UBC MUSIC BUILDING Life Cycle Assessment

Devon Brownlee

University of British Columbia

CIVL 498C

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PROVISIO

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

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

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

UBC MUSIC BUILDING

Life Cycle Assessment

Brownlee, Devon
[redacted]
Model Prepared by Dallas McGowan
November 18, 2013
Civl 489c; Instructed by Rob Sianchuk

Executive Summary

The life cycle assessment study of the UBC Music Building summarized in this report was performed in concert with a number of other LCAs on academic buildings on the UBC Point Grey campus. These studies were all undertaken with the same goal an scope parameters with the intention that the data gathered in the could be used for comparisons.

As part of the study a materials takeoff of the Music Building was performed using OnCentre's OnScreen Takeoff, then completed using the Athena Institute for Sustainable Materials Impact Estimator for Buildings. The Impact Estimator was then used to generate a bill of materials for the building and with that data, generate midpoint environmental impacts based on the United States Environmental Protection Agency TRACI methodology. A detailed review of this model and its associated assumptions, both on the part of the reviewer and those inherent in the model, were evaluated, and where possible, changes and data substitutions were made to obtain greater accuracy.

The largest impacts to global warming potential (kg CO_2 eq) from the construction of the Music Building are due to the materials used in construction, specifically the concrete. Emissions could be reduced by employing more sustainable design in concrete (for example, the inclusion of admixtures such as flyash) and decreasing the amount of concrete in the structure of the building.

When compared to the environmental impacts of other academic buildings on UBC campus, Music Building performs well, regardless of its age. This may well be due to the simplicity of the building design and materials used. As it is an older building, design was less complex due to reduced modelling capacity and materials more locally sourced.

Table of Contents

List of Figures

List of Tables

Life Cycle Assessment of UBC Music Building

General Information on the Assessment

Purpose of the Assessment

This life cycle analysis (LCA) was performed as an exploratory study to determine the midpoint environmental impacts of the design and construction of the Music Building at the University of British Columbia (UBC), if it were built today using present construction practices. This LCA is part of a series of seventeen others carried out over a number of years on academic buildings on UBC's Point Grey Campus with the same goal and scope.[1]

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the music building, broken down by element type as per CIQS level 3. Applications of the data produced in this study include analysis of future environmental performance upgrades to the structure of the building and evaluation of environmental performance of future proposed buildings with similar level 3 elements and usage types. The results of this study may be compared to other building LCAs performed at UBC to determine the changes in environmental performance over time and between varying materials, structure types and building functions. Considering the results of these LCAs in aggregate, the analysis of the Music Building contributes to a database of life cycle impact information for academic buildings that may be utilized to inform the decision making processes of policy makers and building owners in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects.

The intended audience of this assessment are those individuals and organizations at UBC involved with building development and related policies, including, but not limited to, the UBC Sustainability Office, UBC Infrastructure Development and UBC Properties Trust and any other organizations involved in the creation of policies and frameworks for sustainable development on campus. Additional potential audiences include private industry developers, architects, engineers and building owners involved in the design, planning and construction of buildings at UBC campus, as well as engaged in projects at other institutions with similar buildings. Finally, external organizations such as governments, private industry and other universities who may want to engage in performing similar LCA studies within their organizations. !

Identification of the Building

The Music Building was constructed on the UBC Point Grey Campus between 1966 and 1968 as part of the Norman Mackenzie Fine Arts Centre in order to house the Faculty of Music[2], a function it continues

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[1] McGowan, Dallas. (2010). Life Cycle Analysis: The UBC Music Building. *Prepared for UBC Civl 498c, December 2010.*

[2] UBC Library. (n.d.) *Music Building*. Retrieved from http://www.library.ubc.ca/archives/bldgs/musicbuilding.htm.

to serve to the present day[3]. Located at 6361 Memorial Road, the Music Building is approximately 7,900 m^2 over four stories, accessible by an elevator and two stairwells. The basement houses a parking garage that is accessible by two additional stairwells, the second, third and fourth floors contain recital halls; student practice rooms; administrative, faculty and student offices; library and lecture space. Additionally, there is a penthouse above the fourth floor which houses much of the HVAC system. !

Due to the sparse availability of University records from the 1960s, the precise period and time of construction is unknown. The principle architect on the project was Gardiner Thornton Davidson Garrett Masson and Associates, with engineering design provided by Read Jones Christoffersen Ltd. At the time of construction, the Music Building cost $2.5 million with funding being supplied in part by the a Provincial grant of $600,000 from the 3-Universities Capital Fund and a grant of undisclosed value from the Canada Council. Accounting for inflation, the cost of the Music Building is approximately $6.7 million. Present value cost was estimated using a value of 2% inflation, in accordance with the Bank of Canada’s target inflation rate[4].

Other Assessment Information

Client for Assessment	Completed as coursework in Civil Engineering technical elective course at the University of British Columbia.
Name and Qualification of the Assessor(s)	Devon Brownlee; Civil Engineering, Economics Dallas McGowan; Civil Engineering
Impact Assessment Method	Athena Impact Estimator Version 4.2.0208 using US EPA TRACI midpoint impact methodology
Point of Assessment	50 years
Period of Validity	5 years
Date of Assessment	Completed in December 2013
Verifier	Student work, study not verified.

General Information on the Object of Assessment

Functional Equivalent

Functional units are defined in ISO 14044 as a performance characteristic of a system being studied, in this case a structure, which can be to normalize the results of the study[5].

For the UBC Music Building LCA, the functional unit is area, expressed in square metres. This functional unit was chosen as it is common to all buildings, regardless of specific usage. Consequently, the normalized results of this assessment can be used to compare the environmental impact summary measures per functional unit of the Music Building to other academic buildings on campus which have been assessed using the same goal, scope and functional unit.

Aspect of Object of Assessment	**Description**
Building Type	Institutional – Academic
Technical and Functional	To comply with the local building bylaws of Vancouver at

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[3] UBC School of Music. (n.d.) *About the School of Music*. Retrieved from http://www.music.ubc.ca/about-us.html.

[4] Newman, G. Personal Communication, August 2013.

[5] Sianchuk, R. Week5_Inventory Analysis (PDF Document). Retrieved from lecture notes online site: http://civl498c.wikispaces.com/Class+Presentations+and+Handouts

Requirements	the time of design and construction. Interior design Recital halls and practice spaces to be designed with appropriate acoustic properties.
Pattern of Use	Design occupancy unknown. Weekday instructional and office use. Available seven days a week and outside of typical business hours for rehearsal space, student study and special events/concerts.
Required Service Life	100 years [6]

Reference Study Period

EN 15978 states the typical reference study period for assessments of buildings to be equal to their required service life[7]. The LCA of the Music Building was performed with a reference study period of 1 year (differing from the building's required design service life of 100 years), which excludes EN 15978 modules B: Use, C: End of Life and D: Supplementary Information Beyond the Building Life Cycle.

Modules D is outside of the system boundary defined by EN 15978 as the externalities generated beyond the predicted life cycle of the building are so uncertain, being subject to changes in technology and policy and subjective valuations of the assessor, the level of error inherent in these predictions would cause an unnecessary bias in the study[8][9]. Modules B and C are excluded to keep the building assessment manageable within the time constraints imposed by the duration of the Civl 498c course and feasible given the expertise and level of experience of the assessors (students).

Object of Assessment Scope

Construction of the Music Building included the creation of a courtyard and covered walkway joining the Music Building to the Laserre Building, in addition to the construction of the building itself.

Civl 498c Level 3 Elements		**Description**	**Quantity (Amount)**	**Units**
A11	Foundations	Strip and pad footings, quantified using the gross floor area of the lowest floor construction.	2,575	m^2
A21	Lowest Floor Construction	Concrete slab on grade.	2,575	m^2

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[6] UBC Technical Guidelines. (n.d.) *Technical Specifications for Architects and Engineers*. Retrieved from http://www.technicalguidelines.ubc.ca/.

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

[8] Athena Sustainable Materials Institute. (2013) *Athena publishes first North American building declaration to EN 15978*. Retrieved from http://www.athenasmi.org/first-north-american-building-declaration-to-en-15978/.

[9] Athena Sustainable Materials Institute. (2013) *A Grander View: The Enermodal Engineering Office Building – An Environmental Building Declaration According to EN 15978 Standard*. Retrieved from http://www.athenasmi.org/wp-content/uploads/2013/06/EnermodalEnvironmentalDeclaration.pdf.

A22	Upper Floor Construction	Suspended concrete slab.	5,327	m^2
A23	Roof Construction	Asphalt roofing over foam insulated suspended concrete slab.	1,253	m^2
A31	Walls Below Grade	Concrete cast-in-place.	3,148	m^2
A32	Walls Above Grade	Concrete cast-in-place and pre-cast concrete panels.	2,788	m^2
B11	Partitions	Concrete block and wood stud, wood stud; soundproofing insulation and drywall.	3,355	m^2

Statement of Boundaries and Scenarios Used in the Assessment

System Boundary

As the reference period of the study has been limited to 1 year, this study considers EN 15798 Module A: Product stage and Construction Process stage, modules B, C and D are excluded for the reasons discussed previously.

The product stage of Module A includes raw material acquisition, raw material transportation and processing. Upstream processes of the product stage include the production of fuel used in raw materials acquisition and impacts related to resource development. The construction process stage is comprised of transportation of materials to the construction site and the construction installation process. Downstream processes of construction process stage include transportation and disposal of construction waste, impacts related to contractor demobilization, impacts generated during the use of the building and end-of-life management choices when the building is decommissioned.

These upstream and downstream processes have largely not been included within the system boundary of this study. Discussion of them is included as even though they are not quantified as part of this study it is important to be aware of the potential for significant impacts elsewhere in the product lifecycle.

Product Stage

The product stage is comprised of raw material acquisition, raw material transportation and processing, effectively the activities from material acquisition to some product at the factory gate. Included in this stage are the impacts generated by labour and machinery mobilization to mine and/or gather raw materials. Transportation impacts are generated by the fuel energy required in transportation, as well as the impacts to air, water and land by the means of transportation. Finally, impacts in production are generated by the unit processes at the plant, allocated to all of the products generated either by mass, volume or monetary value.

Upstream impacts of the product stage include the impacts generated through the acquisition of resources and generation of energy, labour and machinery personnel to the raw materials site and any long term emissions of the raw materials production. The Athena Building IE accounts for upstream energy production only.

Downstream impacts of the product stage are in two parts, with products contributing to the final building moving into the construction stage, and any additional products of the product phase having impacts outside of the scope of this study.

Construction Stage

The construction stage comprises the transportation of materials to the construction site (from the plant gate) and the construction installation process. This encompasses the movement of construction materials from the production facility to a storage facility, and then to the construction site. The construction installation process includes the movement of materials on-site, energy required for construction equipment and an allotment of excess materials (above the user input) to account for waste.

Upstream processes of the construction stage include the product stage, and transportation impacts associated with labour mobilization to the construction site. Downstream processes include the building operation and maintenance and end of life procedures. These are outside the scope of this study.

Environmental Data

Data Sources

This study primarily utilizes two databases for life cycle inventory data, the Athena Sustainable Materials Institute LCI Database and the National Renewable Energy Laboratory U.S. Life Cycle Inventory Database.

The Athena Database is curated by the Athena Institute and is comprised of data generated from research within the institute and surveys conducted within industry. It comprises data on building materials, energy use, transportation, construction and demolition processes. The database is regionally sensitive, taking into account differences in electricity grids, technology and transportation distances by city-region.

The U.S. LCI database is supported by a number of stakeholders in industry, with the data generated largely through industry partners and research at the institute, guided and supported by a technical advisory committee and a project management team. [10]

Both databases are updated incrementally and continuously.

Data Adjustments and Substitutions

Due to the age of the Music Building, records of its design and construction are sparse. The structural and architectural drawings which form the basis of this study are dated between 1965 and 1966. This corresponds to their filing with UBC Department of Infrastructure Planning – Records, which lists these drawings as “Preliminary”. In their filing system, preliminary drawings encompass all drawings generated up to the construction phase, including the set issued for tender. In the opinion of Records Department staff, it is likely that the set of drawings used to estimate quantities used in this study are from the end of the design phase, i.e. review drawings prior to preparation of tender documents. This seems reasonable, given that the UBC Library records the construction of the music building as occurring between 1966 and 1968.

As a result of using drawings from earlier in the design process, there is no specification of products of products types, particularly for member envelopes. Rather, the drawings employ descriptive measures such as “waterproof barrier”, forcing the modeler to make input assumptions when developing the building model in Athena Building IE. Further, it is likely the types of products used to fulfill this purpose have changed since the construction of the Music Building, which different associated materials production and environmental impacts, however this assumption could not be verified as construction material details, especially pertaining environmental impacts, are unavailable from the period of construction. Since the principle architect for the project, Gardiner Thornton Davidson Garrett Masson and Associates, has since gone out of business, and the consulting engineer, Read Jones Christoffersen, has not retained its record for this project, a detailed construction specification with materials specifications could not be obtained for any additional detail.

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[10] “U.S. Life Cycle Inventory Database." (2012). National Renewable Energy Laboratory, 2012. Accessed November 19, 2012: https://www.lcacommons.gov/nrel/search

Athena Building IE uses live loading characteristics and beam/column tables to estimate structural sections and materials for structural members. As the Music Building was constructed almost 5 years ago it seems reasonable that different loads may have been used during the design. However, due to the nature of the impact estimator, the assessor was unable to verify if the dimensions, and by extension volume of materials, of the structural elements (columns and beams) corresponded to dimensions as stated in the drawings. Consequently live loading characteristics were assumed to be 2.4 kPa, which is in accordance with the National Building Code of Canada (NBC) (2010) and the British Columbia Building Code (BCBC) (2012). However, the NBC, which has a primary role of establishing acceptable structure load magnitudes and patterns, was first published in 1973. Prior to that, all municipalities were responsible for establishing their own building regulations through bylaws. Through correspondence with the City of Vancouver Department of Bylaw Interpretation, the assessor was unable to gain access to a copy of City of Vancouver building bylaws which would have been active during the 1960s. Bylaw interpretation staff are confident that extensive records from that period have not been retained.[11]

Finally, technology has changed in construction materials manufacture and as well as materials standards. The case in which this is easily verifiable, and most relevant to the assessment of the Music Building, is in the case of the addition of flyash as supplementary cementitious material to concrete. Prior to the 1970s, flyash was not widely used as a concrete additive, and only later was its use as a supplementary cementing material recognized by the Canadian Standards Association (CSA)[12]. Consequently, the assertion that concrete in the Music Building contains an “average” amount of flyash in its mix design, the minimum input quantity available, may lead to significant inaccuracies within the model, as concrete is the primary structural material present in the Music Building.

The assessor has substituted life cycle inventory (LCI) data generated by the U.S. Environmental Protection Agency (EPA) for concrete ready-mixes and pre-cast mixes of varying strengths to generate midpoint impacts using TRACI characterization factors. The resultant impacts were used in the model in place of Building IE outputs for concrete containing elements for the material production phase.

Data Quality

The uncertainty in life cycle assessment studies is considered to be generated in five areas of the study: data uncertainty, model uncertainty, temporal uncertainty, spacial uncertainty and variability between sources.[13]

Data uncertainty has impacts in the inventory analysis and impact assessment stages of the study. During the inventory analysis phase, the data used influences the assessor’s allocation of impacts between unit processes and system products. The assessor should be aware of the following characteristics of the datasets utilized over the course of the inventory analysis: age of the data, technology of the process, origin of the raw materials and locality of the process, and the biological characteristics of the impacted environment. As LCA is a rapidly changing field, data collection methodology is still developing, the age of the data may impact its completeness. Further, the age of the data should be taken into account when analyzing the age of the process technology being considered in order to evaluate how closely related it is to the technology of the unit process being studied. The locality of the process and the origin of raw materials have a direct correlation with impacts, as ease of site access, length and difficulty of transportation from source to process plant will all affect energy usage. Finally, the ecological characteristics of the impacted environments should be gauged for similarity to the study, as impacts to tropical rainforest can be expected to diverge from

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[11] City of Vancouver Bylaws Interpretation. Personal Communication, October 2013.

[12] Taheri, A. Personal Communication, October 2013.

[13] Sianchuk, R. Week8_Uncertainty (PDF Document). Retrieved from lecture notes online site: http://civl498c.wikispaces.com/Class+Presentations+and+Handouts

impacts to boreal forest or prairie regions. All of these factors, combined with monetary data on the process, integrate to inform the allocation of impacts between products of the process. Largely, allocation is based on monetary valuation of intermediate products and the physical relationships between all steps of the process.

During the impact assessment phase of the study data uncertainty will propagate an uncertainty in the materials lifetimes within the building and travel potential during the end of life.

Model uncertainty affects the inventory analysis phase and the impact assessment phase of the study. During inventory analysis, the use of a linear or non-linear model will determine whether there are increasing, decreasing or constant returns to input within the system. During impact assessment, it is important to recognize that characterization factors may be unknown for certain inputs, or have a higher degree of uncertainty in when determining how a material input generates midpoint impacts within the model.

During the goal and scope determination for the study, the assessor generates a level of uncertainty due to their choices of functional unit, system boundary, product service life, modeling tool, allocation methods, IA method and IA categories. This is why goal and scope compatibility is crucial when studies are used to make comparative assertions. Accurate and meaningful comparisons between studies cannot be made when the functional units or the system boundary or studies differ significantly.

Temporal variability refers to the effects of time as it relates to both the collation of data during the inventory analysis stage and the long term interpretation of results of the impact assessment. During inventory analysis, it is notable that manufacturing technology for managing emissions is constantly developing, and so there may be fluctuations in generated emissions due to fluctuations in operating efficiency and product demand. The data vintage is also relevant here, as emissions capture technology may have been added or improved at a site since the creation of the data set. During impact assessment, results may be affected by other long term trends independent of the process being studied, i.e. global temperature changes. Also, some impacts may take longer to develop than others, influencing how the result of a study should be considered with increasing time.

Spatial variability occurs during the inventory analysis and impact assessment stages, and accounts for regional differences in production as well as disparity in environmental sensitivity and distribution and travel potential of emissions.

Finally, there is also variability between sources, with different factories producing different emissions and potentially differing technologies and processes to produce the same product. During impact assessment, this translates to variability in human exposure patterns to emissions.

The primary databases used in this study are the Athena Institute LCI Database for material process data and the US LCI Database for energy combustion and pre-combustion processes for electricity generation and transportation data.

In the Athena Building IE model generated for this study, data uncertainty is largely present in two forms. Firstly, where data for a specific product used in the Music Building was unknown or unavailable, the assessor had to use the data for the most similar product available from the Athena LCI database. Secondly, travel potential is largely unknown. The Building IE uses cities as a proxy for regions, performing a regional market share analysis in each area (for this study, Vancouver was used) to develop a weighted average of product transportation profiles. As some products are quite regional, i.e. cement and aggregate and are represented very well by this method, while other products such as steel and aluminum travel far greater distances and are often sourced from offshore. In the model, all offshore products are treated as though they were manufactured in North America, as consistent and reliable international datasets are unavailable. In the case where a significant product was unavailable in the Athena LCA Database (i.e. concrete with no flyash), alternative data sets were located, and the impacts generated using the new data set are substituted into the model, as discussed previously.

The extent of model uncertainty in this study is largely unknown. The exact details of the modeling regime used by the Building IE is proprietary of the Athena Institute and so cannot be commented on here. The characterization factors utilized by the model are from the U.S. EPA TRACI impact methodology. In so far as the products within the model were available within TRACI, any uncertainty in this area is unavoidable. Where an exact product was not available, the assessor chose the next, most similar product to generate impacts.

Uncertainty due to choices has been largely mitigated in this study, as this study has been undertaken as coursework for UBC's Civl 498c course, all studies performed for this course have consistent goal and scope. This ensures that all studies generated through this course will be compatible for the use of future comparisons.

Temporal variability is present through the vintage of the data contained within the U.S. LCI Database and the Athena LCI Database. Much of the Canadian data in the Athena database was generated between 2005 and 2009, with specific product profiles being continually updated and adjusted through to 2012.

Similar to data variability, spatial variability has been addressed in the Building IE through the inclusion of city-regions. These city regions provide information on transportation potential and distribution of emissions, ecological sensitivities, and regional industry practices.

List of Indicators Used for Assessment and Expression of Results

The impact assessment method utilized in this study is the United States Environmental Protection Agency (U.S. EPA) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). TRACI utilizes six midpoint or indicator impact categories with normalization[14]. These are: global warming potential, ozone depletion, eutrophication potential, acidification potential, smog formation potential, and human health respiratory effects potential. The Athena Institute utilizes an additional category, fossil fuel consumption, which is also addressed in this study.[15]

Global warming potential is characterized by the Intergovernmental Panel on Climate Change, which has defined it as the capacity to absorb infrared radiation leading to heating in the earth's atmosphere. Characterized by gas equivalence of kg of carbon dioxide gas (kg CO_2 eq), air emissions cause increased absorption of infrared radiation in the atmosphere, leading to global changes in temperature, precipitation and sea level, potential resulting in effects on water resources, human health, agriculture, forests, special damage and damage to coastal areas.

Ozone depletion potential is characterized by the World Meteorological Organization (WMO), who have defined it as the potential to alter the stratospheric ozone column due to emissions to a substance relative to CFC^{-11}. Characterized by gas equivalence of CFC^{-11} (kg CFC^{-11} eq), emissions cause a reduction in the ozone layer surround the earth, increasing the incidence of UVB rays at earth's surface, potentially resulting damage to agricultural crops, increased incidence of cancer in humans, species damage and material damage.

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[14] United States Environmental Protection Agency. (2012). *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)*. Retrieved from http://www.epa.gov/nrmrl/std/traci/traci.html.

[15] Sianchuk, R. Week6_Impact Assessment (PDF Document). Retrieved from lecture notes online site: http://civl498c.wikispaces.com/Class+Presentations+and+Handouts.

Eutrophication potential is characterized by the U.S. EPA with midpoint impacts influencing the growth of algae in nutrient deficient surface waters. Characterized by kg of nitrogen equivalent (kg N eq), the EPA characterization takes relative algae growth in the aquatic ecosystem, transport and probability of emissions arriving in an aquatic environment into account. Emissions cause increased algae and aquatic weed growth, generating algae blooms releasing toxic leads into the ecosystem and/or generating dead biomass, the decomposition of which leads to an oxygen shortage in the contaminated system, causing death of fish and shellfish, and the toxicity of the water eliminates use by humans, marine mammals and livestock. Extreme cases may even render the area unfit for industrial uses. Recently it has been established that toxicity caused by algal blooms also has carcinogenic effects.

Acidification potential is characterized by the U.S. EPA with midpoint impacts defined by an emissions capacity to form acidifying H+ ions relative to sulphur dioxide, increasing the acidity of water and soil systems. Emissions to water, soil and air are characterized by mass of sulphur dioxide equivalent (kg SO_2 eq) causing acid deposition causing ecotoxicity, acicidifcation of watercourses and reduced plant health in forest and plant ecosystems through leaching of nutrient cations resulting in increased mortality of flora and fauna and significant ecosystem changes.

Smog potential, also referred to as photochemical ozone formation and photo-oxidant formation, is characterized by the U.S. EPA as a given emission's influence on the quantity of ozone formed photochemically in the troposphere. Described by the mass of ozone equivalent generated by an emission (kg O_3 eq), emissions interact with volatile organic compounds and nitrogen oxides, and with exposure to sunlight and long term temperature fluctuations, alter tropospheric ozone concentrations. This can cause reduced photosynthesis in plants leading to increased plant mortality, and when inhaled by humans has impacts on human health and mortality. In particular, smog aggravates conditions including emphysema, bronchitis and asthma, leading to societal impacts through missed school time, restricted activity, increased incidence of hospital in-patient and emergency visits and even causing premature death.

Human health criteria – air emissions is closely related to smog potential. Characterized by the U.S. EPA these are emissions defined by human exposure to air borne particulate matter less than 10 μm in diameter. Emissions are categorized by their mass equivalency to particulate matter 2.5 to 10 μm in diameter (kg $PM_{2.5}$ eq), which when inhaled by a human cause deposition of particulate matter in the alveoli of the lungs. Where the body reacts to the presence of the particulates, health conditions such as chronic coughing and wheezing, asthma, heart disease, chronic bronchitis, emphysema, and pneumonia may develop or be exacerbated. Long term exposure in women also contributes to increased incidence of premature births and low birth weights. Where deposited particulate matter contains harmful or toxic substances, prolonged exposure may result in death.

Fossil fuel consumption has been characterized by the Athena Sustainable Materials Institute as an additional midpoint impact category, defined as all direct and indirect energy used to transform or transport raw materials into products and/or buildings. This includes energy contained in raw or feedstock materials that are utilized as common energy sources during processes and is described by mega-joules (MJ) of energy.

Model Development

A materials quantity takeoff of the building was performed from digital drawings supplied by the UBC Department of Infrastructure Planning – Records, using OnCenter's OnScreen TakeOff version 3.9.0.6, a software too designed to perform material takeoffs with increased speed and accuracy. Produced to increase the accuracy and speed to enhance the bidding capacity of its users, OnScreen TakeOff was utilized in this study to perform linear, area and count measurements of the elements in the Music Building's structure and envelope. OnScreen TakeOff used imported copies of the building plans to simplify the calculations and measurements associated with the takeoff process, while reducing the error associated with these activities.

The linear estimation condition was utilized to estimate walls and footings of known height and thickness, to yield the lengths of these structural features.

Floors, slabs on grade, window areas, spread footings and roof areas were measured using the area condition, which allows the user to generate total surface area. Using known depths, volumes can be easily determined.

The count conditions was used to quantify repetitive, modular features, including columns, beams, windows, doors, and some spread footings. Dimensions were recorded separately, along with any other relevant feature properties in the notes section of the condition for future reference.

The results of the takeoff process where then formatted according to the Canadian Institute of Quantity Surveyors (CIQS) level three elements and transferred into the Athena Building Impact Estimator LCA software. These inputs and their associated assumptions can be viewed in Annex D – Impact Estimator Inputs and Assumptions.

Athena Building IE is used to generate a whole building LCA model of the Music Building, as well as for each of its level three elements, in the Vancouver region as an institutional building type. The IE has been created as a decision making tool to aid the building community in making more environmentally conscious material and design choices based on life cycle impact methodology. Utilizing a series of proprietary algorithms to the user input data, the program completes the takeoff process by generating a bill of materials (BoM) for the model. This BoM is then integrated with the Athena Life Cycle Inventory (LCI) Database, version 4.6, in order to generate a cradle-to-grave LCI profile for the building. In this study, LCI profile results have been limited to a cradle-to-gate analysis, as discussed previously, and with analysis limited to the production and construction phase of the building. To generate appropriate results using the impact estimator the expected service life of the Music Building has been set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building's life cycle being excluded from the scope of the model.

CIQS level three elements have been utilized in the sorting and presentation of the data in this study to facilitate its use in the development of sustainable building policy at UBC and other institutions, to facilitate sustainable materials choices during the design phase of future projects, and to inform analysis as regards areas of building structure and envelope where the largest environmental impacts occur.

A detailed review of the model of the music building was performed, with the assessor verifying all geometric properties in OnScreen TakeOff, with particular attention being given to counts of repeated elements and precise measurements of linear and area conditions. Model assumptions were re-verified and additional information was added to the model to accommodate for older building materials as described previously.

As the Music Building is constructed on a sloping site, ground level access on the east side of the building is on the second floor, and on the west side is on the first floor or basement level. Consequently footings, foundation walls and basement slabs are all stepped to accommodate this. The technical intricacy of this foundation presented a challenge in the estimation of foundation wall and column heights, as well as determination of element A31 – Walls Below Grade. For details of assumptions utilized in materials takeoff, please refer to Annex D. During element sorting, it was determined by the assessor that all walls in the basement/first floor of the structure should be considered below grade, as it was unknown where, if any, walls were entirely above grade.

Similarly, elevator and stair cores have been included in element A22 – Upper Floor Construction, as they are structural components of the building, carrying loads in a way that is comparable to beams and columns.

Reference flows within the LCA process translate the functional unit into specific products within the system being analyzed to allow for comparison on an equivalent basis. Further, this exemplifies trade-offs and consequences of a potential product substitution.[16]

For the model of the Music Building, the reference flows are given by material quantities in each element.

Material	Quantity	Unit
Concrete 20 MPa (flyash av)	115.6088	m3
Concrete 30 MPa (flyash av)	41.414	m3
Rebar, Rod, Light Sections	5.5884	Tonnes

Table 1: A11 Foundations - Bill of Materials

Material	Quantity	Unit
Concrete 20 MPa (flyash av)	270.3811	m3
Welded Wire Mesh / Ladder Wire	2.3271	Tonnes

Table 2: A21 Lowest Floor Construction - Bill of Materials

Material	Quantity	Unit
Concrete 30 MPa (flyash av)	1511.2245	m3
Galvanized Sheet	0.2477	Tonnes
Nails	0.0352	Tonnes
Rebar, Rod, Light Sections	137.6234	Tonnes
Screws Nuts & Bolts	5.0494	Tonnes
Small Dimension Softwood Lumber, kiln-dried	1.0886	m3
Solvent Based Alkyd Paint	1.1791	L
Water Based Latex Paint	9.8075	L
Wide Flange Sections	97.0356	Tonnes

Table 3: A22 Upper Floor Construction - Bill of Materials

Material	Quantity	Unit
#15 Organic Felt	2856.2897	m2
Ballast (aggregate stone)	26307.0693	kg
Concrete 30 MPa (flyash av)	229.419	m3
Expanded Polystyrene	5265.4125	m2 (25mm)
Galvanized Sheet	1.4927	Tonnes
Nails	0.6451	Tonnes
Rebar, Rod, Light Sections	13.058	Tonnes
Roofing Asphalt	16855.7264	kg
Screws Nuts & Bolts	1.1319	Tonnes
Type III Glass Felt	5712.5793	m2

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[16] Weidema, Bo & Henrik Wenzel, Claus Peterson and Klaus Hansen. (2004). The Product, Functional Unit and Reference Flows in LCA. Environmental News, 70. Retrieved from http://www2.mst.dk/Udgiv/Publications/2004/87-7614-233-7/pdf/87-7614-234-5.PDF.

Wide Flange Sections	22.5994	Tonnes

Table 4: A23 Roof Construction - Bill of Materials

Material	Quantity	Unit
Aluminum	2.3623	Tonnes
Concrete 30 MPa (flyash av)	635.7416	m3
EPDM membrane (black, 60 mil)	147.5191	kg
Glazing Panel	0.4056	Tonnes
Nails	0.1391	Tonnes
Rebar, Rod, Light Sections	22.4923	Tonnes

Table 5: A31 Walls Below Grade - Bill of Materials

Material	Quantity	Unit
Aluminum	2.4146	Tonnes
Concrete 20 MPa (flyash av)	296.9835	m3
Concrete Blocks	8880.5299	Blocks
EPDM membrane (black, 60 mil)	149.3878	kg
Galvanized Sheet	0.0294	Tonnes
Glazing Panel	0.6313	Tonnes
Mortar	169.978	m3
Nails	0.1827	Tonnes
Rebar, Rod, Light Sections	38.7898	Tonnes
Screws Nuts & Bolts	0.0093	Tonnes
Small Dimension Softwood Lumber, kiln-dried	2.4106	m3
Water Based Latex Paint	21.7166	L

Table 6: A32 Walls Above Grade - Bill of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	6327.2668	m2
FG Batt R11-15	13545.5328	m2 (25mm)
Joint Compound	6.3147	Tonnes
Nails	0.6629	Tonnes
Paper Tape	0.0725	Tonnes
Small Dimension Softwood Lumber, Green	59.0303	m3
Small Dimension Softwood Lumber, kiln-dried	3.3437	m3
Water Based Latex Paint	30.123	L

Table 7: B11 Partitions - Bill of Materials

Communication of Assessment Results

Life Cycle Results

Impacts of the Music Building structure and envelope have been quantified through the course of this study, the results are summarized in the tables below.

Through class exercises and discussion, it was determined that the potential for global warming impacts was the most pressing, and so should be the focus of these studies.

In the Music Building the majority of global warming impacts are generated by the concrete in the structure, particularly in the wall assemblies below grade, accounting for approximately 18% of impacts.

In Annex A the results of this study are compared to the other studies performed on UBC academic buildings, as well as a campus wide benchmark developed from these studies. Annex B contains a summary of the assessor's recommendations for LCA use and Annex C contains the author's reflections over the course of this study.

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	12594404.48	1028463.442	39074.29191	3786.68648	710.3913131	0.005483939	163074.6795
	Transport	532023.85	32581.70669	198.2527958	5.600673212	13.89566969	1.32537E-06	7018.459668
	Total	13126428	1152619.509	7924.054705	2585.457153	724.2869828	0.005485265	138744.6492
CONSTRUCTION PROCESS	Construction-installation Process	766051.6401	75758.10769	563.6606981	130.4643341	32.87350253	0.000292347	14920.34833
	Transport	749914.87	49697.27018	265.6767949	7.814612602	18.85667125	1.98867E-06	9394.023387
	Total	1515967	125455.3779	829.337493	138.2789467	51.73017377	0.000294336	24314.37172
TOTAL EFFECTS	Non-Transport	13,360,456.12	1,104,221.55	39,637.95	3,917.15	743.26	0.01	177,995.03
	Transport	1,281,938.72	82,278.98	463.93	13.42	32.75	0.00	16,412.48
	Total	14,642,394.84	1,186,500.53	40,101.88	3,930.57	776.02	0.01	194,407.51

Table 8: Music Building - Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	281931.4277	29329.98234	362.2156069	145.1527523	16.21782608	0.000195488	5978.473145
	Transport	19628.63528	1191.544069	7.349726481	0.206763952	0.514488915	4.8522E-08	260.2028647
	Total	301560.063	36900.78341	243.5853334	93.71951621	16.73231499	0.000195536	5010.016009
CONSTRUCTION PROCESS	Construction-installation Process	10627.12528	1657.544447	10.90626412	4.623205106	0.504821805	9.7742E-06	229.748681
	Transport	26725.75983	2040.058291	9.517279989	0.294028717	0.686182127	8.13607E-08	336.547188
	Total	37352.88511	3697.602738	20.42354411	4.917233824	1.191003933	9.85556E-06	566.295869
TOTAL EFFECTS	Non-Transport	292,558.55	30,987.53	373.12	149.78	16.72	0.00	6,208.22
	Transport	46,354.40	3,231.60	16.87	0.50	1.20	0.00	596.75
	Total	338,912.95	34,219.13	389.99	150.28	17.92	0.00	6,804.97

Table 9: A11 Foundation - Summary Measures

		Fossil Fuel	Global Warming	Acidification	Human Health	Eutrophication	Ozone Layer	Smog

		Consumption			Criteria – Respiratory		Depletion	
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	356824.6824	40637.28873	539.4853605	230.1246219	16.18209811	0.000299971	9015.292704
	Transport	30333.16482	1830.850027	11.32654729	0.318354554	0.792653447	7.45751E-08	400.9991362
	Total	387157.8472	54985.26876	360.9369078	149.8729765	16.97475156	0.000300045	7616.44184
CONSTRUCTION PROCESS	Construction-installation Process	16310.47926	2572.83763	16.94883647	7.433111874	0.724741506	1.49985E-05	357.523301
	Transport	47779.57935	3509.224364	16.98420398	0.517580977	1.219127739	1.40066E-07	600.5721302
	Total	64090.05862	6082.061994	33.93304045	7.950692851	1.943869245	1.51385E-05	958.0954312
TOTAL EFFECTS	Non-Transport	373,135.16	43,210.13	556.43	237.56	16.91	0.00	9,372.82
	Transport	78,112.74	5,340.07	28.31	0.84	2.01	0.00	1,001.57
	Total	451,247.91	48,550.20	584.74	238.39	18.92	0.00	10,374.39

Table 10: A21 Lower Floor Construction - Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	5930089.126	471908.5317	4833.58199	1556.859204	410.4238048	0.002162696	72061.59101
	Transport	237842.0669	14723.93646	88.71205974	2.513755178	6.223678516	5.98424E-07	3140.416761
	Total	6167931.193	519668.5381	3481.03405	1006.52396	416.6474833	0.002163294	60433.64777
CONSTRUCTION PROCESS	Construction-installation Process	471390.9261	41243.3373	330.7068785	50.43881312	21.01742984	0.000108343	9837.386113
	Transport	339829.5956	20065.26101	119.9312121	3.399125635	8.414763135	8.05356E-07	4240.344451
	Total	811220.5217	61308.5983	450.6380906	53.83793875	29.43219297	0.000109149	14077.73056
TOTAL EFFECTS	Non-Transport	6,401,480.05	513,151.87	5,164.29	1,607.30	431.44	0.00	81,898.98
	Transport	577,671.66	34,789.20	208.64	5.91	14.64	0.00	7,380.76
	Total	6,979,151.71	547,941.07	5,372.93	1,613.21	446.08	0.00	89,279.74

Table 11: A22 Upper Floor Construction - Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria –	Eutrophication	Ozone Layer Depletion	Smog

					Respiratory			
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	2289628.175	103248.3069	1116.959372	343.4979212	71.15396191	0.000372645	13530.01986
	Transport	42619.36312	2645.00376	15.84500498	0.449788512	1.112230742	1.07452E-07	560.9043751
	Total	2332247.538	111582.2936	704.6143774	248.7477098	72.26619265	0.000372753	11547.74424
CONSTRUCTION PROCESS	Construction-installation Process	108218.6471	7854.794242	56.25897566	12.14337719	3.413624289	1.86306E-05	1594.170261
	Transport	70670.2942	3921.962086	24.88802532	0.692251387	1.736265666	1.57687E-07	879.9207436
	Total	178888.9413	11776.75633	81.14700098	12.83562858	5.149889955	1.87883E-05	2474.091005
TOTAL EFFECTS	Non-Transport	2,397,846.82	111,103.10	1,173.22	355.64	74.57	0.00	15,124.19
	Transport	113,289.66	6,566.97	40.73	1.14	2.85	0.00	1,440.83
	Total	2,511,136.48	117,670.07	1,213.95	356.78	77.42	0.00	16,565.02

Table 12: A23 Roof - Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	1888290.996	225948.4348	2636.910518	990.5459922	98.98654342	0.001399827	41234.30241
	Transport	119287.8474	7024.652968	44.92726558	1.250189668	3.134544945	2.86929E-07	1590.75651
	Total	2007578.843	253176.0828	1800.442783	653.7061818	102.1210884	0.001400114	33793.55892
CONSTRUCTION PROCESS	Construction-installation Process	68473.9482	11001.06729	71.8446588	28.51555723	3.213589928	6.61399E-05	1504.626955
	Transport	145505.1953	11072.15573	51.8381666	1.599389962	3.735856416	4.41654E-07	1833.104326
	Total	213979.1435	22073.22301	123.6828254	30.11494719	6.949446345	6.65815E-05	3337.731281
TOTAL EFFECTS	Non-Transport	1,956,764.94	236,949.50	2,708.76	1,019.06	102.20	0.00	42,738.93
	Transport	264,793.04	18,096.81	96.77	2.85	6.87	0.00	3,423.86
	Total	2,221,557.99	255,046.31	2,805.52	1,021.91	109.07	0.00	46,162.79

Table 13: A31 Walls Below Grade – Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog

Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	1487988.289	134022.3332	1345.337501	490.0790999	85.19360833	0.000733649	19889.12952
	Transport	56668.08701	3566.361244	21.37708243	0.606770244	1.500506802	1.44959E-07	756.7753382
	Total	1544656.376	151338.0245	1158.158584	402.1878702	86.69411513	0.000733794	18668.96986
CONSTRUCTION PROCESS	Construction-installation Process	63738.87136	9681.983991	64.01594496	25.09364214	2.97098456	5.69647E-05	1302.422167
	Transport	88352.36647	6736.673542	31.52116407	0.972775913	2.27183622	2.68736E-07	1114.665475
	Total	152091.2378	16418.65753	95.53710903	26.06641806	5.24282078	5.72334E-05	2417.087642
TOTAL EFFECTS	Non-Transport	1,551,727.16	143,704.32	1,409.35	515.17	88.16	0.00	21,191.55
	Transport	145,020.45	10,303.03	52.90	1.58	3.77	0.00	1,871.44
	Total	1,696,747.61	154,007.35	1,462.25	516.75	91.94	0.00	23,062.99

Table 14: A32 Walls Above Grade - Summary Measures

		Fossil Fuel Consumption	Global Warming	Acidification	Human Health Criteria – Respiratory	Eutrophication	Ozone Layer Depletion	Smog
Life Cycle Stage	Process Module	(MJ)	(kg CO2eq)	(moles of H+eq)	(kg PM10eq)	(kg Neq)	(kg CFC-11eq)	(kg O3eq)
PRODUCT	Manufacturing	359651.7869	23369.15921	166.5675604	30.44388784	12.23347051	0.000319664	1365.865853
	Transport	25644.68668	1599.358161	8.715109339	0.255051104	0.617566319	6.45062E-08	308.4046828
	Total	385296.4736	24968.51737	175.2826697	30.69893895	12.85103683	0.000319728	1674.270535
CONSTRUCTION PROCESS	Construction-installation Process	27291.64276	1746.542795	12.97913962	2.21662742	1.028310602	1.74963E-05	94.47085209
	Transport	31052.08384	2351.935169	10.99674285	0.339460011	0.792639943	9.38151E-08	388.8690729
	Total	58343.7266	4098.477964	23.97588246	2.556087431	1.820950545	1.75901E-05	483.339925
TOTAL EFFECTS	Non-Transport	386,943.43	25,115.70	179.55	32.66	13.26	0.00	1,460.34
	Transport	56,696.77	3,951.29	19.71	0.59	1.41	0.00	697.27
	Total	443,640.20	29,067.00	199.26	33.26	14.67	0.00	2,157.61

Table 15: B11 Partitions - Summary Measures

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Annex A – Interpretation of Assessment Results

Benchmark Development

Benchmarks are developed over the course of many LCA studies with compatible goal and scope to develop an average of product performance over an industry. This allows an additional level of comparison within a study, to show how a product either over- or under-performs an average. Further, over the time the benchmark will show changes in industry practices, either towards or away from certain environmental impacts.

The role of common goal, scope and functional equivalence is crucial in developing a benchmark. Studies used to contribute to an average value must be comparing the same things, with the same units and method of measurement. Goal and scope compatibility and functional equivalency ensures this.

UBC Academic Building Benchmark

The following figures show the results of the Music Building LCA with the results of other LCAs performed on academic buildings at the UBC Point Grey Campus.

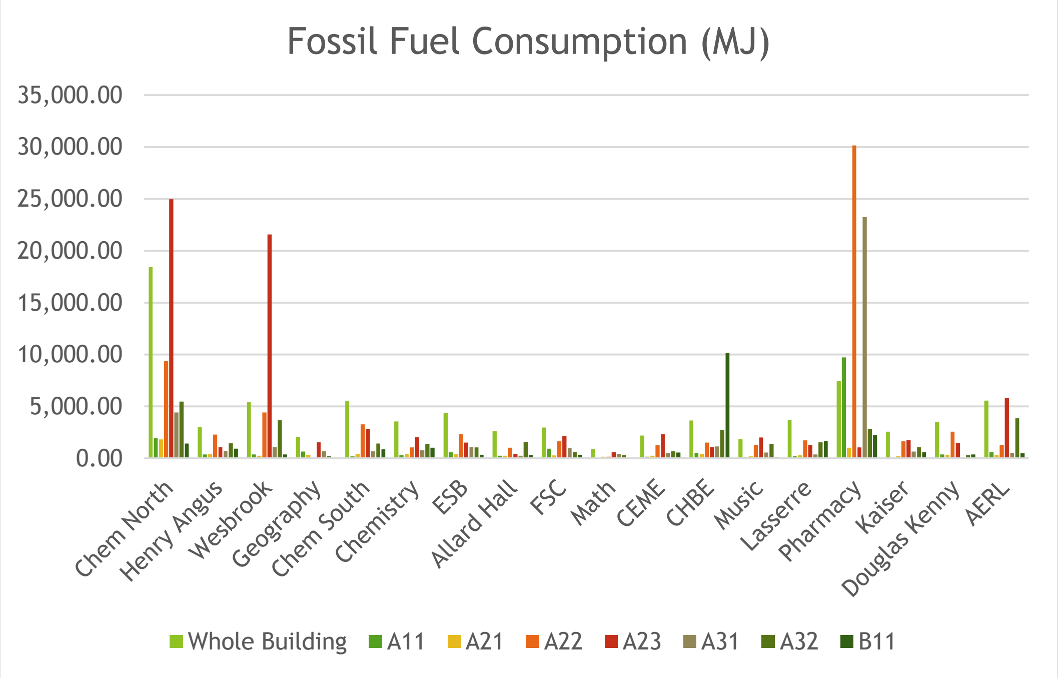

Figure 1: Comparison of Fossil Fuel Consumption

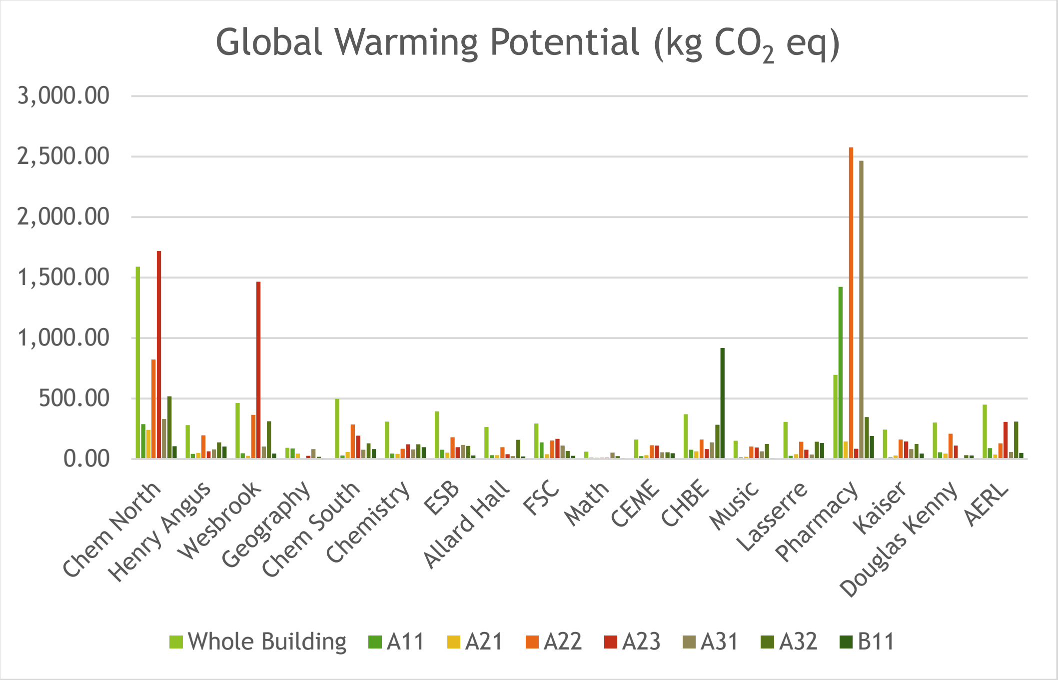

Figure 2: Comparison of Global Warming Potential

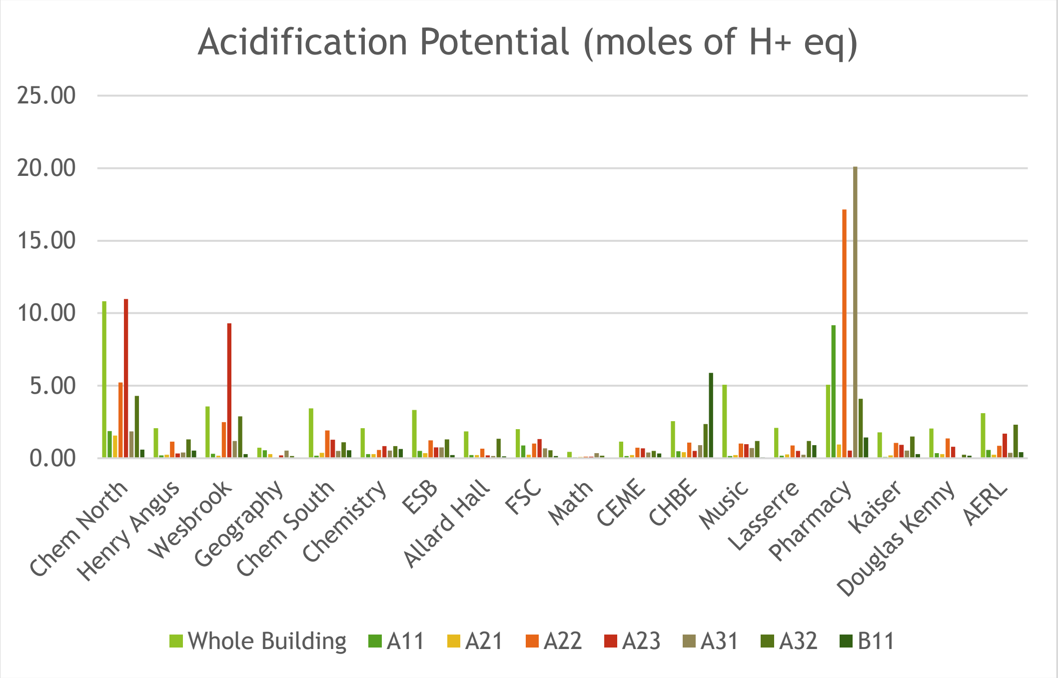

Figure 3: Comparison of Acidification Potential

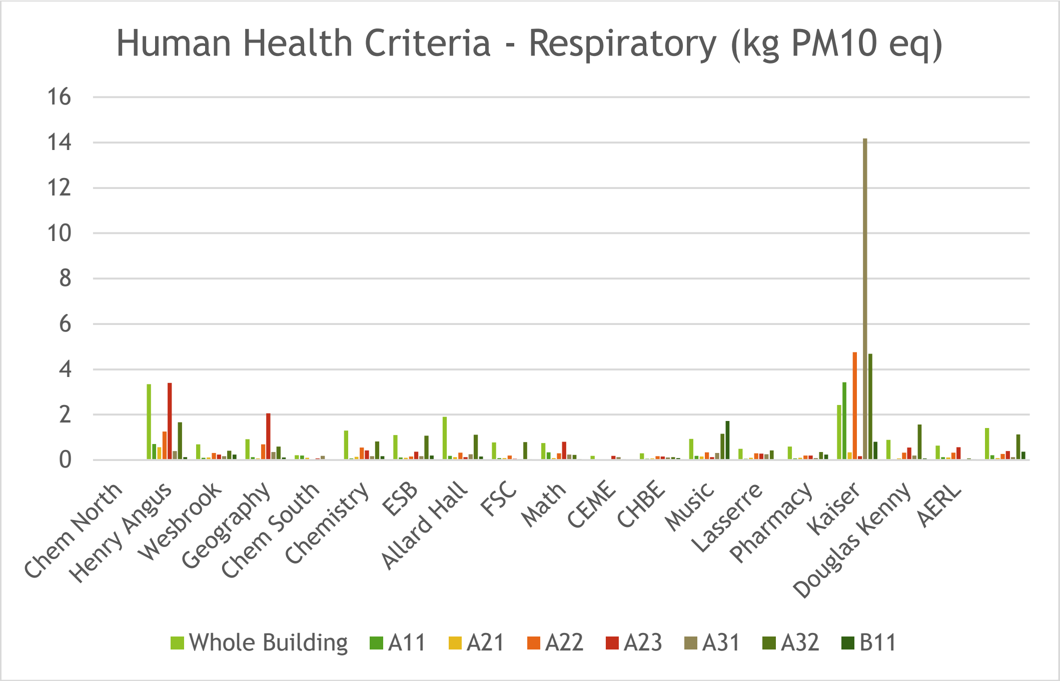

Figure 4: Comparison of Human Respiratory Health Impacts

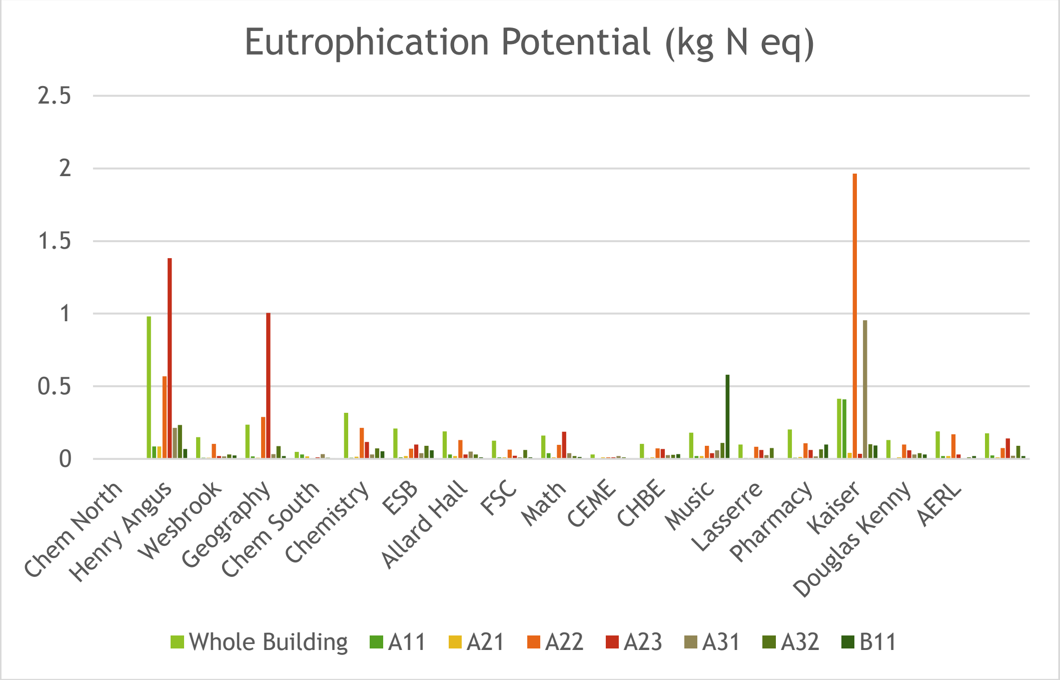

Figure 5: Comparison of Eutrophication Potential

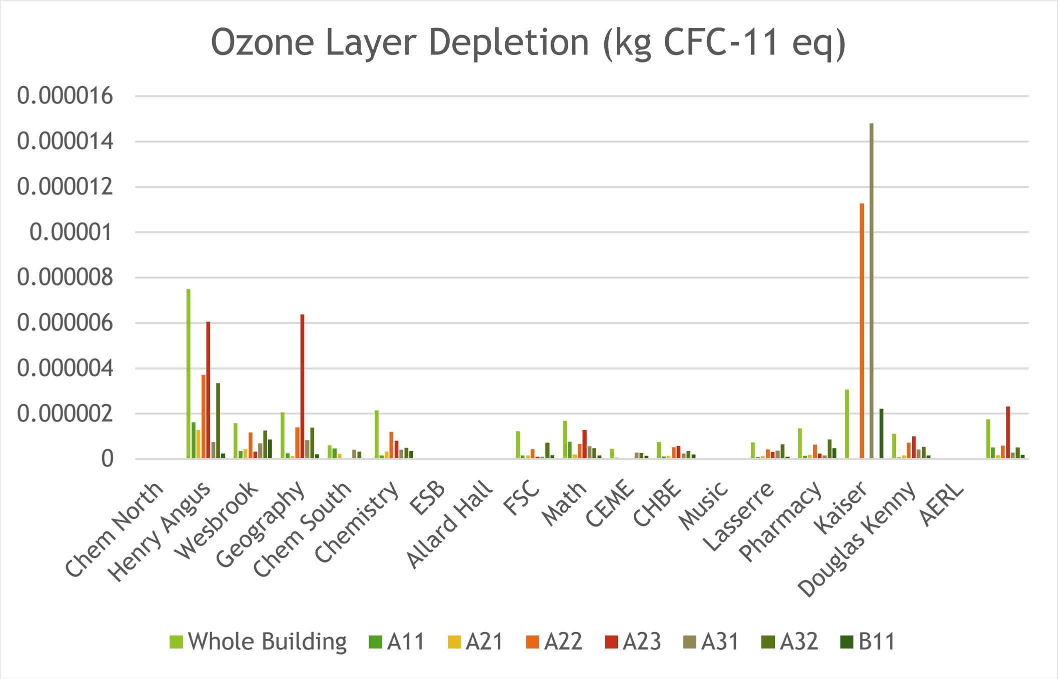

Figure 6: Comparison of Ozone Layer Depletion

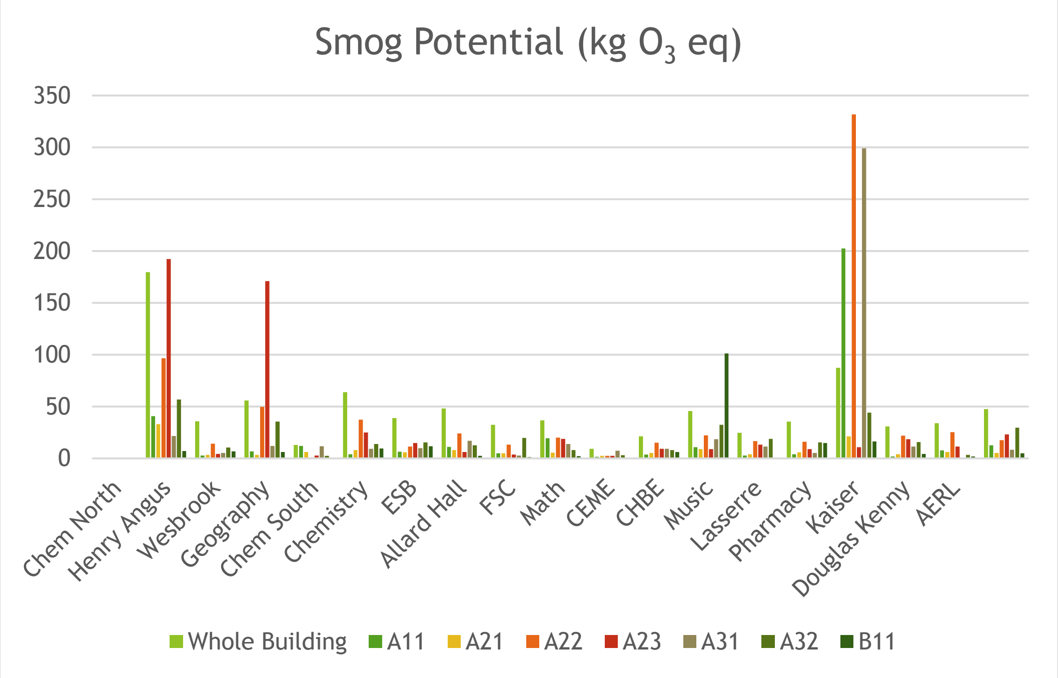

Figure 7: Comparison of Smog Generation Potential

Even though it is an older structure, the performance of the Music Building compares favorably to the other academic structures at UBC campus. For example, in the category of global warming potential, the Music Building falls well below the benchmark established for the campus for all CIQS level 3 elements.

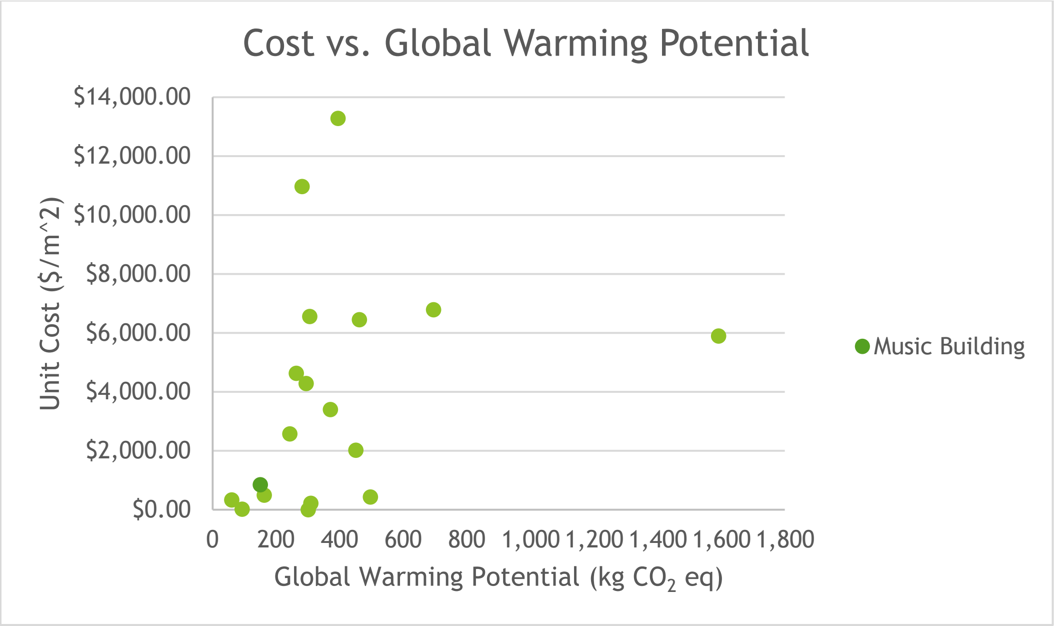

Figure 8: Cost vs. Global Warming Potential

When the global warming impacts of the buildings are evaluated on a cost-per-square-metre basis, the Music Building continues to perform well, still well below most of the others, although it is likely that the comparison of the Music Building on this basis is somewhat skewed. Although the Music Building is an academic building on campus with comparable student usage, the functionality required by Faculty of Music is somewhat different. Much of the area of the music building is not dedicated to classrooms or lecture space, but rather to practice rooms and recital space. Consequently, significant sound proofing measures are required in the Music Building that are not necessary elsewhere on campus. This would likely skew the costs per square metre of the Music Building.

Annex B – Recommendations for LCA Use

The data in these studies can be used to inform sustainable building design policy at a high level by providing quantitative data regarding the impacts of building design choices. Specifically, the choice of materials and assembly types within a structure has significant influence on the environmental impacts associated with the product creation and building construction. Similarly, the databases generated through LCA studies performed on academic buildings at UBC may be used to inform future design choices by making the environmental tradeoffs of materials choices explicit.

However, it is important to note that this study encompasses only the product and construction phases of the building life cycle, where often the majority of impacts will be incurred over the maintenance life of the building. Consequently, it is equally if not more important that building designers and policy makers consider the implications that design choices will have on the operational life of the building.

Annex C – Author Reflection

I came into this class with no significant experience in life cycle analysis. The topic had been introduced conceptually in my civil 201 and 202 classes, where the focus is on sustainability and engineering design principles, which piqued my interest. The topics of the course range over the history and development of LCA practice, the international standards governing its applications (ISO 140440) and the phases of an LCA study – inventory and assessment.

I found the course interesting and especially enjoyed the guest speakers. They were very engaging and it was wonderful to get a feel for the current applications of LCA in industry.

As my primary interests are in the intersection between civil engineering and economics, the symbiosis between life cycle costing and life cycle analysis is very interesting to me.

	Graduate Attribute			
	Name	Description		Comments on which of the CEAB graduate attributes you believe you had to demonstrate during your final project experience.
1	Knowledge Base	Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.	A = applied	The focus of LCA was far more conceptual and focused on societal and environmental impacts than the technical aspects of engineering practice.
2	Problem Analysis	An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.	IA = introduced & applied	The process of reviewing and critiquing a model
3	Investigation	An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and	IA = introduced & applied	The process of reviewing and critiquing a model, extensive research

		interpretation of data, and synthesis of information in order to reach valid conclusions.		
4	Design	An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.	ID = introduced & developed	Discussion of the application of LCA data on design development.
5	Use of Engineering Tools	An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the	DA = developed & applied	Use of specialized industry software such as Athena building IE and onscreen takeoff. Substitution of additional life cycle data resources.

		associated limitations.		
6	Individual and Team Work	An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.	IA = introduced & applied	The project is individual, it required extensive collaboration between classmates.
7	Communication	An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.	DA = developed & applied	Collaboration between classmates, written report and final presentation.

8	Professionalism	An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.	I = introduced	Proposed certification for LCA professionals, level of responsibility.
9	Impact of Engineering on Society and the Environment	An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.	IDA = introduced, developed & applied	I feel that this is a fairly primary focus of LCA. How engineering analysis and design decisions have impacts on the environment. Further, how we quantify those impacts and what we do with that information.
10	Ethics and Equity	An ability to apply professional ethics, accountability, and equity.	I = introduced	Accountability of LCA professionals.

11	Economics and Project Management	An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.	I = introduced	LCA ties to life cycle cost evaluation.
12	Life-long Learning	An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.	I = introduced	Use of research skills, awareness of developing fields of practice.

Annex D – Impact Estimator Inputs and Assumptions

Inputs

Level 1	Level 2	Level 3	Quantity	Units	Assembly Type	Assembly Name	Input Fields	Input Values	
								Known/Measured	EIE Inputs
A Shell	A1 Substructure	A11 Foundation	27717.6953	ft^2					
			2575.05705	m^2	1.2 Concrete Footing				
						Footing_Average Spread			
							Count (#)	-	70
							Length (ft)	-	2.5
							Width (ft)	-	3.50
							Thickness (in)	-	16
							Concrete (psi)	3000	3000
							Concrete flyash %	-	average
							Rebar	#5, 6	#5
						Footing_Average Strip			
							Length (ft)	-	2771.4
							Width (ft)	-	1.33
							Thickness (in)	-	10
							Concrete (psi)	3000	3000

	Concrete flyash %	-	average
	Rebar	#4, 5, 6	#5
Stairwell_Stair Section 4th floor to Penthouse_3' 6" width			
	Length (ft)	-	6.06
	Width (ft)	-	6.06
	Thickness (in)	-	16
	Concrete (psi)	3500	4000
	Concrete flyash %	-	average
	Rebar	-	#5
Stairwell_Stair Section CC_4' 8" width			
	Length (ft)	-	19.44
	Width (ft)	-	19.44
	Thickness (in)	-	16
	Concrete (psi)	3500	4000
	Concrete flyash %	-	average
	Rebar	-	#5
Stairwell_Stair Section DD_4' 10" width			

	Length (ft)	-	24.00
	Width (ft)	-	24.00
	Thickness (in)	-	16
	Concrete (psi)	3500	4000
	Concrete flyash %	-	average
	Rebar	-	#5
Stairwell_Stair Section SE Corner_4' 0" width			
	Length (ft)	-	7.35
	Width (ft)	-	7.35
	Thickness (in)	-	16
	Concrete (psi)	3500	4000
	Concrete flyash %	-	average
	Rebar	-	#5

A2	Structure	A21	Lowest Floor Construction	27717.6953	ft^2	
				2575.05705		1.1 Concrete Slab-on-Grade

SOG_2" Seal

	Length (ft)	53.08	37.53
	Width (ft)	53.08	37.53
	Thickness (in)	2	4
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
SOG_4"			
	Length (ft)	105.62	105.62
	Width (ft)	105.62	105.62
	Thickness (in)	4	4
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average
SOG_5"			
	Length (ft)	110.10	123.10
	Width (ft)	110.10	123.10
	Thickness (in)	5	4
	Concrete (psi)	3000	3000
	Concrete flyash %	-	average

A22	Upper Floor Construction	57343.9717	ft^2
		5327.427	

3.1 Column

s and Beams					
	Column_Floor 2 Support_Avg				
			Number of Beams	76	76
			Beam Type	Concrete	Concrete
			Number of Columns	72	72
			Column Type	Concrete	Concrete
			Floor to floor height (ft)	-	12.84
			Bay sizes (ft)	-	17.6
			Supported span (ft)	-	17.6
			Live load (psf)	-	75
	Column_Floor 3 Support_Concrete Columns				
			Number of Beams	66	66
			Beam Type	WF Steel	WF Steel
			Number of Columns	24	24
			Column Type	Concrete	Concrete

		Floor to floor height (ft)	12.5	12.5
		Bay sizes (ft)	-	24.83
		Supported span (ft)	-	24.83
		Live load (psf)	-	75
	Column_Floor 4 Support_WF Columns			
		Number of Beams	34	34
		Beam Type	WF Steel	WF Steel
		Number of Columns	43	43
		Column Type	WF Steel	WF Steel
		Floor to floor height (ft)	12.5	12.5
		Bay sizes (ft)	-	18.44
		Supported span (ft)	-	18.44
		Live load (psf)	-	75
2.1 Concrete Cast-				

In-Place Wall				
	Wall_10" Concrete Elevator Shaft Wall_With Openings			
		Length (ft)	10	10
		Height (ft)	64.5	80.625
		Thickness (in)	10	8
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Rebar	#4, 6	#5
	Door Opening	Number of Doors	4	4
		Door Type	Metal Elevator Doors	Steel Interior Doors
	Wall_8" Concrete Stairwell Shaft			
		Length (ft)	140	140
		Height (ft)	62.17	62.17
		Thickness (in)	8	8
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average

		Rebar	#4, 6	#5
	Door Opening	Number of Doors	14	14
		Door Type	Wooden	Solid Wood Door

4.1 Concrete Suspended Slab				
	Floor_Recital Hall Approximation			
		Length (ft)	-	159.49
		Width (ft)	-	17.60
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	100
	Floor_Suspended Concrete Floor 2			
		Floor Width (ft)	-	1,267.56
		Span (ft)	-	17.6
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	75
	Floor_Suspended Concrete Floor			

	3			
		Floor Width (ft)	-	596.05
		Span (ft)	-	24.83
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	75
	Floor_Suspended Concrete Floor 4			
		Floor Width (ft)	-	793.33
		Span (ft)	-	18.44
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	75
	Floor_Suspended Concrete Floor 5			
		Floor Width (ft)	-	144.5
		Span (ft)	-	19.37
		Concrete (psi)	3500	4000

		Concrete flyash %	-	average
		Life load (psf)	-	75

A23	Roof Construction	13484.1462	ft^2
		1252.71763	

5.1 Concrete Suspended Slab				
	Roof_Fourth Floor			
	Envelope	Roof Width (ft)	-	575.98
		Span (ft)	-	18.44
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	75
		Category	Asphalt Roofing	4 - Ply Built-up Asphalt Roof System
		Material	Vapour Barrier and Rigid Insulation	Expanded Polystyrene, Glass Felt
		Thickness (in)	4	4
	Roof_Fifth Floor			
		Roof Width (ft)	-	177.5

		Span (ft)	-	16.13
		Concrete (psi)	3500	4000
		Concrete flyash %	-	average
		Life load (psf)	-	45
	Envelope	Category	Asphalt Roofing	4 - Ply Built-up Asphalt Roof System
		Material	Vapour Barrier and Rigid Insulation	Expanded Polystyrene, Glass Felt
		Thickness (in)	4	4

	Column_Roof and Penthouse Support_WF Column			
		Number of Beams	30	30
		Beam Type	WF Steel	WF Steel
		Number of Columns	39	39
		Column Type	WF Steel	WF Steel
		Floor to floor height (ft)	12.5	12.5

	Bay sizes (ft)	-	19.37
	Supported span (ft)	-	19.37
	Live load (psf)	-	75
Column_Penthouse Roof Support			
	Number of Beams	7	7
	Beam Type	WF Steel	WF Steel
	Number of Columns	11	11
	Column Type	WF Steel	WF Steel
	Floor to floor height (ft)	12.5	12.5
	Bay sizes (ft)	-	16.13
	Supported span (ft)	-	16.13
	Live load (psf)	-	45

A3	Exterior Enclosure	A31	Walls Below Grade	33880.35	ft^2

		3147.58616		2.1 Concrete Cast-In-Place Wall					
					Wall_Average Concrete				
							Length (ft)	-	1,435.00
							Height (ft)	-	23.61
							Thickness (in)	-	8
							Concrete (psi)	3500	4000
							Concrete flyash %	-	average
							Rebar	#4, 6	#5
						Window Opening	Number of Windows	81	81
							Area Covered	1,468	1,468
							Fixed/Operable	Fixed	Fixed
							Frame Type	Aluminum	Aluminum
							Glazing Type	None	None
						Door Opening	Number of Doors	9	9
							Door Type	Glass Door	Aluminum Exterior Door, 80% Glaze
A32	Walls Above	30012.04	ft^2						

Grade

2788.20855

2.2 Concrete Block Wall				
	Wall_4" Block Wall_10' Tall			
	Door Opening	Length (ft)	717	359
		Height (ft)	10	10
		Thickness (in)	4	8
		Rebar	-	#4
		Number of Doors	5	5
		Door Type	Wooden	Solid Wood Door
	Wall_6" Block Wall_10' Tall			
	Door Opening	Length (ft)	459	344
		Height (ft)	10	10
		Thickness (in)	6	8
		Rebar	-	#4
		Number of Doors	21	21
		Door Type	Wooden	Solid Wood Door
	Wall_8" Block Wall_10' Tall			
		Length (ft)	106	106
		Height (ft)	10	10

		Thickness (in)	8	8
		Rebar	-	#4
	Door Opening	Number of Doors	5	5
		Door Type	Wooden	Solid Wood Door
2.3 Curtain Wall				
	Curtain Wall_Penthouse Skylight			
		Length (ft)	24	24
		Height (ft)	9.67	9.67
		Percent Viewable Glazing	-	80%
		Percent Spandrel Panel	-	20%
		Thickness of Insulation (in)	-	0
		Spandrel Type (Metal/Glass)	Metal	Metal
2.5 Concrete Pre-				

Cast				
	Wall_Exterior Precast_18' 6" Tall			
	Window Opening	Length (ft)	267	267
		Height (ft)	18.5	18.5
		Thickness (in)	-	5 1/2
		Concrete (psi)	-	3000
		Concrete flyash %	-	average
		Rebar	-	#4
		Number of Windows	2	2
		Area Covered	750	750
		Fixed/Operable	Fixed	Fixed
		Frame Type	None	None
		Glazing Type	None	None
	Wall_Exterior Precast_34' 4" Tall			
		Length (ft)	488	488
		Height (ft)	34.33	34.33
		Thickness (in)	-	5 1/2
		Concrete (psi)	-	3000

										Concrete flyash %	-	average
										Rebar	-	#4
									Window Opening	Number of Windows	92	92
										Area Covered	1,661	1,661
										Fixed/Operable	Fixed	Fixed
										Frame Type	Aluminum	Aluminum
										Glazing Type	None	None
B	Interiors	B1	Partitions & Doors	B11	Partitions	36110	ft^2					
						3354.72733		2.4 Wood Stud				
									Wall_4" Interior Wood Wall_10' 0" Tall			
										Length (ft)	448	448
										Height (ft)	10	10
										Wall Type	Interior	Interior
										Sheathing Type	None	None
										Stud Spacing	-	16 o.c.
										Stud Type	-	Green Lumber
										Stud Thickness	2 x 4	2 x 4
									Envelope	Category	Gypsum Board	Gypsum Board

		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"
		Category	Gypsum Board	Gypsum Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"
		Category	Soundproofing	Insulation
		Material	-	Fiberglass Batt
		Thickness	-	4"
	Door Opening	Number of Doors	28	28
		Door Type	Wooden	Solid Wood Door
	Wall_4" Interior Wood Wall_Type 2A_10' 0" Tall			
		Length (ft)	870	870
		Height (ft)	10	10
		Wall Type	Interior	Interior
		Sheathing Type	None	None
		Stud Spacing	-	16 o.c.
		Stud Type	-	Green Lumber
		Stud Thickness	2 x 4	2 x 4
	Envelope	Category	Gypsum Board	Gypsum

				Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"
		Category	Soundproofing	Insulation
		Material	-	Fiberglass Batt
		Thickness	-	4"
	Wall_6" Interior Wood Wall_10' 0" Tall			
	Envelope	Length (ft)	1,307	1,307
		Height (ft)	10	10
		Wall Type	Interior	Interior
		Sheathing Type	None	None
		Stud Spacing	-	16 o.c.
		Stud Type	-	Green Lumber
		Stud Thickness	2 x 6	2 x 6
		Category	Gypsum Board	Gypsum Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"
		Category	Gypsum Board	Gypsum Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"

		Category	Soundproofing	Insulation
		Material	-	Fiberglass Batt
		Thickness	-	4"
	Door Opening	Number of Doors	65	65
		Door Type	Wooden	Solid Wood Door
	Wall_8" Interior Wood Wall_10' 0" Tall			
	Envelope	Length (ft)	986	986
		Height (ft)	10	10
		Wall Type	Interior	Interior
		Sheathing Type	None	None
		Stud Spacing	-	16 o.c.
		Stud Type	-	Green Lumber
		Stud Thickness	2 x 6	2 x 8
		Category	Gypsum Board	Gypsum Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"
		Category	Gypsum Board	Gypsum Board
		Material	-	Gypsum Regular 1/2"
		Thickness	-	1/2"

			Category	Soundproofing	Insulation
			Material	-	Fiberglass Batt
			Thickness	-	4"
		Door Opening	Number of Doors	15	15
			Door Type	Wooden	Solid Wood Door

Assumptions

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundation	In the Impact Estimator, slab on grade inputs are limited to being either a 4” or 8” thickness. Since the actual SOG thicknesses for the Music building were not always exactly 4” or 8” thick, the areas measured in OnScreen required calculations to adjust the areas to accommodate this limitation. Concrete stairs were modelled as footings as opposed to slab on grade or extra basic material because they would not include any rebar in the Impact Estimator. The footings (Footing_Average Spread and Footing_Average Strip) are aggregations of a variety of concrete footing sizes. This was done to minimize the number of Impact Estimator Impacts, and reduce the chance of incorrect entries. All flyash contents are assumed to be average. This is done because the drawings do not specify a flyash content and the Impact Estimator requires a flyash input.		
	1.1 Concrete Slab-on-Grade		
		1.1.1 SOG_2" Seal	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[((2,817 ft2) x (2”/12))/(4”/12)] = 37.53 feet

		1.1.2 SOG_4"	The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[(Measured Slab Area)] = sqrt[(1,1156 ft2)] = 105.62 feet
		1.1.3 SOG_5"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator. The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt[((Measured Slab Area) x (Actual Slab Thickness))/(4”/12)] = sqrt[((12,122 ft2) x (5”/12))/(4”/12)] = 123.10 feet
	1.2 Concrete Footing		

1.2.1 Footing_Average Spread

This value was obtained by calculating a total volume of all the concrete spread footings given by OnScreen. The count was multiplied by the height, width and depth to obtain a total volume. Then a fixed dimension of 2'6" x 3'6" x 16" was used to back calculate a count of footings.

Name	**Width**	**Length**	**Height**	**Count**	**Volume**
Footing_10' 7" x 11' 10" x 24" Spread	10.58	11.83	2.00	1.00	250.47
Footing_2' 0" x 2' 4" x 15"_Spread	2.00	2.33	1.25	1.00	5.83
Footing_2' 10" x 3' 8" x 16"_Type D	2.83	3.67	1.33	4.00	55.41
Footing_2' 11" x 2' 4" x 15"_Slab	2.92	2.33	1.25	1.00	8.51
Footing_2' 3" x 3' 10" x 12"_Spread	2.25	3.83	1.00	1.00	8.63
Footing_2' 6" x 3' 6" x 16"_Spread	2.50	3.50	1.33	2.00	23.33
Footing_2' 7" x 2' 0" x 19"_Slab	2.58	2.00	1.58	5.00	40.90
Footing_2' 9" x 1' 3" x 16"_Slab	2.75	1.25	1.33	2.00	9.17
Footing_3' 2" x 2' 6" x 24"_Spread	3.17	2.50	2.00	2.00	31.67
Footing_3' 3" x 2' 8" x 16"_Spread	3.25	2.67	1.33	1.00	11.56
Footing_3' 6" x 4' 4" and 3' 2" x 2' 6" x 12" Spread L	3.50	4.33	1.00	3.00	45.50
	3.17	2.50	1.00	3.00	23.75
Footing_3' 8" x 2' 8" x 16"_Slab	3.67	2.67	1.33	2.00	26.07
Footing_3' 9" x 2'4" x 10"_Spread Footing	3.75	2.33	0.83	1.00	7.29
Footing_4' 10" x 3' 3" x 16"_Type C	4.83	3.25	1.33	5.00	104.72
Footing_4' 6" x 4' 0" x 12"_Spread	4.50	4.00	1.00	2.00	36.00
Footing_5' 0" x 5' 0" x 16"_Spread	5.00	5.00	1.33	2.00	66.67
Footing_5' 0" x 6"6" x 21" Spread	5.00	6.50	1.75	1.00	56.88
Footing_5' 3"x3'1"x16"_Spread	5.25	3.08	1.33	2.00	43.17
Footing_5' 4" x 4' 2" x 16"_Type A	5.33	4.17	1.33	16.00	474.07
Footing_5' 5" x 4' 6" x 18"_Type B	5.42	4.50	1.50	1.00	36.56
Footing_8' 0" x 4' 2" x 24" Spread	8.00	4.17	2.00	2.00	133.33
Footing_9' 10" x 7' 0" x 24"_Spread	9.83	7.00	2.00	1.00	137.67

= [(Sum of volume) / (Volume 2’6” x 3’6” x 16” footing)]

= [(1,637 ft3) / ((2+6/12)*(3+6/12)*(16/12))]

= 70.16 footings

1.2.2 Footing_Average Strip

This value was obtained by calculating a total volume of all the concrete strip footings given by OnScreen. The length was multiplied by the depth and width to obtain a volume. Then using a fixed cross section of 1’ 4” wide by 10” deep was used to determine an overall length.

Name	Height	Width	Length	Volume
Footing_1' 4" x 10"_Continuous Strip	0.833333	1.333	1,047	1,163
Footing_2' 2" x 12"_Continuous Footing	1	2.167	7	15
Footing_2' 6" x 12"_Continuous Strip	1	2.5	16	40
Footing_2' 7" x 12"_Continuous Strip	1	2.583	71	183
Footing_2' 8" x 12"_Continuous Strip	1	2.667	13	35
Footing_2' 8" x 18"_Continuous Footing	1.5	2.667	98	392
Footing_3' 0" x 8"_Continuous Footing	0.666667	3	50	100
Footing_3' 6" x 12"_Continuous Strip	1	3.5	64	224
Footing_3' 6" x 16"_Continuous Strip	1.333333	3.5	16	75
Footing_3' 8" x 12"_Continuous Strip	1	3.667	35	128
Footing_4' 2" x 21"_Continuous Footing	1.75	4.167	90	656
Footing_4' 6" x 12"_Continuous Strip	1	4.5	15	68

= [(Sum of volume) / (Area of 1’4” x 10” footing)]

= [(3,079 ft3) / ((1+4/12)*(10/12))]

= 2771.4 feet

1.2.3 Stairwell_Stair Section 4th floor to Penthouse_3' 6" width

OnScreen provided a sectional area. This area was multiplied by the width of the stairwell to obtain a volume of concrete. Then this volume was reduced to a rectangular dimension with a fixed depth of 1' 4". The square root was taken of this area to obtain a square dimension. The calculation is as follows;

= [sqrt((Area of stair section) * (Width of section) / (Depth))]

= [sqrt((14 sf) * (3.5 ft) / (1.33 ft))]

			= 6.06 feet
		1.2.4 Stairwell_Stair Section CC_4' 8" width	OnScreen provided a sectional area. This area was multiplied by the width of the stairwell to obtain a volume of concrete. Then this volume was reduced to a rectangular dimension with a fixed depth of 1' 4". The square root was taken of this area to obtain a square dimension. The calculation is as follows; = [sqrt((Area of stair section) * (Width of section) / (Depth))] = [sqrt((108 sf) * (4.67 ft) / (1.33 ft))] = 19.44 feet
		1.2.5 Stairwell_Stair Section DD_4' 10" width	OnScreen provided a sectional area. This area was multiplied by the width of the stairwell to obtain a volume of concrete. Then this volume was reduced to a rectangular dimension with a fixed depth of 1' 4". The square root was taken of this area to obtain a square dimension. The calculation is as follows; = [sqrt((Area of stair section) * (Width of section) / (Depth))] = [sqrt((159 sf) * (4.83 ft) / (1.33 ft))] = 24.00 feet

<table>
<tr><td></td><td></td><td>1.2.6 Stairwell_Stair Section SE Corner_4' 0" width</td><td>OnScreen provided a sectional area. This area was multiplied by the width of the stairwell to obtain a volume of concrete. Then this volume was reduced to a rectangular dimension with a fixed depth of 1' 4". The square root was taken of this area to obtain a square dimension. The calculation is as follows;
= [sqrt((Area of stair section) * (Width of section) / (Depth))]
= [sqrt((18 sf) * (4 ft) / (1.33 ft))]
= 7.35 feet</td></tr>
<tr><td rowspan="2">2 Walls</td><td colspan="3">The height of the walls had to be adjusted to fit into the limitations on wall widths imposed by the Impact Estimator. A fixed width, typically 8" or 12" is required. Multiple concrete walls were aggregated into one continuous wall to simplify inputs into the Impact Estimator. The actual specified strength of concrete for use in cast in place walls was 3500psi. This value was rounded up to 4000psi for input to the Impact Estimator.</td></tr>
<tr><td colspan="3">2.1 Concrete Cast-In-Place Wall</td></tr>
</table>

2.1.1 Wall_Average Concrete

This value was obtained by calculating a total volume of all the concrete foundation walls, measured in OnScreen. The length of each wall was multiplied by its respective width and height to obtain a volume for each wall. Then these volumes for each wall were summed. This total volume was divided by a fixed thickness of 8” and a fixed length of 1,435 feet to obtain an average wall height. No envelope materials were input. The calculations are as follows;

Name	Height	Thickness	Length	Volume
Wall_10" Concrete Elevator Shaft Wall_No Openings	74.58	0.83	30.00	1864.58
Wall_12" Concrete Wall_30' 1" Tall	30.08	1.00	21.00	631.75
Wall_18" Concrete Reinforcement Wall_South East Corner	32.58	1.50	10.00	488.75
Wall_8" Concrete Footing Wall_14'9" Tall	14.75	0.67	156.00	1534.00
Wall_8" Concrete Wall_13'9" Tall	13.75	0.67	49.00	449.17
Wall_8" Concrete Wall_14'0" Tall	14.00	0.67	38.00	354.67
Wall_8" Concrete Wall_14'1" Tall	14.08	0.67	20.00	187.78
Wall_8" Concrete Wall_14'1" Tall	14.08	0.67	146.00	1370.78
Wall_8" Concrete Wall_14'7" Tall	14.58	0.67	93	908.69
Wall_8" Concrete Wall_15'3" Tall	15.25	0.67	110.00	1118.33
Wall_8" Concrete Wall_17'0" Tall	17.00	0.67	69.00	782.00
Wall_8" Concrete Wall_20'5" Tall	20.42	0.67	16.00	217.78
Wall_8" Concrete Wall_22'9" Tall	22.75	0.67	78.00	1183.00
Wall_8" Concrete Wall_24'6" Tall	24.50	0.67	30.00	490.00
Wall_8" Concrete Wall_28' 1" Tall	28.08	0.67	40.00	748.89
Wall_8" Concrete Wall_30' 1" Tall	30.08	0.67	162.00	3249.00
Wall_8" Concrete Wall_31'3" Tall	31.25	0.67	25.00	520.83
Wall_8" Concrete Wall_32'0" Tall	32.00	0.67	62.00	1322.67
Wall_8" Concrete Wall_32'7" Tall	32.58	0.67	56.00	1216.44
Wall_8" Concrete Wall_33'10" Tall	33.83	0.67	166.00	3744.22
Wall_8" Concrete Wall_4'6" Tall	4.50	0.67	46.00	138.00
Wall_8" Concrete Wall_8'8" Tall	8.67	0.67	12.00	69.33

= [(Sum of volume) / (Sectional area of a 8” by 1492’ wall)]

= [(22,590 ft3) / ((8/12)*(1,435 ft))]

= 23.61 feet

A rebar size of #5 was input into the Impact Estimator. This is because the Impact Estimator will not accept the

			measured value of #4 rebar.
		2.1.2 Wall_10" Concrete Elevator Shaft_With Openings	Impact Estimator only allows wall thicknesses of 8" or 12" to be input. For this reason, the wall was narrowed and heightened to make a 10' long 8" thick wall. The calculation is as follows = [(Wall Height 10") / (Ratio of Wall Thicknesses) = [(64.5 ft) / (10"/8") = 80.625 feet A rebar size of #5 was input into the Impact Estimator. This is because the Impact Estimator will not accept the measured value of #4 rebar.
		2.1.2 Wall_8" Concrete Stairwell Shaft	A rebar size of #5 was input into the Impact Estimator. This is because the Impact Estimator will not accept the measured value of #4 rebar.
	2.2 Concrete Block Wall		
		2.2.1 Wall_4" Block Wall_10' Tall	Interior block wall. Assumed that no surface covering was used. Rebar size of #4 was assumed because no rebar was specified. Impact Estimator uses a cement block size of 8"x8"x16". For this reason this wall was shortened by one half to generate an equivalent length of 8" wall. The calculation is as follows; = [(Wall Length 4") / (Ratio of Wall Thicknesses) = [(717 ft) / (8"/4") = 358.5 feet

		2.2.2 Wall_6" Block Wall_10' Tall	Interior block wall. Assumed that no surface covering was used. Rebar size of #4 was assumed because no rebar was specified. Impact Estimator uses a cement block size of 8"x8"x16". For this reason this wall was shortened to generate an equivalent length of 8" wall. The calculation is as follows; = [(Wall Length 6") / (Ratio of Wall Thicknesses) = [(459 ft) / (8"/6") = 344.25 feet
		2.2.3 Wall_8" Block Wall_10' Tall	Interior block wall. Assumed that no surface covering was used. Rebar size of #4 was assumed because no rebar was specified.
	2.3 Curtain Wall		
		2.3.1 Wall_CurtainWall_Penthouse Skylight	Assumed 80% glazing with aluminum frame and 20% spandrel. A value of 0" was assumed for insulation as this feature is a skylight. Values are all approximated as the actual feature is on the roof and is only specified in the architectural drawings.
	2.4 Wood Stud Wall		
		2.4.1 Wall_4" Interior Wood Wall_10' 0" Tall	Because the stud spacing, or type is not explicitly stated, a 2 x 4 green lumber stud with 16" spacing was assumed. Gypsum board was assumed to be Regular 1/2" wall board, on both sides of the wall. Because these walls contain asbestos soundproofing insulation that is not included in the Impact Estimator, it was assumed that the insulation could be modeled with 4" of fiberglass batt insulation.
		2.4.2 Wall_4" Interior Wood Wall_Type 2A_10' 0" Tall	Because the stud spacing, or type is not explicitly stated, a 2 x 4 green lumber stud with 16" spacing was assumed. Gypsum board was assumed to be Regular 1/2" wall board, on one side of the wall. Because these walls contain asbestos soundproofing insulation that is not included in the Impact Estimator, it was assumed that the insulation could be modeled with 4" of fiberglass batt insulation.

		2.4.3 Wall_6" Interior Wood Wall_10' 0" Tall	Because the stud spacing, or type is not explicitly stated, a 2 x 6 green lumber stud with 16" spacing was assumed. Gypsum board was assumed to be Regular 1/2" wall board, on both side of the wall. Because these walls contain asbestos soundproofing insulation that is not included in the Impact Estimator, it was assumed that the insulation could be modeled with 4" of fiberglass batt insulation.
		2.4.4 Wall_8" Interior Wood Wall_10' 0" Tall	Because the stud spacing, or type is not explicitly stated, a 2 x 8 green lumber stud with 16" spacing was assumed. Gypsum board was assumed to be Regular 1/2" wall board, on both side of the wall. Because these walls contain asbestos soundproofing insulation that is not included in the Impact Estimator, it was assumed that the insulation could be modeled with 4" of fiberglass batt insulation.
	2.5 Concrete Pre-Cast		
		2.5.1 Wall_Exterior Precast_18' 6" Tall	A number of assumptions were made for the input of this wall to the Impact Estimator. The following values were assumed; 5 1/2" wall thickness, 3000psi concrete, #4 rebar and average flyash content.
		2.5.2 Wall_Exterior Precast_34' 4" Tall	A number of assumptions were made for the input of this wall to the Impact Estimator. The following values were assumed; 5 1/2" wall thickness, 3000psi concrete, #4 rebar and average flyash content.
3 Columns and Beams	The concrete columns extending from the foundation to the base of the second floor were of varying heights so their height was caluclated using a weighted average. Pillasters were modeled as columns due to the large amounts of reinforcement in the pillaster concrete. This however, may be an overestimate of the material used. The connection between the columns and the tops of the pillasters is not clear and therefore was assumed to be a typical column beam connection. All concrete was specified to have a strength of 3500psi but was rouned up to 4000psi for input into the Impact Estimator.		
	3.1 Concrete Column		

3.1.1 Column_Floor 2 Support_Avg

Because the columns extending from the foundations to the first floor are of variable height, a weighted average was done to find an average length of columns based on their counts and lengths. The OnScreen count of columns and pillasters was combined to obtain a count of 72. The calculations are as follows;

Name		Elev. of Footing	Elev. 2nd Floor Base	Height	Count	H*C
Column_Floor 2 Support_355' 9"	Base Elev	355.75	372.33	16.58	2	33.17
Column_Floor 2 Support_356' 3"	Base Elev	356.25	372.33	16.08	1	16.08
Column_Floor 2 Support_356' 6"	Base Elev	356.50	372.33	15.83	1	15.83
Column_Floor 2 Support_357' 6"	Base Elev	357.50	372.33	14.83	2	29.67
Column_Floor 2 Support_358' 5"	Base Elev	358.42	372.33	13.92	6	83.50
Column_Floor 2 Support_358' 8"	Base Elev	358.67	372.33	13.67	6	82.00
Column_Floor 2 Support_359' 11"	Base Elev	359.92	372.33	12.42	6	74.50
Column_Floor 2 Support_359' 2"	Base Elev	359.17	372.33	13.17	6	79.00
Column_Floor 2 Support_359' 8"	Base Elev	359.67	372.33	12.67	3	38.00
Column_Floor 2 Support_361' 3"	Base Elev	361.25	372.33	11.08	1	11.08
Column_Floor 2 Support_361' 6"	Base Elev	361.50	372.33	10.83	13	140.83

= [Sum(Height*Count)/Sum(Count)]

=[(603.67 ft) / (47)]

= 12.84 feet each with a count of 72

Because of the variability of bay and span sizes, they were calculated using the following calculation;

= sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)]

= sqrt[(22,309 ft2) / (72)]

= 17.60 feet

The live loading was assumed to be 75 psf.

		3.1.2 Column_Floor 3 Support_Concrete Columns	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(14,800 ft2) / (24)] = 24.83 feet The live loading was assumed to be 75 psf.
		3.1.3 Column_Floor 4 Support_WF Columns	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(14,629 ft2) / (43)] = 18.44 feet The live loading was assumed to be 75 psf.
		3.1.4 Column_Roof and Penthouse Support_WF Columns	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(14,629 ft2) / (39)] = 19.37 feet The live loading was assumed to be 75 psf.

		3.1.5 Column_Penthouse Roof Support	Because of the variability of bay and span sizes, they were calculated using the following calculation; = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(2,863 ft2) / (11)] = 16.13 feet The live loading was assumed to be 45 psf.
4 Floors	The Impact Estimator calculated the thickness of the material based on floor width, span, concrete strength, concrete flyash content and live load. The concrete strength was specified to be 3500psi but due to the limitations of the Impact Estimator, a value of 4000psi was used. In addition, live loadings were assumed because these were not specified.		
		4.1.1 Floor_Recital Hall Approximation	The length and width of the floor area was determined using the following equation; = [Measured Supported Floor Area / Span of Columns and Beams] = [2,807 ft2 / 17.6 ft] = 159.49 feet The live loading was assumed to be 100 psf.
		4.1.1 Floor_Suspended Concrete Floor 2	The length and width of the floor area was determined using the following equation; = [Measured Supported Floor Area / Span of Columns and Beams] = [22,309 ft2 / 17.6 ft] = 1,267.56 feet The live loading was assumed to be 75 psf.

		4.1.1 Floor_Suspended Concrete Floor 3	The length and width of the floor area was determined using the following equation; = [Measured Supported Floor Area / Span of Columns and Beams] = [14,800 ft2 / 24.83 ft] = 596.05 feet The live loading was assumed to be 75 psf.
		4.1.1 Floor_Suspended Concrete Floor 4	The length and width of the floor area was determined using the following equation; = [Measured Supported Floor Area / Span of Columns and Beams] = [14,629 ft2 / 18.44 ft] = 793.33 feet The live loading was assumed to be 75 psf.
		4.1.1 Floor_Suspended Concrete Floor 5	The length and width of the floor area was determined using the following equation; = [Measured Supported Floor Area / Span of Columns and Beams] = [2799 ft2 / 19.37 ft] = 144.50 feet The live loading was assumed to be 75 psf.
5 Roof	The live load was assumed to be 75 psf and the concrete strength was set to 4,000psi instead of the specified 3,500psi due to limitations from the Impact Estimator.		
	5.1 Concrete Suspended Slab		

		4.1.1 Roof_Fourth Floor	The length and width of the roof area was determined using the following equation; = [Measured Supported Roof Area / Span of Columns and Beams] = [10,621 ft2 / 18.44 ft] = 575.98 feet The live loading was assumed to be 75 psf. Expanded polystyrene and glass felt was assumed to be used in the asphalt roof system. It was also assumed that the roofing is not inverted.
		4.1.1 Roof_Fifth Floor	The length and width of the roof area was determined using the following equation; = [Measured Supported Roof Area / Span of Columns and Beams] = [2,863 ft2 / 16.13 ft] = 177.50 feet The live loading was assumed to be 45 psf. Expanded polystyrene and glass felt was assumed to be used in the asphalt roof system. It was also assumed that the roofing is not inverted.