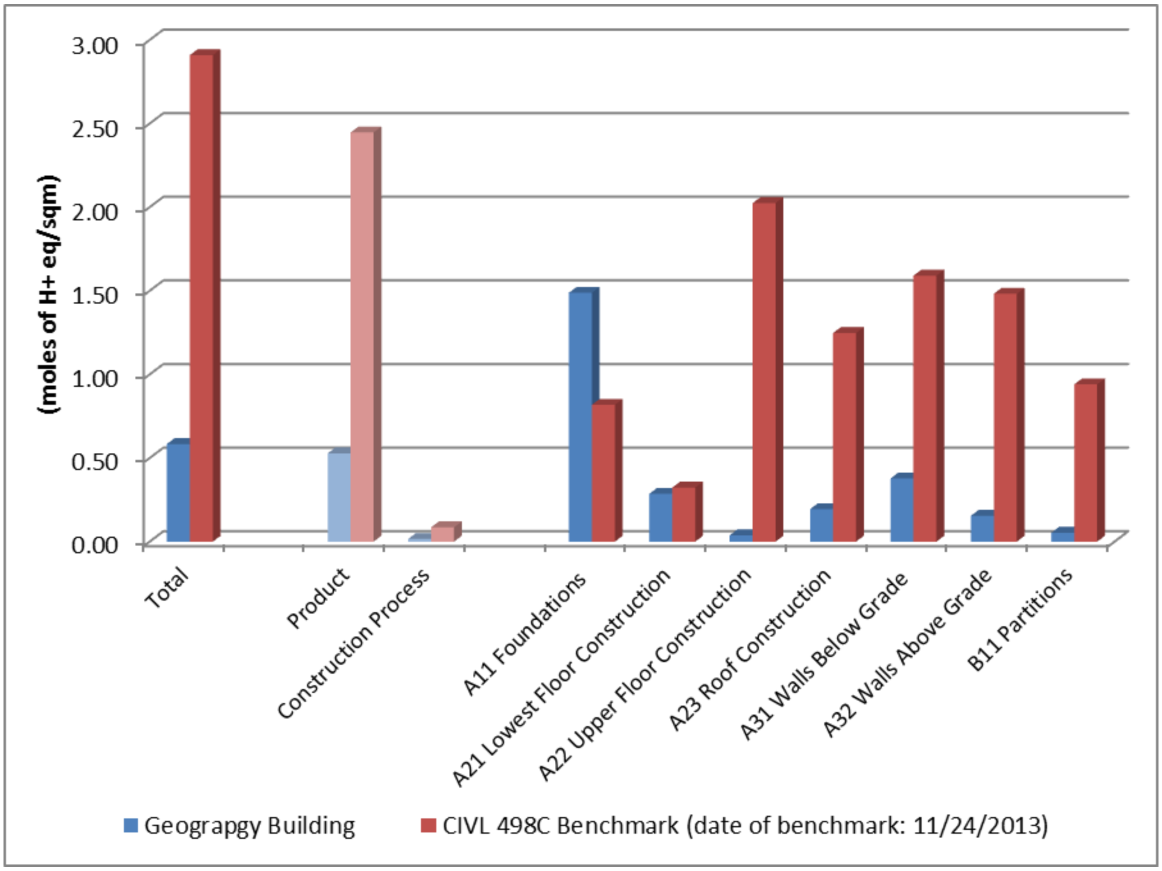


Figure 24 Acidification Benchmarking for Life Cycle Stages and level 3 elements

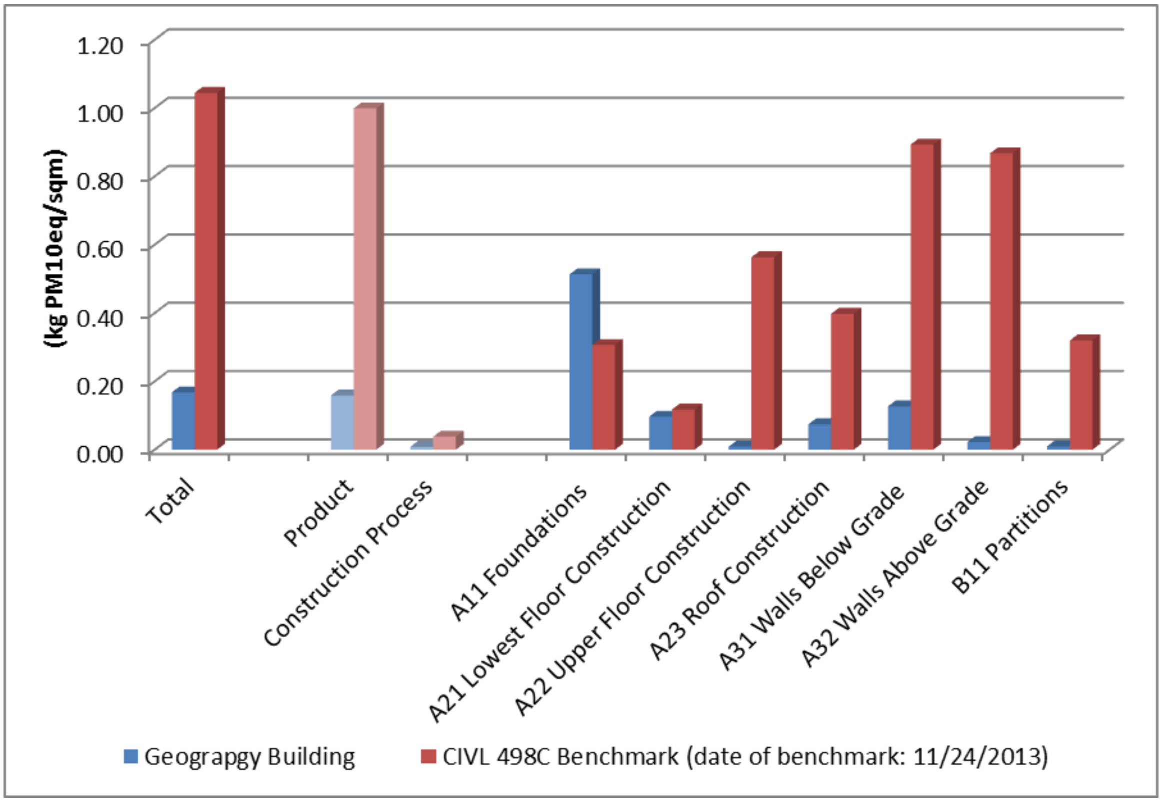


Figure 25 Human Health Criteria (Respiratory) Benchmarking for Life Cycle Stages and level 3 elements

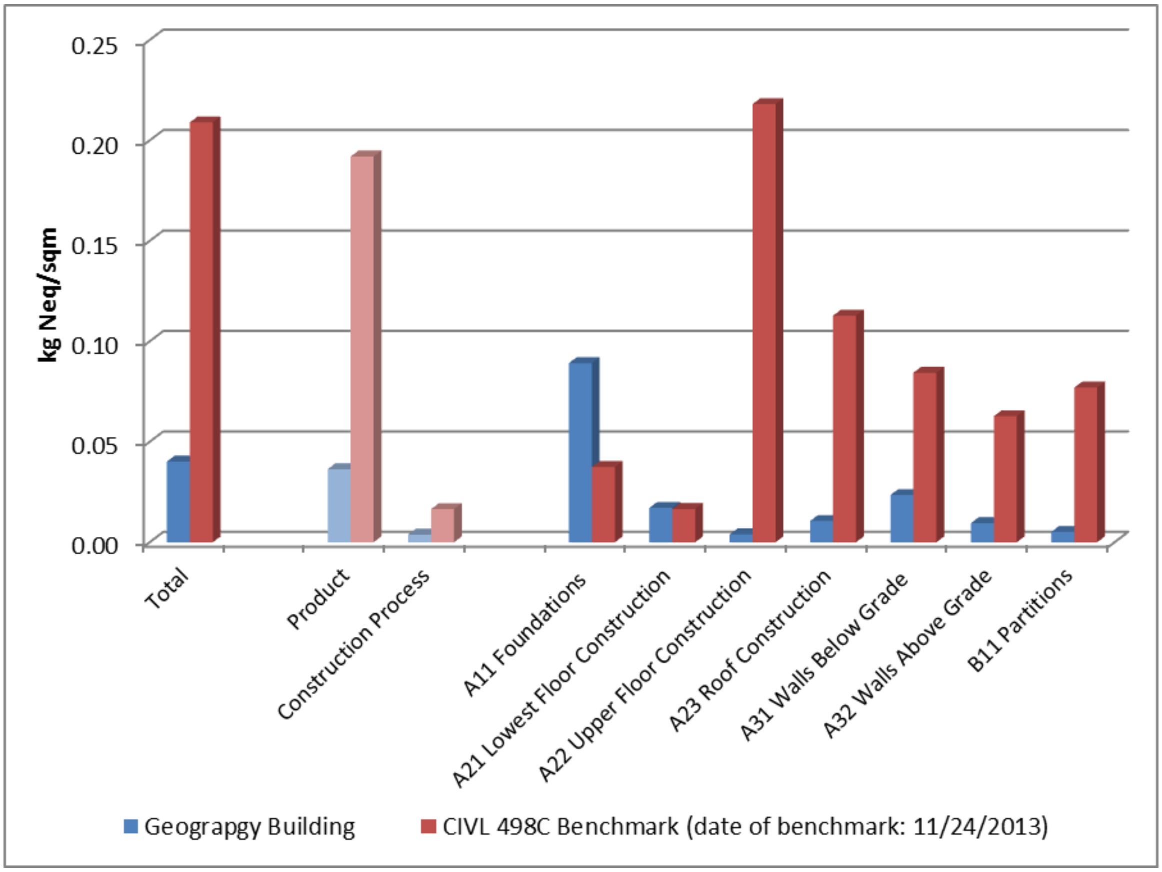


Figure 26 Eutrophication Benchmarking for Life Cycle Stages and level 3 elements

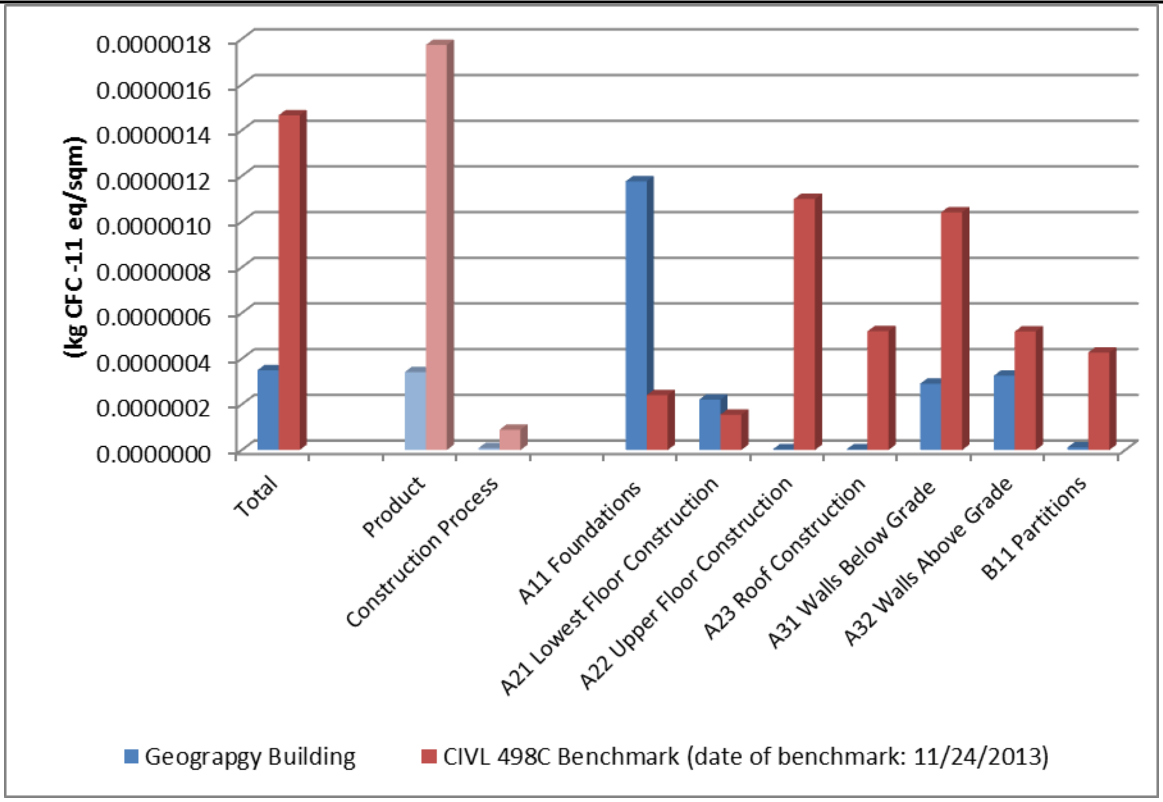


Figure 27 Ozone Layer Depletion Benchmarking for Life Cycle Stages and level 3 elements

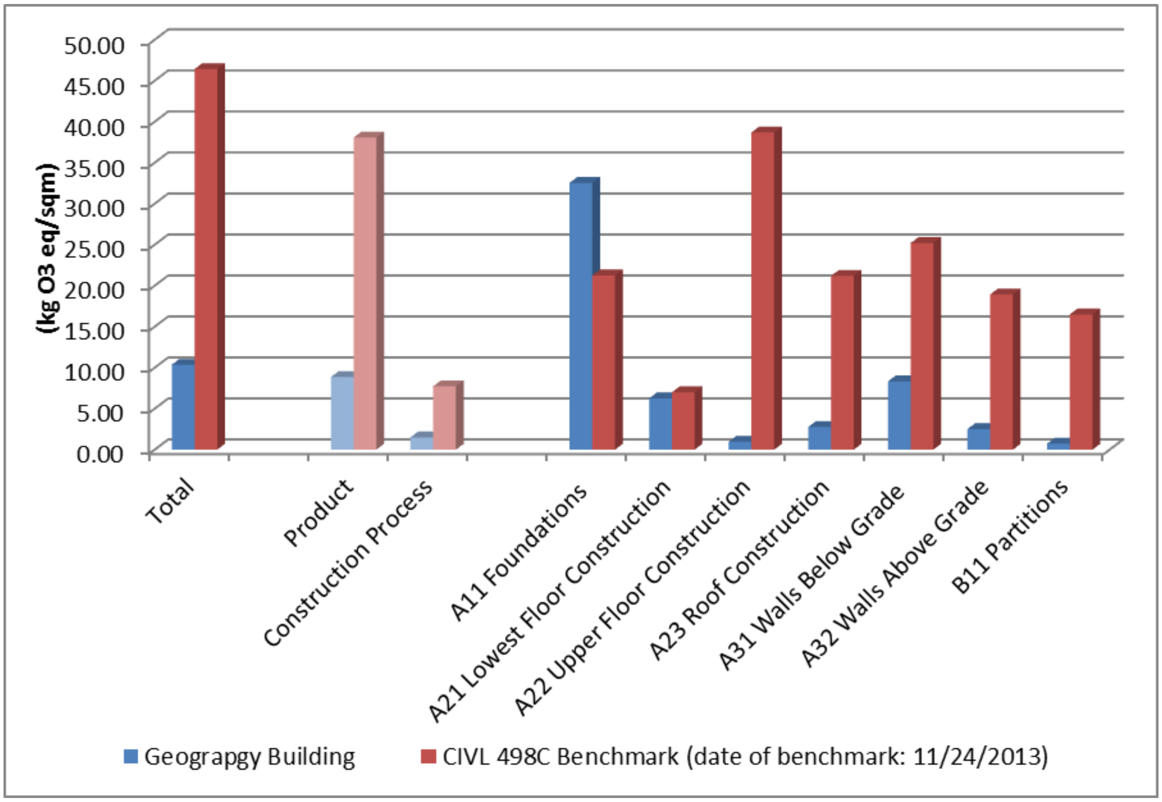


Figure 28 Smog Benchmarking for Life Cycle Stages and level 3 elements

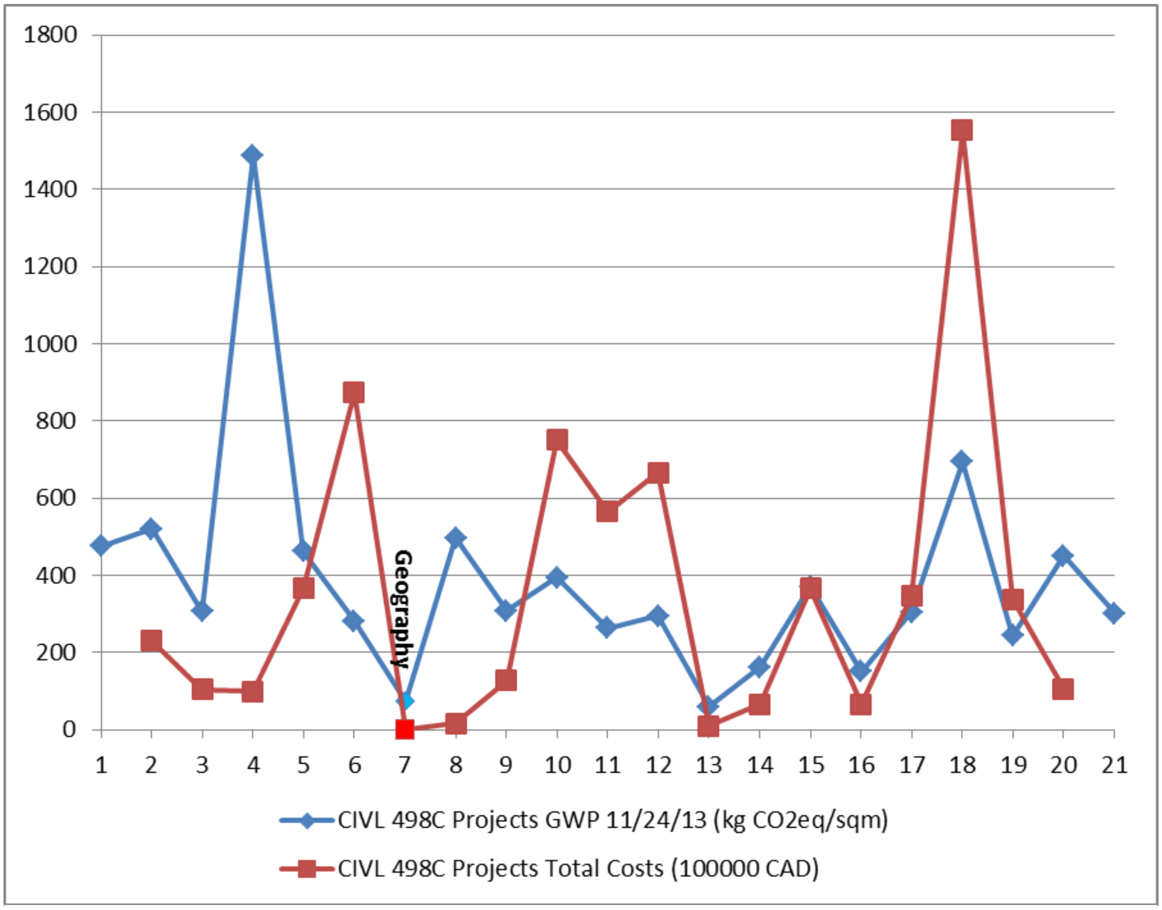


Figure 29 Scatter plot of Total Cost and GWP impacts of CIVIL 498C 2014 studies

Anex B - Recommendations for LCA Use

LCA is a study of the environmental impacts of a system over a specific life span. The presented study was a Cradle-to-Grave (including Product and Construction stages) environmental impact analysis of the Geography Building on UBC campus. However, having a holistic perspective in LCA study is crucial, both in terms of lifecycle stages and elements included, in order to identify all the impacts and hotspots in a system. Although LCA for separate elements is helpful for having more sustainable choices in material/product selection, these studies are not enough to optimize the overall impact of a building. For instance, material with less embodied energy may be preferred in a Cradle-to-Grave LCA study, but they may be less preferred when the energy consumption in the building's use stage is included in assessments. A building LCA study, early in the design stage will significantly affect the material/component, or service selection decisions. More over an LCA study for an existing building can help making efficient decisions to improve the building's performance.

In order to have an accurate LCA study, a detailed region specific LCI database is required, so that the environmental impacts of products and systems are assessed based on location characteristics such as available technology, distances, energy type, environmental sensitivity of the place, etc. Institutes such as Athena and NREL have already developed a thorough database for North America's regions. However, as the interest in using LCA method in the construction industry increases, more studies will be conducted on building products and buildings. Using these case studies, more comprehensive region specific LCI databases will be created. Also benchmark for different building types and functions will be developed against which buildings' performance can be assessed. Incorporating LCA in building assessment certifications, such as including it in the latest version of Leadership in Energy and Environmental Design Certification (LEED v.4) can significantly help promoting the use of LCA in building industry[45].

A challenge in LCA is how to interpret the results. The results of an LCA study are presented as mid-point environmental impact categories, which are not connected to each other in the way they are reported. Thus, different studies may prioritize the impact categories differently based on the sensitivity of the context, study goals, or even personal benefits. To make the study result more reliable, a third party institute can conduct region specific studies to identify the categories which may have more significant impact or sensitivity in that place and assign weightings to the impact categories based on that analysis.

UBC has high environmental goals and its campus is considered as a living laboratory for the technological, environmental, economic and societal aspects of sustainability[46]. Such ambitions make UBC a perfect place for actively applying and developing LCA methods in design, maintenance, and renovation of different building types on campus. The first step is to develop a database of different building on campus to create a benchmark for assessment and comparison purposes. This initiation has already been started in CIVL 498C course. However, as these studies are done mainly by undergraduate students who do not have much expertise in LCA, it is necessary that these studies be reviewed and improved by LCA professionals. Moreover, this database can be sorted and categorize for different purposes. For instance, old buildings can have their own category for comparison and renovation/improvement decision makings.

Annex C - Author Reflection

The first time I read about LCA was in 2011 when I was conducting a research on incorporating the recycling value of construction materials in building assessment systems, such as LEED[47]. Through that study I realized that current material assessment methods and strategies incorporated in building rating systems are more focused on upstream impacts, mainly operation stage and more recently production stage. They mainly do not consider the building or product's whole lifecycle in their assessment. Thus, they may not be able to help the stakeholders choose the best product/service for their projects. I also read about LCA challenges and uncertainties in regard to how to allocate environmental impacts to different functional units of a system, how to predict the end of life of a system, and also the lack of a comprehensive region specific LCI database.

Currently I am a graduate student at UBC in Master of Advanced Studies in architecture (MASA) program. In my thesis I am studying the influence of different stakeholders' priorities on extending useful lifetime of construction materials. Sometimes the environmental benefits of these strategies are

---

[45] (Todd, 2013)
[46] (UBC Sustainability, 2013)
[47] (Saghafi & Hosseini Teshnizi, 2011)

not in line with influential stakeholders' priorities/benefits, involved in different stages of construction products lifecycle, thus stakeholders do not put so much effort into applying them. In my case studies, I am studying lifecycle costs/benefits of construction products and allocating them to different stakeholders involved in products lifecycle. I was highly interested to know the details of LCA methods and how they actually assess and assign different environmental impacts. It was not easy to understand it just by reading the publications. Thus I audited the CIVL 498C course to experience using LCA methods for a building.

During the course I realized that getting involved in details of LCA study is so challenging and different from the concept of the LCA. I learned to deal with detailed quantities of materials used in a building and incorporate them in modeling softwares to obtain LCA environmental result. This experience greatly helped me to understand the importance and challenges of LCA.

Annex D – Impact Estimator Inputs and Assumptions

Major Group Elements	**Group Elements**	**Element**	**Quantity**	**Units**	**Assembly Type**	**Assembly Name**	**Input Fields**	**Known/Measured Information**	**IE Inputs**
A Shell	**A1 SUBSTRUCTURE**	**A11 Foundations**	**272.39**	**m2**					
					Concrete Footing				
						1.1.1 - 2'3" Concrete Footings			
							Length (ft)	175.500	175.500
							Width (ft)	2.250	2.250
							Thickness (in)	9.000	9.000
							Concrete (psi)	-	4000.000
							Concrete flyash %	-	average
							Rebar	-	#4
						1.1.2 - 2'9" Concrete Footings			
							Length (ft)	22.000	22.000
							Width (ft)	2.750	2.750
							Thickness (in)	9.000	9.000
							Concrete (psi)	-	4000.000
							Concrete flyash %	-	average
							Rebar	-	#4
						1.1.3 - 1'9" Concrete Footings			
							Length (ft)	267.750	267.750
							Width (ft)	1.750	1.750
							Thickness (in)	9.000	9.000
							Concrete (psi)	-	4000.000
							Concrete flyash %	-	average

			Rebar	-	#4
		1.1.4 - 2'3"x2'9" Concrete Footings			
			Length (ft)	16.500	16.500
			Width (ft)	2.250	2.250
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.5 - 3'3" Concrete Footings			
			Length (ft)	65.000	65.000
			Width (ft)	3.250	3.250
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.6 - 4'x4' Concrete Footings			
			Length (ft)	8.000	8.000
			Width (ft)	4.000	4.000
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.1.7 - Foundation Exterior Wall with Footings			
			Length (ft)	1091.000	1091.000
			Width (ft)	1.667	1.667
			Thickness (in)	9.000	9.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	average
			Rebar	-	#4
		2.1.1 - Foundation Exterior Wall with Footings			
			Length (ft)	1091.000	1363.750
			Height (ft)	3.500	3.500
			Thickness (in)	10.000	8.000
			Concrete (psi)	-	4000.000
			Concrete flyash %	-	Average
			Rebar	-	#5
		2.1.2 - Foundation Exterior Wall without Footings			
			Length (ft)	47.000	58.750
			Height (ft)	3.500	3.500
			Thickness (in)	10.000	8.000
			Concrete (psi)	-	4000.000

						Concrete flyash %	-	Average
						Rebar	-	#5
					2.1.4 - Foundation 8'' Interior Concrete Wall			
						Length (ft)	342.000	342.000
						Height (ft)	3.500	3.500
						Thickness (in)	8.000	8.000
						Concrete (psi)	-	4000.000
						Concrete flyash %	-	Average
						Rebar	-	#5
A2 STRUCTURE	**A21 Lowest Floor Construction**	**80.83**	**m2**					
				Slabs on grade				
					1.2.1 - Foundation Concrete Floor			
						Length (ft)	34.438	34.438
						Width (ft)	16.000	16.000
						Thickness (in)	4.000	4.000
						Concrete (psi)	-	4000.000
						Concrete flyash %	-	average
				4.1 Suspended Slab				
					4.1.1 - Ground Concrete Floor			
						Floor Width (ft)	19.938	19.938
						Span (ft)	16.000	16.000
						Concrete (psi)	-	4000.000
						Live load (psf)	-	50.000
						Concrete flyash %	-	average
	A22 Upper Floor Construction	**4740.28**	**m2**					
				4.2 Wood Joist Floor				
					4.2.1 - Ground Floor Area			
						Floor Width (ft)	2257.600	2257.600
						Span (ft)	10.000	10.000
						Decking Type	Wood	Plywood
						Live load (psf)	50.000	50.000
						Decking Thickness	-	1/2 in
					4.2.3 - Ground Sloped Lecture Room			
						Floor Width (ft)	253.200	253.200
						Span (ft)	10.000	10.000
						Decking Type	None	None
						Live load (psf)	50.000	50.000
						Decking Thickness	-	1/2 in
					4.2.4 - Ground Level Lecture Room			

	Floor Width (ft)	92.500	92.500
	Span (ft)	10.000	10.000
	Decking Type	Wood	Plywood
	Live load (psf)	50.000	50.000
	Decking Thickness	-	1/2 in
4.2.2 - First Floor Floor Area			
	Floor Width (ft)	2493.000	2493.000
	Span (ft)	10.000	10.000
	Decking Type	Wood	Plywood
	Live load (psf)	50.000	50.000
	Decking Thickness	-	1/2 in
Stair Construction			
1.1.8 - Ground Entrance Stairs			
	Length (ft)	20.000	20.000
	Width (ft)	5.667	5.667
	Thickness (in)	8.000	8.000
	Concrete (psi)	-	4000.000
	Concrete flyash %	-	average
	Rebar	-	#4
1.1.9 - Ground Entrance Stairs 2			
	Length (ft)	29.000	29.000
	Width (ft)	7.000	7.000
	Thickness (in)	12.000	12.000
	Concrete (psi)	-	4000.000
	Concrete flyash %	-	average
	Rebar	-	#4
1.1.10 - Ground Entrance Stairs 3			
	Length (ft)	7.500	7.500
	Width (ft)	3.000	3.000
	Thickness (in)	8.000	8.000
	Concrete (psi)	-	4000.000
	Concrete flyash %	-	average
	Rebar	-	#4
5.1.35 - Ground Lecture Room Stairs			
	Softwood Lumber (small, kiln dried) (Mbfm)	0.096	0.096
5.1.36 - Ground Interior Stairs Up			
	Softwood Lumber (small, kiln dried) (Mbfm)	0.139	0.139
5.1.37 - FF Interior Stairs Down			

					Softwood Lumber (small, kiln dried) (Mbfm)	0.109	0.109
				5.1.38 - Ground Lecture Room			
					Softwood Lumber (small, kiln dried) (Mbfm)	1.178	1.178
			Columns & Beams				
				5.1.1 - Ground 8''x18'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.444	0444
				5.1.2 - Ground 8''x16'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	1.515	1.515
				5.1.3 - Ground 8''x14'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.345	0.345
				5.1.4 - Ground 6''x8'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.064	0064
				5.1.5 - Ground 10''x16'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.507	0.507
				5.1.18 - Ground 6''x8'' Wood Post			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.540	0.540
				5.1.19 - Ground 8''x8'' Wood Post			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.648	0.648
				5.1.20 - Ground 8''x10'' Wood Post			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.810	0.810
			5.1 Wood				
				5.1.12 - Foundation 6''x6'' Wood Girder			
					Softwood Lumber (large, kiln dried) (Mbfm)	4.650	4.650
				5.1.13 - Foundation 6''x10'' Wood Girder			
					Softwood	2.680	2.680

						Lumber (large, kiln dried) (Mbfm)		
				5.1.14 - Foundation 6''x8'' Wood Girder				
						Softwood Lumber (large, kiln dried) (Mbfm)	1.284	1.284
				5.1.15 - Foundation 6''x6'' Wood Post				
						Softwood Lumber (large, kiln dried) (Mbfm)	2.688	2.688
				5.1.16 - Foundation 8''x10'' Wood Post				
						Softwood Lumber (large, kiln dried) (Mbfm)	2.333	2.333
				5.1.17 - Foundation 8''x8'' Wood Post				
						Softwood Lumber (large, kiln dried) (Mbfm)	0.187	0.187
A23 Roof Construction	**2394.58**	**m2**						
			3.1 Wood Joist					
				3.1.1 - Roof Area				
						Roof Width (ft)	2577.500	2577.500
						Span (ft)	10.000	10.000
						Decking Type	-	None
						Live load (psf)	35.000	50.000
						Decking Thickness	-	1/2 in
					Envelope	Category	Vapour Barrier	Vapour Barrier
						Material	-	Polyethylene 6 mil
						Thickness (in)	-	-
						Category	Cladding	Cladding
						Material	Shiplap	Wood Shiplap Siding - Cedar
						Thickness (in)	-	-
						Category	Roof Envelopes	Roof Envelopes
						Material	Asphalt	Roofing Asphalt
						Thickness (in)	-	-
				2.2.12 - Roof Area				
						Wall Type	Exterior	Exterior
						Length (ft)	63.000	63.000
						Height (ft)	68.000	68.000
						Sheathing	None	None
						Stud thickness	2 x 4	2 x 4
						Stud Spacing	16 o.c.	16 o.c.
						Stud Type	Kiln dried	Kiln dried

2.2.13 - Roof Area 2			
	Wall Type	Exterior	Exterior
	Length (ft)	50.000	50.000
	Height (ft)	19.000	19.000
	Sheathing	None	None
	Stud thickness	2 x 4	2 x 4
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
2.2.14 - Roof Area 3			
	Wall Type	Exterior	Exterior
	Length (ft)	17.300	17.300
	Height (ft)	61.000	61.000
	Sheathing	None	None
	Stud thickness	2 x 4	2 x 4
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
2.2.15 - Roof Area 4			
	Wall Type	Exterior	Exterior
	Length (ft)	45.500	45.500
	Height (ft)	14.000	14.000
	Sheathing	None	None
	Stud thickness	2 x 4	2 x 4
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
Columns & Beams			
5.1.6 - First Floor 8''x14'' Wood Beam			
	Softwood Lumber (large, kiln dried) (Mbfm)	0.345	0.345
5.1.7 - First Floor 6''x10'' Wood Beam			
	Softwood Lumber (large, kiln dried) (Mbfm)	0.170	0.170
5.1.8 - First Floor 6''x8'' Wood Beam			
	Softwood Lumber (large, kiln dried) (Mbfm)	0.116	0.116
5.1.9 - First Floor 10''x16'' Wood Beam			
	Softwood Lumber (large, kiln dried) (Mbfm)	1.667	1.667
5.1.10 - First Floor 8''x16'' Wood Beam			
	Softwood Lumber (large, kiln dried)	0.896	0.896

					(Mbfm)		
				5.1.11 - First Floor 10''x18'' Wood Beam			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.555	0.555
			5.1 Wood				
				5.1.21 - First Floor 8''x8'' Wood Post			
					Softwood Lumber (large, kiln dried) (Mbfm)	1.024	1.024
				5.1.22 - First Floor 6''x8'' Wood Post			
					Softwood Lumber (large, kiln dried) (Mbfm)	0.384	0.384
				5.1.23 - First Floor Truss			
					Softwood Lumber (large, kiln dried) (Mbfm)	1.854	1.854
			5.2 Steel				
				5.2.1 - First Floor Truss			
					Rebar Rod Light Sections (Tons)	0.360	0.360
					Cold Rolled Steel (Tons)	1.587	1.587
A3 EXTERIOR ENCLOSURE	**A31 Walls Below Grade**	**54.26**	**m2**				
				2.1.3 - Foundation 6'' Interior Concrete Wall			
					Length (ft)	88.000	66.000
					Height (ft)	3.500	3.500
					Thickness (in)	6.000	8.000
					Concrete (psi)	-	4000.000
					Concrete flyash %	-	Average
					Rebar	-	#5
				2.1.5 - Foundation 7'' Interior Concrete Wall			
					Length (ft)	79.000	69.125
					Height (ft)	3.500	3.500
					Thickness (in)	7.000	8.000
					Concrete (psi)	-	4000.000
					Concrete flyash %	-	Average
					Rebar	-	#5
	A32 Walls Above Grade	**3188.65**	**m2**				
			Walls Above Grade				
				2.2.1 - Ground Exterior Wall			
					Wall Type	Exterior	Exterior
					Length (ft)	1096.000	1096.000

	Height (ft)	13.500	13.500
	Sheathing	Plywood	Plywood
	Stud thickness	2 x 6	2 x 6
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
Window Opening	Number of Windows	332.000	332.000
	Total Window Area (ft2)	3229.722	3229.722
	Frame Type	Wood	Wood
Door Opening	Glazing Type	-	Standard Glazing
	Number of Doors	10.000	10.000
	Door Type	-	Solid Wood
Envelope	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
	Category	Cladding	Cladding
	Material	Lath and Stucco	Stucco - Over porous sruface
	Thickness	-	-
	Category	Cladding	Cladding
	Material	Shiplap	Wood Shiplap Siding - Cedar
	Thickness	-	-
5.1.24 - Ground Exterior Wall **Lath**			
	Softwood Lumber (small, kiln dried) (Mbfm)	5.058	5.058
2.2.2 - First Floor Exterior Wall			
	Wall Type	Exterior	Exterior
	Length (ft)	1050.000	1050.000
	Height (ft)	12.000	12.000
	Sheathing	Plywood	Plywood
	Stud thickness	2 x 6	2 x 6
	Stud Spacing	16 o.c.	16 o.c.
Window Opening	Stud Type	Kiln dried	Kiln dried
	Number of Windows	334.000	334.000
	Total Window Area (ft2)	4024.583	4024.583
	Frame Type	Wood	Wood
	Glazing Type	-	Standard Glazing
Envelope	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
	Category	Cladding	Cladding

						Material	Lath and Stucco	Stucco - Over porous sruface
						Thickness	-	-
						Category	Cladding	Cladding
						Material	Shiplap	Wood Shiplap Siding - Cedar
						Thickness	-	-
					5.1.25 - First Floor Exterior Wall **Lath**			
						Softwood Lumber (small, kiln dried) (Mbfm)	3.811	3.811
B INTERIORS	**B1 PARTITIONS & DOORS**	**B11 Partitions**	**3935.37**	**m2**				
					2.2.3 - Ground 2''x4'' Stud Interior Wall			
						Wall Type	Interior	Interior
						Length (ft)	617.000	617.000
						Height (ft)	13.500	13.500
						Sheathing	-	None
						Stud thickness	2 x 4	2 x 4
						Stud Spacing	16 o.c.	16 o.c.
						Stud Type	Kiln dried	Kiln dried
					Door Opening	Number of Doors	21.000	21.000
						Door Type	-	Solid Wood
					Envelope	Category	-	Gypsum board
						Material	Lath and Plaster	Gysum Regular 1/2"
						Thickness	-	-
						Category	-	Gypsum board
						Material	Lath and Plaster	Gysum Regular 1/2"
						Thickness	-	-
					5.1.26 - Ground 2''x4'' Stud Interior Wall **lathath**			
						Softwood Lumber (small, kiln dried) (Mbfm)	3.528	3.528
					2.2.4 - Ground 2''x4'' Stud Interior Wall with Steel Vestibule			
						Wall Type	Interior	Interior
						Length (ft)	17.000	17.000
						Height (ft)	13.500	13.500
						Sheathing	1/4" Ply. Both Sides	Plywood
						Stud thickness	2 x 4	2 x 4
						Stud Spacing	16 o.c.	16 o.c.
						Stud Type	Kiln dried	Kiln dried
					Door Opening	Number of Doors	1.000	1.000
						Door Type	Steel Vestibule	Steel Interior Door
					Envelope	Category	-	Gypsum board

	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
5.1.27 - Ground 2''x4'' Stud Interior Wall with Steel Vestibule **Lath**			
	Softwood Lumber (small, kiln dried) (Mbfm)	0.094	0.094
2.2.5 - Ground 2''x6'' Stud Interior Wall			
	Wall Type	Interior	Interior
	Length (ft)	145.000	145.000
	Height (ft)	13.500	13.500
	Sheathing	-	None
	Stud thickness	2 x 6	2 x 6
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
Envelope	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
5.1.28 - Ground 2''x6'' Stud Interior Wall **lath**			
	Softwood Lumber (small, kiln dried) (Mbfm)	0.870	0.870
2.2.6 - Ground 2''x4'' Stud Hallway Wall			
	Wall Type	Interior	Interior
	Length (ft)	919.000	919.000
	Height (ft)	13.500	13.500
	Sheathing	1/4" Ply. Both Sides	Plywood
	Stud thickness	2 x 4	2 x 4
	Stud Spacing	16 o.c.	16 o.c.
	Stud Type	Kiln dried	Kiln dried
Door Opening	Number of Doors	44.000	44.000
	Door Type	-	Solid Wood
Envelope	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
	Category	-	Gypsum board
	Material	Lath and Plaster	Gysum Regular 1/2"
	Thickness	-	-
5.1.29 - Ground 2''x4'' Stud Hallway Wall **lath**			
	Softwood Lumber (small,	5.149	5.149

				kiln dried) (Mbfm)		
			2.2.7 - Ground 2''x4'' Stud Lecture Room Wall			
				Wall Type	Interior	Interior
				Length (ft)	126.000	126.000
				Height (ft)	1.500	1.500
				Sheathing	1/4" Ply. Both Sides	Plywood
				Stud thickness	2 x 4	2 x 4
				Stud Spacing	16 o.c.	16 o.c.
				Stud Type	Kiln dried	Kiln dried
			Envelope	Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
				Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
			5.1.30 - Ground 2''x4'' Stud Lecture Room Wall **lath**			
				Softwood Lumber (small, kiln dried) (Mbfm)	0.084	0.084
			2.2.8 - First Floor 2''x4'' Stud Interior Wall			
				Wall Type	Interior	Interior
				Length (ft)	631.000	631.000
				Height (ft)	12.000	12.000
				Sheathing	-	None
				Stud thickness	2 x 4	2 x 4
				Stud Spacing	16 o.c.	16 o.c.
				Stud Type	Kiln dried	Kiln dried
			Door Opening	Number of Doors	16.000	16.000
				Door Type	-	Solid Wood
			Envelope	Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
				Category	-	Gypsum board
				Material	Lath and Plaster	Gypsum Regular 1/2"
				Thickness	-	-
			5.1.31 - First Floor 2''x4'' Stud Interior Wall **lath**			
				Softwood Lumber (small, kiln dried) (Mbfm)	3.233	3.233
			2.2.9 - First Floor 2''x6'' Stud Interior Wall			
				Wall Type	Interior	Interior
				Length (ft)	195.000	195.000
				Height (ft)	12.000	12.000
				Sheathing	-	None
				Stud thickness	2 x 6	2 x 6
				Stud Spacing	16 o.c.	16 o.c.
				Stud Type	Kiln dried	Kiln dried

			Door Opening	Number of Doors	7.000	7.000
				Door Type	-	Solid Wood
			Envelope	Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
				Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
			5.1.32 - First Floor 2''x6'' Stud Interior Wall **lath**			
				Softwood Lumber (small, kiln dried) (Mbfm)	0.982	0.982
			2.2.10 - First Floor 2''x16'' Stud Interior Wall			
				Wall Type	Interior	Interior
				Length (ft)	37.000	74.000
				Height (ft)	12.000	12.000
				Sheathing	-	None
				Stud thickness	2 x 16	2 x 8
				Stud Spacing	16 o.c.	16 o.c.
				Stud Type	Kiln dried	Kiln dried
			Envelope	Category	-	Gypsum board
				Material	Lath and Plaster	Gysum Regular 1/2"
				Thickness	-	-
				Category	-	
				Material	Lath and Plaster	
				Thickness	-	
			5.1.33 - First Floor 2''x16'' Stud Interior Wall **lath**			
				Softwood Lumber (small, kiln dried) (Mbfm)	0.197	0.197
			2.2.11 - First Floor 2''x4'' Stud Hallway Wall			
				Wall Type	Interior	Interior
				Length (ft)	704.000	704.000
				Height (ft)	12.000	12.000
				Sheathing	-	None
				Stud thickness	2 x 4	2 x 4
				Stud Spacing	16 o.c.	16 o.c.
				Stud Type	Kiln dried	Kiln dried
			Door Opening	Number of Doors	35.000	35.000
				Door Type	-	Solid Wood

			Envelope	Category Material Thickness	- Lath and Plaster -	Gypsum board Gysum Regular 1/2" -
				Category Material Thickness	- Lath and Plaster -	Gypsum board Gypsum Regular 1/2" -
			5.1.34 - First Floor 2''x4'' Stud Hallway Wall			
				Softwood Lumber (small, kiln dried) (Mbfm)	3.464	3.464

Table 15 Level 3 Sorted Impact Estimator Inputs

Major Group Elements	Group Elements	Assembly Type	Assembly Name	Assumptions
A Shell	**A1 SUBSTRUCTURE**	**A11 Foundation**		
		Concrete Footing		
		▪ Column footings on the foundation were measured using the count condition with the width and length provided from drawing 401-06-016, and the thickness provided from drawing 401-06-17. ▪ Concrete strength was not given and was therefore assumed to be 4000psi ▪ Rebar was not given and was therefore assumed to be #4 ▪ Concrete fly ash content was not given and was therefore assumed to be average ▪ Length of footing was calculated by multiplying the length of each footing by the number of footings of that type		
			1.1.1 - 2'3" Concrete Footings	
			▪ Length: 2.25*78=175.5 ft	
			1.1.2 - 2'9" Concrete Footings	
			▪ Length: 2.75*8=22 ft	
			1.1.3 - 1'9" Concrete Footings	
			▪ Length: 1.75*153=267.75 ft	
			1.1.4 - 2'3"x2'9" Concrete Footings	
			▪ Length: 2.75*60=16.5ft	
			1.1.5 - 3'3" Concrete Footings	
			▪ Length: 3.25*20=65ft	
			1.1.6 - 4'x4' Concrete Footings	
			▪ Length: 4*2=8ft	
			1.1.7 - Foundation Exterior Wall with Footings	
			▪ The strip footing below the exterior concrete wall was modeled using the width provided from drawing 401-06-016 and the linear condition used to measure the Foundation Exterior Wall with Footings. ▪ Length of footing was given by the length takeoff from the Foundation Exterior Wall with Footings (2.1.1)	
			2.1.1 - Foundation Exterior Wall with Footings	

- Crawlspace wall below exterior walls of the ground level (Section Drawings: 401-06-16/19/20)
- Thickness of 10” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (10”/8”) for a total length of 1363.75’ to meet the concrete volume.

Length = 1091*10"/8" = 1363.75 ft

2.1.2 - Foundation Exterior Wall without Footings

- Crawlspace wall below ground entrance stairs (Section Drawings: 401-06-16/20)

Total Length = 47*10"/8" = 58.75 ft

2.1.4 - Foundation 8'' Interior Concrete Wall

- Crawlspace wall below Ground concrete floor, interior stair cases and lecture hall. Details in section A-A, B-B Drawing 401-06-019/020.

A2 STRUCTURE

A21 Lowest Floor Construction

Slabs on grade

1.2.1 - Foundation Concrete Floor

- Foundation Concrete Floor was modeled as a slab on grade using the area condition, with a thickness measurement of 4” from section drawings (401-06-19/020).
- Concrete strength was not given and was therefore assumed to be 4000psi
- Concrete fly ash content was not given and was therefore assumed to be average

4.1 Suspended Slab

4.1.1 - Ground Concrete Floor

- Span assumed to be 16ft. The floor area, 19.938ft, is then attained by dividing the concrete floor area from takeoff model into 16ft.
- Live load assumed to be 50 psf based on live load for first floor.
- Concrete strength was not given and was therefore assumed to be 4000psi
- Concrete fly ash content was not given and was therefore assumed to be average

A22 Upper Floor Construction

- Although, Ground Floor Area and Ground Level Lecture Room are the lowest floor in most of the building area, they are included in A22 rather than A21. It is due to the CIQS categorization which includes the Suspended floors and decks and Inclined and stepped floors in A22 element category.

4.2 Wood Joist Floor

- An live load of 50psf is given for roof loading in drawing 401-07-001, a list of specifications from a 2004 renovation.
- Spans were assumed to be 10ft.
- The wood joist floors were assumed to have ½” thick plywood decking based on knowledge of the decking being wood.

4.2.3 - Ground Sloped Lecture Room

- the sloped section of the lecture room was modeled to have a slope based on the dimensions of the risers and treads of the steps, as seen in drawing 401-06-019
- A sloped wood joist floor was modeled, and the addition material used for the steps was added as extra basic material (5.1.38 - Ground Lecture Room).
- No plywood decking was added to this floor area because the steps were modeled using extra wood (5.1.35)

Stair Construction

1.1.8 - Ground Entrance Stairs

- The concrete stairs on the ground level which were measured using the area condition, with the average thickness estimated from the cross section as shown in drawing 401-06-020.
- The concrete stairs are on the lowest level. However, as stair structure is only included in A22 element category of modified version of CIQS, used in this LCA, I didn't include the ground level stairs in A21, but rather in A22 element category.
- Concrete thickness assumed to be linear by estimating the average thickness between the crest and the trough of the step, as seen in Figure 5

5.1.35 - Ground Lecture Room Stairs

- Steps were assumed to have dimensions of 7'x½"
- Stringer board (or diagonal) assumed to have dimensions of 2"x8"
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given in Table 18)

5.1.36 - Ground Interior Stairs Up

- Steps were assumed to have dimensions of 5.5'x½"
- Stringer board (or diagonal) assumed to have dimensions of 2"x8"
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given in Table 19)

5.1.37 - FF Interior Stairs Down

- Steps were assumed to have dimensions of 5.5'x½"
- Stringer board (or diagonal) assumed to have dimensions of 2"x8"
- Volumes were calculated based on wood dimensions and lengths, and were doubled to accommodate identical stairwells (Note: Lengths of treads, risers and diagonals given in Table 20)

5.1.38 - Ground Lecture Room

- Steps were assumed to have dimensions of 50'x½"
- Stringer board (or diagonal) assumed to have dimensions of 2"x8"
- Volumes were calculated based on wood dimensions and lengths (Note: Lengths of treads, risers and diagonals given in Table 21)

Columns & Beams

5.1 Wood

- Volumes of beams, posts and girders were calculated based on given dimensions and modeled length, and converted into Mbfm

V Mbfm = (w"*d"*l")*12in/ft)/(1000bmf/Mbfm)

A23 Roof Construction

- The roof of the building was made up of two wood joist sections. The lower portion, highlighted in Figure 6, was modeled as a wood joist roof, while the upper portion was modeled as 4 separate wall sections with 2"x4" wood studs.
- Sloped sections of the "wall sections" were assumed to be flat.

3.1 Wood Joist

- Spans were assumed to be 10ft. The roof width is then assessed by dividing the roof area from takeoff model into 10ft.
- Roofing asphalt assumed based on known asphalt roof
- Polyethylene 6mil vapour barrier assumed

- An live load of 35psf is given for roof loading in drawing 401-07-001; however, the roof live load is inputted as 50psf due to IE limits.

2.2.12 - Roof Area

- Width of roof area given by dividing the highlighted area by the length, as shown in Figure 7
- Area modeled twice to account for symmetric design

2.2.13 - Roof Area 2

- Width of roof area given by dividing the highlighted area by the length, as shown in Figure 7
- Area modeled twice to account for symmetric design

2.2.14 - Roof Area 3

- Width of roof area given by dividing the highlighted area by the length, as shown in Figure 7
- Area modeled twice to account for symmetric design

2.2.15 - Roof Area 4

- Width of roof area given by dividing the highlighted area by the length, as shown in Figure 7

5.1 Wood

5.1.23 - First Floor Truss

- Extra wood for the first floor truss was calculated as seen in the Table 22

5.2 Steel

5.2.1 - First Floor Truss

- Steel for the first floor truss was calculated as extra material (Tables 23 and 24)
- Rods were assumed to be “Rebar Rod Light Sections”
- Plates were assumed to be “Cold Rolled Sheet”

A3 EXTERIOR ENCLOSURE

A31 Walls Below Grade

- The foundation concrete walls were assumed to have a height of 3.5’, based on an average of measurements from drawings 401-06-019 and 401-06-020.
- Concrete strength was not given and was therefore assumed to be 4000 psi
- Rebar was not given and was therefore assumed to be #4
- Concrete fly ash content was not given and was therefore assumed to be average

2.1.3 - Foundation 6'' Interior Concrete Wall

- Exterior wall for neutralizing tank in the basement. Details in Drawing 401-06-016
- Thickness of 6” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (6”/8”) for a total length of 66.00’ to meet the concrete volume.

Length = 88*6"/8" = 66 ft

2.1.5 - Foundation 7'' Interior Concrete Wall

- Exterior wall for tank room in the basement. Details in section B-B Drawing 401-06-020
- Thickness of 7” was given, however 8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (7”/8”) for a total length of 69.125’ to meet the concrete volume.

Length = 79*7"/8" = 1363.75 ft

		A32 Walls Above Grade
		■ The doors and windows within the ground and first floor walls were modeled using count conditions. ■ All doors, except for the steel vestibule which was assumed to be a 32”x7’ steel interior door, were assumed to be 32”x7’ solid wood doors. ■ The windows were assumed to be fixed windows with standard glazing, and were modeled as wood frames based on site inspections. ■ Window glazing was not given and was therefore assumed to be standard glazing ■ Total lath volumes for the exterior and interior walls were calculated by multiplying the calculated lath volume per 1’x1’ area—as seen in Table 21 with assumed lath dimensions and spacing—by the twice the total area of the wall, to account for laths on both sides of the walls.
B INTERIORS	**B1 PARTITIONS & DOORS**	**B11 Partitions**
		■ The doors and windows within the ground and first floor walls were modeled using count conditions. ■ All doors, except for the steel vestibule which was assumed to be a 32”x7’ steel interior door, were assumed to be 32”x7’ solid wood doors. ■ The windows were assumed to be fixed windows with standard glazing, and were modeled as wood frames based on site inspections. ■ Window glazing was not given and was therefore assumed to be standard glazing ■ ½” regular gypsum board was used as a surrogate for plaster due to IE limitations ■ **Shiplap** siding was assumed to be cedar given that the laths in the building are cedar as well ■ Batten and paper were not modeled due to IE limitations
		2.2.6 - Ground 2''x4'' Stud Hallway Wall
		■ Hallway walls were also assumed to have plywood sheathing, based on drawing 401-06-030, a drawing from a building renovation in 1963.
		2.2.7 - Ground 2''x4'' Stud Lecture Room Wall
		■ This wall was added to accommodate the additional wall height within the lecture room ■ A height of 1.5’ was assumed as the average increased wall height
		2.2.10 - First Floor 2''x16'' Stud Interior Wall
		■ Stud thickness of 2”x16” was given, however 2”x8” was used due to IE limitations, therefore length of the exterior wall was multiplied by a factor of (16”/8”) for a total length of 74’ to meet the concrete volume Length = 37*16"/8" = 74 ft ■ Gypsum board was only modeled once due to doubling in the wall length

Table 16 Level 3 Sorted Assumptions

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
1st Flight	8	10	6	8	48

Table 17 Ground Lecture Room Stairs

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
1st Flight	14	10	6	13.5	69.33

Table 18 Ground Interior Stairs Up

	# of Steps	Tread (in)	Rise (in)	Diagonal (ft)	Volume (fbm)
1st Flight	11	10	6	10.5	54.33

Table 19 First Floor Interior Stairs Down

	# of Steps	Tread (in)	Rise (in)	Volume (fbm)
1st Flight	12	34	7	1178

Table 20 Ground Lecture Room Steps

Dimensions	Spacing	Boards per 4'x4'	Boards per 1'x1'	Volume per Board (fbm)	Volume per 1'x1' (fbm)
4'x2"x1/4"	1/4"	21.333	1.333	0.167	0.222

Table 21 Laths quantity measurements

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Rise	Run	Total Volume
1	Wood Tie Beam	10"x10"	51.00	42.50	425.00	0.00	51.00	425.00
1	Wood Tie Beam	10"x12"	51.00	51.00	510.00	0.00	51.00	510.00
2	Wood Post	10"x12"	13.50	13.50	135.00	13.50	0.00	270.00
2	Diagonal Posts	10"x12"	15.05	15.05	150.46	12.50	8.38	300.93
2	Diagonal Posts	10"x8"	14.98	9.98	99.85	12.50	8.25	199.69
2	Diagonal Posts	10"x6"	14.84	7.42	74.20	12.50	8.00	148.41
	Total V = 1854.03 fbm							

Table 22 Extra wood for the first floor truss

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Rise
2	Rod (End upset)	2"	13.500	0.022	0.295	0.589
2	Rod (End upset)	1.5"	13.500	0.022	0.295	0.589
1	Rod (End upset)	1.25"	13.500	0.022	0.295	0.295

Total V= 1.473 ft3
Total W= 720.147 lbs
Total W= 0.360 tons

Table 23 First Floor Truss steel Rods

#	Material	Dimension	Length/Height (ft)	Area (sqft)	Volume (fbm)	Rise
2	Plate	1/2"x10"	5.750	4.792	2.396	4.792
6	Plate	3/8"x3"x10"	-	0.208	0.078	0.469
4	Plate	8"x8"x3/8"	-	0.444	0.167	0.667
6		6"x6"x3/8"	-	0.250	0.094	0.563

Total V= 6.490 ft3
Total W= 3173.562 lbs
Total W= 1.587 tons

Table 24 First Floor Truss steel Plates